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Sources of Australian Labour Productivity Change 1950–1994

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This study examines sources of Australian labour productivity change from 1950 to 1994. Time-series data are used to estimate a model capturing the interaction between labour productivity, fixed capital, human capital, telecommunications, trade openness and international competitiveness. Attention is given to the time-series properties of these data. ADF tests for unit roots are employed, and the sensitivity of the tests to non-linear transformations and structural breaks are considered. Estimates suggest that policies that promote investment, economic integration and international competitiveness will improve short-run labour productivity. In the long run, fixed capital accumulation is the dominant source of productivity improvement.

I Introduction

The analysis of labour productivity is an area of great interest to both economists and policy makers. A major focus of this literature is the development of macroeconomic models that reflect contemporary policy issues. In Solow-Swan (1956) growth models, long-run economic growth depends on exogenous population (or labour force) growth and technological progress. More recent growth models highlight the gains from international trade. Trade results in economies of scale, a greater competitive discipline (which enhances productivity in both the traded and non-traded goods sectors), and the increased transmission of knowledge and production methods (Krugman 1979 and 1987, Romer 1986, Grossman and Helpman 1991). Further, Dowrick (1994) finds that increased openness to trade improves productivity growth by separately stimulating investment, employment and technical progress. The dynamic role of human capital in the growth process is emphasized by Lucas (1988), Romer (1989) and Becker *et al.* (1990). In particular, Lucas (1988) shows that human capital accumulation raises investment in both human and fixed capital, and improves productivity.

Current analysis suggests that the form of investment can affect productivity. Empirical research by DeLong and Summers (1991), Levine and Renelt (1992) and Blomstrom *et al.* (1996) shows that fixed capital investment is an important determinant of economic growth. Aschauer (1989), DeLong and Summers (1991), and Otto

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and Voss (1996) argue that specific types of investment, such as public infrastructure and machinery and equipment, have a strong association with productivity and growth. In particular, investment in information technology and telecommunications (ITT) can increase national productivity by reducing transport and transaction costs, improve marketing information, and accelerate the diffusion of knowledge (Greenstein and Spiller 1995, Karanaratne 1995).

The Solow-Swan modelling approach is most useful in explaining productivity movements from 1945 to 1973, when Australia enjoyed a period of sustained economic growth. Occasional supply-side shocks emanated from the primary sector, but generally growth was uniform and unemployment low. Economic policy focused on expanding the labour supply, through migration, and facilitating capital inflow. Monetary and fiscal policy maintained price stability and full employment, while direct controls on imports maintained external balance (Maddock 1987).

Since 1974, growth in Australian gross domestic product (GDP) has slowed. The initial decline in performance coincided with the world downturn following the 1973 oil price shock, increased labour costs and a decline in the international competitiveness of traditional markets (Pagan 1987). In the 1980s economic policy became increasingly orientated towards the international sector. Tariff reductions and the floating of the dollar assisted the development of a more outward looking economy and there was a concerted move towards regional integration. There was a significant shift in Australian exports away from Europe towards Asia and a fall in the importance of agricultural exports relative to minerals.[1] More recently, the fastest growing exports have been in manufacturing and services with the share of total merchandise trade rising from 25 to 33 per cent between 1990 and 1994 (Department of Foreign Affairs and Trade [DFAT] 1994). Both the Hawke and Keating governments implemented microeconomic reforms in the finance and ITT sectors aimed at improving national productivity and international competitiveness. Reforms in the tertiary education sector also reflected increased emphasis on the need to provide an education platform to develop a more advanced internationally competitive economy (Robinson and Rodan 1990).

[1] Europe accounted for more than half of Australian exports during the 1950s, but this share had fallen to 12 per cent by 1994. During the same period, the share of Asian exports increased from about 10 per cent to more than 60 per cent (DFAT 1994).

This study empirically examines the sources of Australian productivity change over the period 1950 to 1994. Time-series data are used to estimate an econometric model that captures the dynamic interaction between labour productivity (measured by aggregate output per labour unit), fixed capital, human capital, ITT capital, openness to trade, and international competitiveness. The econometric analysis gives careful attention to the time-series properties of these data. In particular it is recognized that the Augmented Dickey Fuller (ADF) test for a unit root is sensitive to nonlinear data transformations and may yield invalid inferences. Accordingly, the procedure developed by Frances and McAleer (1997) is adopted, whereby all ADF auxiliary equations are tested to ensure they have the correct functional form. Structural breaks are also considered as failure to adequately account for breaks in the underlying (deterministic) trend function can bias the ADF statistic.

