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Keywords

Labour productivity, Cointegration analysis, Australia.

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AN EMPIRICAL ANALYSIS OF AUSTRALIAN LABOUR PRODUCTIVITY*

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ABSTRACT

This study presents a model capturing sources of Australian aggregate labour productivity using annual time series data from 1970 to 2001. Labour productivity, or real output per hour worked, in this model is determined by real net capital stock in information technology and telecommunications (ITT), real net capital stock in the non-ITT sector, trade openness, human capital, the wage rate, international competitiveness, and the union membership rate. Given the lack of long and consistent time series data, multivariate cointegration techniques are inappropriate as the cointegration results will be sensitive to the lag length, the inclusion or exclusion of the intercept term or a trend in the cointegration equation and/or the vector autoregression (VAR) specification. Therefore, the Engle-Granger representation theorem and the Hausman weak exogeneity test have been employed to determine the short and long-term drivers of Australian productivity. Empirical estimates indicate that, in the long-term, policies aimed at promoting various types of investment, trade openness, international competitiveness, and the use of wage as an stimulant in a decentralised wage negotiation system, will improve labour productivity. In the short term, all the above variables except for human capital and labour reforms, which both need more time to evolve, determine productivity performance.

Keywords: Labour productivity, Cointegration analysis, Australia.

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I. INTRODUCTION

There is a consensus among economists that productivity growth plays a substantial role in enhancing standards of living and international competitiveness. According to econometric studies based on growth-accounting models, it is argued that increased productivity over the last three decades has contributed to two-thirds of the 80 per cent rise in per capita income in Australia (Industry Commission, 1997). As higher productivity translates into higher per capita income, Australians benefit from higher standards of health care, better education and public welfare. However, while productivity contributes to at least fifty percent of total real income growth, it should be borne in mind that the empirical estimates based on growth-accounting models understate the actual contribution of productivity to economic prosperity (Dowrick and Nguyen, 1989) and Dowrick, 1998).

For instance, Romer (1990) demonstrates the way in which public and private resources devoted to the development of new ideas and new products can accelerate economic growth. On the other hand, the neo-Schumpeterian models of Aghion and Howitt (1998) analyse the economic impact of research into product improvement rather than product diversity. Nevertheless their overall conclusions are the same as those of Romer. That is, increases in productivity, brought about by new or improved products and processes, such as information and communications technologies (ICTs), will directly and indirectly result in increased returns to capital investment and consequently lead to a sustained level of growth of GDP. Therefore, it can be stated that the estimates based on growth-accounting procedures underestimate the true contribution of productivity growth.

In order to address this theoretical pitfall, new growth theories identify the channels through which economic institutions and reform processes can stimulate the rate of investment in physical capital, human capital, technological know-how and knowledge capital. These factors exert a sustained and positive effect on the long-run growth of the economy (Rebelo, 1991). Unlike the traditional neo-classical growth models of Swan (1956) and Solow (1956), in the new endogenous growth models institutions and policy arrangements do matter and can impact not only on the level of economic activity but also on its long-run growth path. Undoubtedly higher productivity growth leads to more sustainable long-term economic prosperity, but the main issue is “how can productivity be further stimulated?”

Over the last two decades there has been considerable interest in determining the sources of productivity in Australia. Within the Productivity Commission, these in-depth studies have resulted in a number of publications such as Industry Commission (1997), Productivity Commission (1999, 1998) and Parham *et al.* (2000, 2001). Dawkins and Rogers (1998) review a wide range of productivity studies in the post-1980 period, ranging from survey based firm-level case studies to aggregate macroeconomic time-series analyses. According to their comprehensive review of the productivity literature, the major determinants of productivity at the national level are capital intensity, international openness, factor prices, the union membership rate (as a proxy for labour reforms), international competitiveness, human capital investment, and infrastructure.

Dowrick (1990), in his empirical examination of labour productivity, identified the major determinants of the 1980s productivity slump. His econometric results indicate that the labour productivity slowdown after 1983 was mainly associated with capital

dilution, reflecting a small fall in investment as well as a sharp expansion of hours worked between 1983 and 1988. Given the cyclical variation in productivity levels due to “hoarding” of capital and labour in downturns, his study concluded that “underlying multifactor productivity growth had not declined subsequent to the introduction of centralised wage setting in 1983. Rather, it was the wage restraint of the Accord which had contributed to high employment growth and the consequent slowdown in labour productivity” (Dowrick, 1998, p.4).