The paper is organized as follows. Section II specifies a model of labour productivity and describes the econometric methods and data used to estimate the model. Tests for unit roots, correct functional form of the ADF equation, and structural breaks are described and conducted in Section III. In Section IV, cointegration analysis is used to examine the long-run relationship between labour productivity, fixed capital, and ITT capital. An error-correction model is estimated therein, incorporating the short-run dynamics of the system with the information from the cointegrating relationship. Concluding remarks are presented in Section V.

II Model, Method and Data

To examine the evolution of aggregate output a production function is specified based on the supply side approach of Aschauer (1989) and Romer (1989). The general model is given by:

$$Y = f(L, K, H, ITT), \tag{1}$$

where Y is aggregate output, L is labour, K is fixed capital, H is human capital, and ITT is ITT capital. In the spirit of Dowrick (1994), the model is used to examine labour productivity and so the explanation is augmented by including variables to capture Australian openness to trade and international competitiveness:

$$Y/L = g(K/L, H/L, ITT/L, T/L, IC) \tag{2}$$

where, *(T/L)* is openness (volume of trade per worker) and *(IC)* is international competitiveness (ratio of export to import prices). With the variables measured in natural logarithms *(ln)* and linearity assumed, the estimated parameters represent labour productivity elasticities with respect to fixed capital, human capital, *ITT* capital, openness and competitiveness.

Assuming $ln(Y/L)$, $ln(K/L)$, $ln(H/L)$, $ln(ITT/L)$, $ln(T/L)$ and $ln(IC)$ are nonstationary and integrated of the same order, (2) can be tested for cointegration using methods developed by Johansen (1991) and Johansen and Juselius (JJ) (1990). When the variables are cointegrated the estimated cointegrating vector(s) represent the long-run equilibrium relationship and must be included in the short-run model to remove this source of omitted variable bias. Engle and Granger (1987) prove there exists a corresponding error-correction model of the form:

$$
\begin{aligned}
\Delta ln(Y/L)_t = \beta_0 &+ \sum_{j=0}^{\ell} \beta_{1j}\, \Delta\, ln(K/L)_{t-j} + \sum_{j=0}^{\ell} \beta_{2j}\, \Delta\, ln(H/L)_{t-j} \\
&+ \sum_{j=0}^{\ell} \beta_{3j}\, \Delta\, ln(ITT/L)_{t-j} \\
&+ \sum_{j=0}^{\ell} \beta_{4j}\, \Delta\, ln(T/L)_{t-j} + \sum_{j=0}^{\ell} \beta_{5j}\, \Delta\, ln(IC)_{t-j} \\
&+ \sum_{j=1}^{\ell} \beta_{6j}\, \Delta\, ln(Y/L)_{t-j} \\
&+ \sum_{i}^{r} \delta_i\, [ln(Y/L)_{t-1} - \alpha_i^{T}\, X_{t-1}] + v_t \qquad (3)
\end{aligned}
$$

where Δ denotes the first-difference operator, β_{ij} are the estimated short-term effects, r is the number of cointegrating relationships, δ_i are the estimated coefficients for the lagged error correction term(s), α_i is a vector of cointegrating coefficients, ^{T} is the transpose operator, X equals $[ln(K/L)_t, ln(H/L)_t, ln(ITT/L)_t, ln(T/L)_t, ln(IC)_t]$, and v_t is a white-noise error term. The error correction terms are formed from the cointegrating residuals and δ_i measures how changes in $ln(Y/L)_t$, $ln(K/L)_t$, $ln(H/L)_t$, $ln(ITT/L)_t$, $ln(T/L)_t$ and $ln(IC)_t$ respond to departures from the long-run equilibrium. Short-run convergence to equilibrium is assured when δ_i is both negative and significant. Since the first-differenced variables and the error correction terms are stationary, ordinary least squares (OLS) will be consistent and provide unbiased estimates of standard errors.

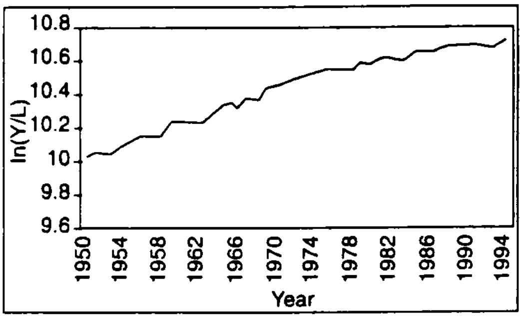
Annual data for Y_t (GDP at 1990 constant prices), K_t (gross fixed capital stock at 1990 constant prices), L_t (labour force), H_t (tertiary student enrolment), ITT_t (telephones), T_t (exports plus imports at 1990 constant prices) and IC_t (ratio of export to import prices at 1990 prices) are obtained from Foster (1996), Mitchell (1995) and the International Telecommunications Union (ITU) (1995). Proxy variables for human capital, ITT capital, openness and international competitiveness are used in the analysis. The measure of human capital is similar to that employed by Romer (1989) and the World Bank (1994). Use of this measure assumes that all human capital formation takes place in the tertiary sector. It is ITU practice to count telephones, and main telephone lines per capita, as measures of ITT infrastructure and network development. This proxy is adequate for this study as most Australian telecommunications investment prior to the early 1990s was directed at expanding basic telephony rather than rolling out broadband, cellular, and satellite networks. The proxy for openness is based on total trade and is similar to that used by Dowrick (1994) except that trade is deflated by worker, not GDP. International competitiveness refers to the ability of a country to expand its market share in global markets. The ratio of export to import prices is used to measure international competitiveness as Australian exports are predominantly primary goods and are relatively sensitive to shifts in the terms of trade.[2]

Plots of these data are provided in Figure 1 through Figure 6. Maddock and McLean (1987) and Blundell-Wignall (1993) document numerous events in Australia's post-1950 economic history which can be viewed as potential exogenous break points in these data. They include the substantial

[2] A common question asked by econometricians when using proxy variables is whether or not to include or omit the variable. While McCallum (1972) and Wickens (1972) show that the bias is worse if the proxy is omitted (even if it is a poor proxy), their 'reduction-in-bias' conclusion is subject to many qualifications. In particular, the reduction-in-bias will not hold if the number of proxy variables in the model is greater than one. Since proxies for human and ITT capital are used in this analysis, little can be said about the direction of bias except that it may increase or decrease with the introduction of the two proxy variables. A time-series for Australian ITT capital, measured from capital expenditure on property and plant used for telecommunications services, is currently being compiled by the authors. Including this observed variable in the model will act to reduce bias (if bias exists) and will capture the wider impact of telecommunications investment in cellular, digital and satellite technologies.

FIGURE 1

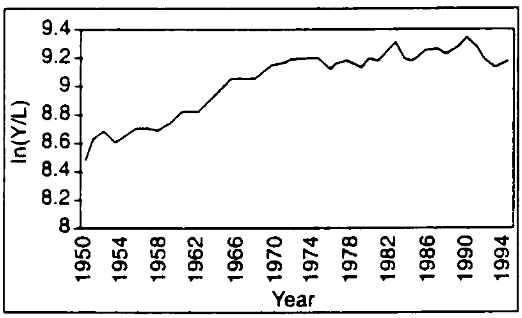
Labour Productivity 1950–1994



Source: Foster (1996).

FIGURE 2

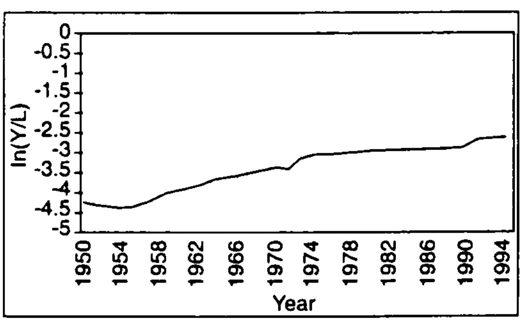
Fixed Capital 1950–1994



Source: Foster (1996).

FIGURE 3

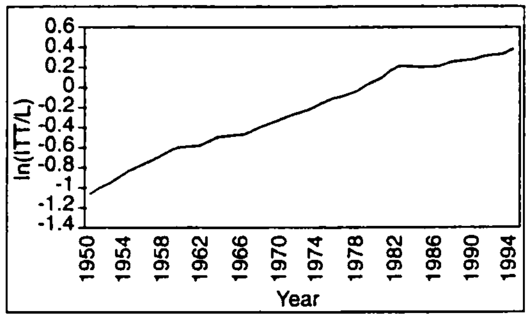
Human Capital 1950–1994



Source: Foster (1996), Mitchell (1995).

FIGURE 4

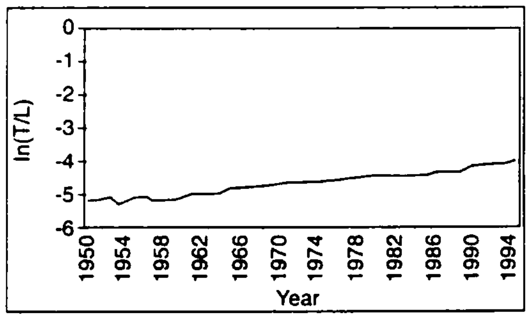
ITT Capital 1950–1994



Source: Foster (1996), ITU (1995), Mitchell (1995).