Barro (1991) and Barro and Lee (1994) in their seminal work echoed the importance of human capital or a better educated labour force as a major determinant of economic growth and productivity. Other studies, *inter alia*, Aschauer (1989) and Otto and Voss (1994), provided empirical evidence that specific types of investment in the core public infrastructure of transport and communication and water systems can also stimulate productivity and growth. Similarly, according to Greenstein and Spiller (1995), Karunaratne (1995), Parham *et al.* (2001), investment in information technology and telecommunications (ITT) should also be regarded as an important stimulant of productivity. They demonstrate that investment in ITT results in curtailing transport and transactions costs, facilitating the process of technological diffusion, accelerating the diffusion of knowledge and providing better marketing information. In a comparative study of nine OECD countries (including Australia) Colecchia and Schreyer (2001) have recently found that, depending on the country, ITT has contributed between 0.2 and 0.5 percentage points per year to economic growth. It is interesting to note that in the context of Australia during the 1980-1985 period this contribution was, on average, 0.27 percent but it rose to 0.79 percent during the 1995-2000 period. See Colecchia and Schreyer

(2001). Therefore, it can be concluded that the impact of ITT on output growth and productivity has demonstrated an accelerating pattern over time. This result is also consistent with the empirical findings of Parham *et al.* (2001).

DeLong and Summers (1991) believe that a change in the composition of investment (more capital expenditure on machinery and equipment rather than construction) can accelerate productivity due to technological and learning externalities which place the social return to physical investment above the private return.

Furthermore, Dowrick (1994) finds that increased openness to trade stimulates productivity growth through increased competition, specialisation and transfer of knowledge. Dowrick (1994) found that the recent trade openness experienced in Australia may have been responsible for approximately one-fifth of a percentage point in the productivity surge of the 1990s. Microeconomic reforms in Australia have also substantially contributed to increased productivity by reducing institutional and regulatory barriers to the flow of foreign goods and providing businesses with greater flexibility to adjust to a more competitive environment. Moreover, these reforms have been pivotal in the uptake of ICTs. The degree of trade openness, and the uptake of ICTs as quantifiable proxy variables, can reflect, in part, the impacts of Australian microeconomic reforms.

Lowe (1995) examines the relationship between real wages growth and labour productivity at the industry level and his research indicates that a positive relationship between these two variables exists. More recently a study by Madsen and Damania (2001), using annual manufacturing data for 22 OECD countries for the 1960-1993 period clearly indicates that an increase in the real wage rate can steepen or even reverse

the slope of the demand for labour. They argue that rising real wages “give firms incentives to innovate and to invest in newer and more efficient vintages of capital and to utilise labour more efficiently; thus rendering labour and capital productivities positive functions of real wages” (Madsen and Damania, 2001, p.324).

Freeman and Medoff (1984) in their discussion of the effect of unions on labour productivity, argue that there are two faces of unions: the ‘monopoly face’ and the ‘collective voice face’. The former could result in decelerating productivity through restrictive work practices and industrial action, whereas the latter could lower labour turnover and improve communications, and thus give a rise to higher productivity performance (Metcalf 1990). Dawkins and Rogers (1998), in their survey of the literature, reach the conclusion that the positive or negative impact of unionisation on productivity is an empirical matter. There are two Australian studies that have already examined this issue, namely Crockett, *et al.* (1990) and Drago and Wooden (1992). Adopting a multivariate analysis, both of these studies used the 1990 Australian Workplace Industrial Relations Survey (AWIRS). These studies present some evidence of negative union effects on productivity.

Finally, Savage and Madden (1998) employ a multivariate cointegration technique to determine the short- and long-term sources of Australian labour productivity during the 1950-1994 period. Their results indicate that, in the short term, Australian labour productivity is mainly determined by the real capita stock per worker, investment in ITT (as proxied by telephones per capita), trade openness (real exports plus imports per worker), international competitiveness, and human capital (proxied by tertiary student

enrolment per worker). However, in the long term, fixed capital accumulation and investment in ITT are the only significant determinants of productivity improvement.

All the above-mentioned studies of productivity and economic growth have been instrumental in identifying sources of Australian labour productivity in this paper. The present study makes a contribution to the literature in relation to the specification of an aggregate productivity model as well as the use of a new database which was not available earlier. These issues are discussed in the next section.

The structure of this paper is as follows. In Section II a theoretical model is postulated which explains the long-term and short-term factors affecting Australia's labour productivity since 1970 using the Engle-Granger representation theorem. Section III discusses the types and sources of the data employed in this study. In this section three unit root tests are utilised to determine the time series properties of the data. This section also presents the empirical econometric results for the short and long-term labour productivity models, as well as policy implications of the study. Section IV provides some concluding remarks.

II. THEORETICAL FRAMEWORK

As seen from the previous section there is an existing research literature on the sources of Australia's labour productivity both at the micro and macro levels. Following Madden and Savage (1998), the supply side approach of Aschauer (1989) and Romer (1989) is used to specify a production function for aggregate output, *viz.*

$$Y_t = f(L_t, K_{1t}, K_{2t}, S_t) \quad (1)$$

Where Y is aggregate output (real GDP), L is labour, K_1 is the real non-ITT capital stock, K_2 is the real stock of capital in the ITT sector, and S is a proxy for human capital.