FIGURE 5

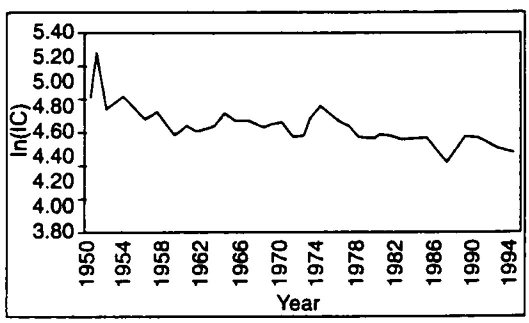
Openness 1950–1994



Source: Foster (1996).

FIGURE 6

International Competitiveness 1950–1994



Source: Foster (1996).

increase in Australian export revenue in 1951 with the advent of the Korean War, tertiary sector reforms between 1972 and 1975, the 1973 unilateral reduction in tariffs by the Whitlam Labor government in 1973, the 1973 oil price shock, and the floating of the Australian Dollar in 1983. Given the time of break (relative to sample size) of the 1951 Korean War event, only the 1973 and 1983 events are considered below in Section III.

III Unit Roots, Functional Form and Structural Change

When examining time-series data it is standard practice to use the ADF test for a unit root. The ADF auxiliary equation is:

$$\Delta \ln Z_t = \mu + \gamma t + \beta \ln Z_{t-1} + \sum_{i=1}^{k\,max} \eta_i \, \Delta \ln Z_{t-1} + e_t , \tag{4}$$

where Z is the variable under examination, t is a deterministic time trend, k_{max} is the maximum lag length chosen *a priori* for the lagged differenced variable, and e_t is a white-noise error term. Under the null hypothesis of a unit root, Ho: $\beta = 0$, the series Z_t is non-stationary. Two critical assumptions are maintained in the estimation of (4); the logarithmic transformation is correct and there are no structural breaks in the trend function.

Granger and Hallman (1991) and Frances and McAleer (1997) argue that the ADF test for a unit root is sensitive to nonlinear transformations. For instance, ADF tests on the logarithm of a variable often report stationarity, when the same variable measured in levels is found to be non-stationary. Such sensitivity requires that the ADF regression equation be tested to ensure that the variable has been appropriately transformed. Frances and McAleer examine the effects of nonlinear transformations on the ADF regression within the class of Box-Cox models. They propose a test for correct functional form in (4) by including an additional variable, $(\Delta lnZ_{t-1})^2$, in the modified ADF (MADF) regression equation:

$$\Delta \ln Z_t = \mu + \gamma t + \beta \ln Z_{t-1} + \sum_{i=1}^{k\,max} \eta_i \, \Delta \ln Z_{t-1} + \lambda(\Delta lnZ_{t-1})^2 + e_t . \tag{5}$$

The following approach is adopted when testing for a single unit root and a nonlinear transformation. First, i is determined by estimating the ADF for a sufficiently long lag length to eliminate serial correlation, and presuming $\ln Z_t$ is the correct transformation.[3] Second, for a given i, the significance of λ in the MADF regression is tested. Should the additional variable be statistically significant, the ADF regression is inappropriately transformed and does not yield a valid inference in testing for a single unit root in $\ln Z_t$.

Initially, ADF and MADF regression equations are estimated for $\ln(Y/L)_t$, $\ln(K/L)_t$, $\ln(H/L)_t$, $\ln(ITT/L)_t$, $\ln(T/L)_t$ and $\ln(IC)_t$ over the period 1950 to 1994. The ADF and MADF test statistics, with and without trend, are clearly different and exclusion of the deterministic trend suggests bias due to the omission of relevant variables. Thus, ADF and MADF regression results with trend are reported in Table 1.

The results in Table 1 do not reject the null hypothesis $\lambda=0$ for any of the time series, indicating that the natural logarithmic transformation is appropriate when testing for a single unit root. The ADF statistics show that the null hypothesis of a unit root cannot be rejected for $\ln(Y/L)_t$, $\ln(K/L)_t$, $\ln(H/L)_t$ and $\ln(ITT/L)_t$. However, the unit root hypothesis is rejected for both $\ln(T/L)_t$ and $\ln(IC)_t$ and the variables are presumed integrated of order zero.

Perron (1989) suggests that widespread evidence of unit roots in many long-run macroeconomic time series may be due to structural change in their deterministic trend function. The omission of structural change variables from the ADF auxiliary equation can bias the ADF test statistic and lead to incorrect inference. Perron considers ADF equations that allow three types of structural change to occur in the trend function:

$$\Delta \ln Z_t = \mu + \gamma t + \theta Du + dD(TB) + \beta \ln Z_{t-1} + \sum_{i=1}^{k\,max} \eta_i \, \Delta \ln Z_{t-1} + e_t , \tag{6}$$

$$\Delta \ln Z_t = \mu + \gamma t + \delta DT^* + \theta Du + \beta \ln Z_{t-1} + \sum_{i=1}^{k\,max} \eta_i \, \Delta \ln Z_{t-1} + e_t , \tag{7}$$

$$\Delta \ln Z_t = \mu + \gamma t + \theta Du + \phi DT + dD(TB) + \beta \ln Z_{t-1} + \sum_{i=1}^{k\,max} \eta_i \, \Delta \ln Z_{t-1} + e_t , \tag{8}$$

[3] Here k_{max} is chosen *a priori* to be six and the lag structure is sequentially reduced so that the last lagged differenced term is statistically significant and the error terms are not serially correlated. As the sample consists of annual data, the Lagrange Multiplier test for first-order serial correlation is appropriate.

TABLE 1

Test for a Unit Root and Correct Functional Form 1950–1994

Variable	i	ADF	$LM(1)$	Het	MADF	$t(\lambda)$
$ln(Y/L)_t$	3	0.175	1.525	0.252	0.270	0.933
$ln(K/L)_t$	6	−0.447	0.676	4.554^a	−0.421	0.065
$ln(H/L)_t$	2	−1.844	2.376	0.207	−2.154	0.406
$ln(ITT/L)_t$	1	−1.650	1.023	2.543	−1.535	0.013
$ln(T/L)_t$	0	−3.745^a	0.002	0.060	−3.797	1.433
$ln(IC)_t$	0	−5.407^a	0.021	0.143	−7.479	0.462

1. $LM(1)$ is the Lagrange Multiplier statistic for first-order serial correlation. 2. Het is Ramsey's (1969) test for heteroskedasticty. 3. a denotes significance at the 5 per cent level. 4. $t(\lambda)$ is the t-ratio for testing the significance of λ, distributed standard normal. 5. ADF critical values from Enders (1995).

where T_B is the time of the structural break, $D(TB)=1$ if $t=T_B+1$ and 0 otherwise, $Du=1$ if $t>T_B$ and 0 otherwise, $DT^*=t-T_B$ if $t>T_B$ and 0 otherwise, and $DT=t$ if $t>T_B$ and 0 otherwise. Equation (6) allows for a one-time change in the intercept of the trend function, while (7) allows for a change in the slope of the trend function. Equation (8) allows a change in the intercept and the slope of the trend function to take place simultaneously.[4] Further, the Frances-McAleer (1997) modification is applied to (6) through (8) to permit testing of the appropriateness of the logarithmic transformation.[5]

The results from estimating (6), (7) and (8) with structural change at 1973 are reported in Table 2 through Table 4. Table 4 indicates that the unit root hypothesis can be overturned for $ln(H/L)_t$, that is, $ln(H/L)_t$ is stationary around a deterministic trend with a joint crash and trend change in 1973.[6] Estimation results with structural change at 1983 are reported in Table A1 through Table A3 of the Appendix. There is no evidence to support structural change in the trend function in 1983.

IV Estimation Results

ADF tests for a unit root indicate that $ln(T/L)_t$, $ln(IC)_t$ and $ln(H/L)_t$ are trend stationary, while $ln(Y/L)_t$, $ln(K/L)_t$ and $ln(ITT/L)_t$ are difference stationary.[7] Tests for cointegration between $ln(Y/L)_t$, $ln(K/L)_t$ and $ln(ITT/L)_t$ are conducted using the JJ maximum eigenvalue and trace statistics. The JJ tests are implemented using a vector autoregression (VAR) and a range of lags (k) ranging from one to six. An optimal lag structure was selected on the basis of achieving a consistent number of cointegrating vectors (r) from both the maximum eigenvalue and trace statistics, minimization of the Schwartz Bayesian Information Criterion, and the elimination of serial correlation.[8] The results based on the JJ tests for cointegration are reported in Table 5. The optimal lag structure for the VAR is three and the eigenvalue and trace statistic reject the null hypothesis of $r \leq 1$ against $r = 2$. This suggests that there are two statistically significant cointegrating relationships between the $I(1)$ variables $ln(Y/L)_t$, $ln(K/L)_t$ and $ln(ITT/L)_t$.

Since $\Delta ln(Y/L)_t$, $\Delta ln(K/L)t$, $\Delta ln(ITT/L)_t$, $ln(T/$

[4] Zivot and Andrews (1992) argue that Perron's choice of exogenous trend breaks are based on prior observation and maybe subject to problems with 'pretesting'. They suggest many trend breaks are not exogenous but are realizations of the data-generating process. For instance, the growth slow-down following the 1973 oil crisis, could be interpreted as a shock, or a combination of shocks, from the underlying errors. This interpretation implies that breaks in trend can be adequately modelled through the error process. Alternatively, Zivot and Andrews (1992) recognize that any number of events could be viewed *ex ante* as possible structural breakpoints and propose unit root tests whereby breakpoints are data determined. However, this 'endogenous test' is somewhat limited because of its low power against trend stationary alternatives.

[5] An anonymous referee suggested the extension of the Frances-McAleer procedure to the Perron test for structural breaks.

[6] The changes to the tertiary sector introduced by the Whitlam government are presumably the reason why $ln(H/L)$ experienced a structural break in 1973.

[7] Further testing (not reported here) shows that $\Delta ln(Y/L)_t$, $\Delta ln(K/L)_t$, and $\Delta ln(ITT/L)_t$ are stationary.

[8] Tests for first-order serial correlation are carried out in each equation of the VAR with $k = 3$. None of the LM(1) test statistics is significant at the 5 per cent level.

TABLE 2

Test for a Unit Root in the Presence of a 1973 Crash

Variable	i	ADF	$LM(1)$	Het	MADF	$t(\lambda)$
$ln(Y/L)_t$	4	2.086	0.470	0.464	2.069	−0.252
$ln(K/L)_t$	6	−0.022	0.713	5.407	0.064	0.343
$ln(H/L)_t$	0	−0.830	3.877^{a}	0.076	−1.255	1.653
$ln(ITT/L)_t$	1	−1.966	1.696	1.849	−1.693	−0.137

1. *LM(1)* is the Lagrange Multiplier statistic for first-order serial correlation. 2. *Het* is Ramsey's (1969) test for heteroskedasticty. 3. *a* denotes significance at the 5 per cent level. 4. $t(\lambda)$ is the t-ratio for testing the significance of λ, distributed standard normal. 5. ADF critical values from Zivot and Andrews (1992).

TABLE 3

Test for a Unit Root in the Presence of a 1973 Trend Change

Variable	i	ADF	$LM(1)$	Het	MADF	$t(\lambda)$
$ln(Y/L)_t$	4	−1.909	0.124	0.461	−1.852	−0.207
$ln(K/L)_t$	5	−3.414	0.433	0.157	−3.337	−0.126
$ln(H/L)_t$	2	−4.581^{a}	2.931	1.596	−4.304	0.822
$ln(ITT/L)_t$	1	−2.980	0.546	0.850	−2.643	0.414

1. *LM(1)* is the Lagrange Multiplier statistic for first-order serial correlation. 2. *Het* is Ramsey's (1969) test for heteroskedasticty. 3. *a* denotes significance at the 5 per cent level. 4. $t(\lambda)$ is the t-ratio for testing the significance of λ, distributed standard normal. 5. ADF critical values from Zivot and Andrews (1992).

$L)_t'$, $ln(IC)_t'$, $ln(H/L)_t'$ and the error correction terms are stationary, the following error correction model can be estimated by OLS:

$$
\begin{aligned}
\Delta ln(Y/L)_t = \pi_0 &+ \sum_{j=0}^{l} \pi_{1j}\, \Delta\, ln(K/L)_{t-j} + \sum_{j=0}^{l} \pi_{2j}\, ln(H/L)'_{t-j} \\
&+ \sum_{j=0}^{l} \pi_{3j}\, \Delta\, ln(ITT/L)_{t-j} \\
&+ \sum_{j=0}^{l} \pi_{4j}\, ln(T/L)'_{t-j} + \sum_{j=0}^{l} \pi_{5j}\, ln(IC)_{t-j} \\
&+ \sum_{j=1}^{l} \pi_{6j}\, \Delta\, ln(Y/L)_{t-j} \\
&+ \theta_1\, [ln(Y/L)_{t-1} - \hat{\alpha}_1^{T}\, X^*_{t-1}] \\
&+ \theta_2\, [ln(Y/L)_{t-1} - \hat{\alpha}_2^{T}\, X^*_{t-1}] + \varepsilon_t \qquad (9)
\end{aligned}
$$

where π_{ij} are the estimated short-run effects, 'defines the de-trended series, θ_i are the coefficients for the lagged error correction terms, α_i is a vector of cointegrating coefficients, $X^*=[ln(K/L)_t, ln(ITT/L)_t]$, and ε_t is a white-noise error term. Equation (9) is estimated for the period 1950 to 1994 and regression results reported in Table 6.

The econometric model is well specified, satisfying a range of diagnostic tests for model adequacy. These include the Lagrange Multiplier test for first-order serial correlation and Ramsey's (1969) tests for functional form and heteroskedasticity. The signs of the estimated parameters conform to *a priori* expectations and all are statistically significant at the 5 per cent level, except human capital. The coefficients for the lagged error-correction terms sum to −0.326 and are jointly significant at the 5 per cent level (F_{calc} = 4.266).

Estimated short- and long-run elasticities are presented in Table 7. All estimates are inelastic. The impact of fixed capital, ITT capital and openness are similar and dominate the short-run explanation of labour productivity.

Labour productivity elasticities with respect to fixed capital, ITT capital and openness are 0.197, 0.264, and 0.211 respectively. The remaining significant short-run source of productivity growth is international competitiveness which has an elasticity −0.059.[9] These significant findings for

[9] The measure of international competitiveness employed here is the ratio of export to import prices. We recognize that prices could change nominally and work through the exchange rate. Accordingly we re-

TABLE 4
Test for a Unit Root in the Presence of a 1973 Joint Crash and Trend Change

Variable	i	ADF	$LM(1)$	Het	MADF	$t(\lambda)$
$ln(Y/L)_t$	4	−1.324	0.042	0.420	−1.287	−0.192
$ln(K/L)_t$	5	−3.355	0.559	0.154	−3.277	−0.118
$ln(H/L)_t$	2	-4.221^a	3.681	1.721	−3.947	0.863
$ln(ITT/L)_t$	1	−2.834	0.688	0.789	−2.552	0.403

1. *LM(1)* is the Lagrange Multiplier statistic for first-order serial correlation. 2. *Het* is Ramsey's (1969) test for heteroskedasticty. 3. *a* denotes significance at the 5 per cent level. 4. $t(\lambda)$ is the t-ratio for testing the significance of λ, distributed standard normal. 5. ADF critical values from Zivot and Andrews (1992).

TABLE 5
Johansen and Juselius test for cointegration between $ln(Y/L)_t$, $ln(K/L)_t$ and $ln(ITT/L)_t$

H_0:	H_a:	Eigenvalue	Critical value	Trace	Critical value
$r = 0$	$r \geq 1$	23.49^a	20.97	40.73^a	29.68
$r \leq 1$	$r = 2$	15.34^a	14.07	17.23^a	15.41

1. *a* denotes significance at the 5 per cent level. 2. Critical values from Johansen and Juselius (1990).

sectoral investment (ITT), openness, and international competitiveness support new growth theory explanations for short-run deviations from the long-run growth path of labour productivity (DeLong and Summers 1991, Krugman 1987 and, Dowrick 1994). The long-run elasticities are consistent with the finding that fixed capital accumulation determines the growth path of productivity in the long run.

V Conclusions

This paper empirically examines sources of Australian labour productivity change from 1950 to 1994. Time-series data are used to estimate an econometric model capturing the dynamic interaction between labour productivity and fixed capital, human capital, ITT capital, openness to trade and international competitiveness. ADF tests for a unit root are carried out on these data. Diagnostic tests reveal that the logarithmic transformation is an appropriate data transformation in all ADF auxiliary equations, and the Perron ADF equations. Unit root tests show that openness and international competitiveness are stationary around a deterministic trend, human capital is stationary around a breaking trend in 1973, while labour productivity, fixed capital and ITT capital are difference stationary.

Tests for cointegration show the existence of a cointegrating relationship between the difference stationary variables, labour productivity, fixed capital and ITT capital. An error correction model is estimated incorporating the short-run dynamics of the system with the information from the cointegrating relationship. The model is well specified and the coefficients are used to estimate labour productivity elasticities for both the short and long run. All short-run elasticities have the anticipated signs and all are significant determinants of productivity, except for human capital. This result is not entirely unexpected. The proxy used is not the preferred measure as it does not include human capital augmentation through on-the-job training, and that obtained from post graduate study.

The strong positive relationship between fixed capital and labour productivity suggests that investment is a key source of long-run productivity growth. The importance of investment, and policies that promote it, is reflected in recent Australian policy settings. These include the low inflation focus of monetary policy, structural adjustment in the 1996/97 Commonwealth budget, the Superannuation Guarantee Charge and increased emphasis on public infrastructure investment (particularly through the One Nation

estimate the model using real exchange rates. The results are qualitatively identical.

TABLE 6

Estimates from Equation (9)

Variable		Estimated parameter	t-ratio
Constant	π_0	2.420[a]	2.376
$\Delta ln(K/L)_t$	π_{10}	0.197[a]	3.502
$ln(H/L)'_t$	π_{20}	0.045	0.723
$\Delta ln(ITT/L)_t$	π_{30}	0.264[a]	2.006
$ln(T/L)'_t$	π_{40}	0.211[a]	3.149
$ln(IC)'_{t-1}$	π_{51}	−0.059[a]	−1.990
$\Delta ln(Y/L)_{t-1}$	π_{61}	−0.284[a]	−2.363
$ln[(Y/L)_{t-1} - \alpha_1 X_{t-1}]$	θ_1	−0.239[b]	−1.792
$ln[(Y/L)_{t-1} - \alpha_2 X_{t-1}]$	θ_2	−0.087[b]	−1.918
Adjusted R^2			0.617
F-statistic, $F(8, 34)$			9.454[a]
Serial correlation, LM(1)			2.758
Functional Form			2.267
Heteroskedasticity			0.122

1. *a* denotes significance at the 5 per cent level. 2. *b* denotes statistical significance at the 10 per cent level.

TABLE 7

Labour Productivity Elasticities

Variable	Short Run	Long Run
Fixed capital	0.197[a]	0.453[a]
Human capital	0.045	–
ITT capital	0.264[a]	0.183[a]
Openness	0.211[a]	–
International competitiveness	−0.059[a]	–

1. *a* denotes significance at the 5 per cent level. 2. Long-run elasticity estimates are provided for those variables contained in the cointegrating vector.

policy statement). Sectoral investment in ITT infrastructure is also an important source of labour productivity performance. This is not surprising as reform of the ITT sector has been at the forefront of the microeconomic reform agenda since the Beazley Report (1990). The estimated ITT elasticities suggest that impact of this investment occurs mostly in the short run. Expansion of the telephone networks leads to increased traffic, and as such, has an immediate impact on labour productivity.

The period of study has seen major changes in the composition and direction of Australian trade. Trade policy has concentrated on the reversal of a protectionist stance and the development of an outward orientation through economic integration. The microeconomic reform agenda of successive governments has been concerned with increasing national productivity and international competitiveness. Both openness to trade and international competitiveness are shown to be significant short-run sources of Australian labour productivity performance.

APPENDIX

TABLE A.1

Test for a Unit Root in the Presence of a 1983 Crash

Variable	i	ADF	$LM(1)$	Het	MADF	$t(\lambda)$
$ln(Y/L)_t$	3	0.651	1.408	1.078	0.760	0.660
$ln(K/L)_t$	6	0.089	1.086	4.881[a]	0.080	−0.008
$ln(H/L)_t$	2	−2.327	1.809	0.112	−2.710	0.618
$ln(ITT/L)_t$	0	−2.244	3.303	4.481	−2.464	1.961

1. *LM(1)* is the Lagrange Multiplier statistic for first-order serial correlation. 2. *Het* is Ramsey's (1969) test for heteroskedasticty. 3. *a* denotes significance at the 5 per cent level. 4. $t(\lambda)$ is the t-ratio for testing the significance of λ, distributed standard normal. 5. ADF critical values from Zivot and Andrews (1992).

TABLE A.2

Test for a Unit Root in the Presence of a 1983 Trend Change

Variable	i	ADF	$LM(1)$	Het	MADF	$t(\lambda)$
$ln(Y/L)_t$	3	0.692	1.922	1.144	0.810	0.861
$ln(K/L)_t$	2	−0.654	0.003	0.001	−0.631	0.085
$ln(H/L)_t$	2	−2.658	1.673	0.074	−2.404	0.622
$ln(ITT/L)_t$	1	−3.212	1.434	1.109	−2.414	1.131

1. *LM(1)* is the Lagrange Multiplier statistic for first-order serial correlation. 2. *Het* is Ramsey's (1969) test for heteroskedasticty. 3. *a* denotes significance at the 5 per cent level. 4. $t(\lambda)$ is the t-ratio for testing the significance of λ, distributed standard normal. 5. ADF critical values from Zivot and Andrews (1992).

TABLE A.3

Test for a Unit Root in the Presence of a 1983 Joint Crash and Trend Change

Variable	i	ADF	$LM(1)$	Het	MADF	$t(\lambda)$
$ln(Y/L)_t$	3	0.721	1.791	1.282	0.796	0.655
$ln(K/L)_t$	2	−0.643	0.003	0.001	−0.622	0.098
$ln(H/L)_t$	2	−2.591	1.903	0.075	−2.386	0.626
$ln(ITT/L)_t$	1	−2.969	1.216	0.916	−3.213	0.708

1. *LM(1)* is the Lagrange Multiplier statistic for first-order serial correlation. 2. *Het* is Ramsey's (1969) test for heteroskedasticty. 3. *a* denotes significance at the 5 per cent level. 4. $t(\lambda)$ is the t-ratio for testing the significance of λ, distributed standard normal. 5. ADF critical values from Zivot and Andrews (1992).

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