One may argue that the parameter estimates from a Cobb-Douglas production function can be biased if the aggregate production function is homogenous of degree greater than one. Therefore it is very important to test if the assumption of constant returns to scale applies for an aggregate production function. There is a recent study by Connolly and Fox (2001) that tests the assumption of constant returns to scale (the null) for various sectors of the Australian economy. They conclude that this restriction is not rejected for the following sectors: Construction; Electricity, Gas and Water; Transport and Storage; Retail Trade; and the Market sector. However their Wald test results also indicate that the null hypothesis is rejected for three sectors of Construction; Finance and Insurance; and Wholesale Trade. At an aggregate level, using the data employed in this study, the constant returns to scale assumption has been tested and the results (not reported here but available from the author upon request) indicate that the null hypothesis (the sum of all production input elasticities with respect to output is equal to 1) cannot be rejected. This assumption has also been adopted in a number of other studies in the analysis of productivity in Australia. See, *inter alia*, Industry Commission (1997, Appendix B), and Lowe (1995).

By dividing both sides of equation (1) by L_t , one obtains the following relation which is used to measure labour productivity:

$$Y_t / L_t = \varphi(K_{1t} / L_t, K_{2t} / L_t, S_t / L_t) \quad (2)$$

In addition to physical capital stock (both in ITT and non-ITT) per worker and human capital per worker, Dowrick (1994) has already shown that trade openness and international competitiveness are also two important sources of Australia's productivity miracle. As discussed earlier, Madden and Savage (1998) have incorporated these two

important factors in their productivity model. However, they calculate labour productivity by dividing real GDP by total participants in the labour force. It is argued that as the composition of the labour force, in terms of the number of part-time and full-time workers, varies over time, output per worker becomes an inadequate or misleading measure of labour productivity. In other words, if productivity is defined as output per worker, an increase in the number of part-time workers (while output and the total number of hours worked in the economy remain unchanged), can wrongly indicate a decline in productivity. In order to overcome this problem, in this study productivity is defined as output per hour worked.

Also following Lowe (1995), and Madsen and Damania (2001), the productivity model is augmented by the real wage rate which can also positively impact on productivity as an incentive. Finally the model incorporates the effect of unionisation (as a proxy for labour reforms) on labour productivity as proposed by Freeman and Medoff (1984) in the previous section.

Therefore, the aggregate labour productivity model in this study is specified, in log form, as follows:

$$\ln\left(\frac{Y}{L_t}\right) = \beta_0 + \beta_1 \ln\left(\frac{K_{1t}}{L_t}\right) + \beta_2 \ln\left(\frac{K_{2t}}{L_t}\right) + \beta_3 \ln\left(\frac{S_t}{L_t}\right) + \beta_4 \ln\left(\frac{T_t}{L_t}\right) + \beta_5 \ln\left(\frac{W_t}{P_t}\right) + \beta_6 \ln(R_t) + \beta_7 \ln(U_t) + e_t \quad (3)$$

Where Y is real GDP (\$million in 1999 constant prices), L is total hours worked in the economy (in million), K_1 is non-ITT stock of capital (\$million in 1999 constant prices), K_2 is ITT stock of capital (covering the stock of computers, electronic equipment, and computer software, \$million in 1999 constant prices), S is total number of postgraduate students (persons) as a proxy for human capital, T is Trade or total export plus total

imports (\$million in 1999 constant prices), W is nominal wage rate (\$), P is the consumer price index (1990=100), R is the real exchange rate (trade weighted index, 1995=100), U is the union membership rate (percent), \ln denotes the natural logarithm, and β_i are elasticities to be estimated.

As can be seen from equation (3), this model has a comprehensive and non-restrictive specification based on the previous studies. It should be borne in mind that Madden and Savage (1998) used total number of telephone lines as a proxy to capture the impact of ITT on Australia's labour productivity, whereas this study utilises a newly compiled database of the stock of capital in the ITT sector covering three components of computers, electronic equipment, and computer software.

A new and more accurate measure of international competitiveness (R) has been compiled by the Reserve Bank of Australia (RBA) for the 1970-2001 period. For the first time this measure (*i.e.* the trade weighted real exchange rate) is used in the context of an aggregate productivity model. Therefore, the proposed model has not only a comprehensive and unrestricted specification but also it uses more accurate measures of productivity, the impact of ITT and international competitiveness.

In equation (3) let us now assume that: a) the dependent and all independent variables are integrated of order 1; b) the resulting residuals (ε_t) are white noise or $I(0)$ and; c) all the explanatory variables on the right hand side are weakly exogenous with respect to the dependent variable. If these assumptions hold, according to the Engle-Granger representation theorem (Engle and Granger, 1987), it can be argued that equation (3) is cointegrated capturing a long-term relationship between labour productivity, and its major determinants namely: 1) the real stock of capital (buildings, machinery, tools, all

non-ITT equipment) per hour worked, or K_1/L ; 2) the real stock of computers, electronic equipment and software per hour worked or K_2/L ; 3) human capital as proxied by the total number of postgraduate students per hour worked, or S/L ; 4) trade openness or total real exports plus real total imports per hour worked, or T/L ; 5) the real wage rate, or W/P ; 6) international competitiveness, or R (trade weighted real exchange rate); 7) the union membership rate, or U . It is theoretically expected that if K_1/L , K_2/L , S/L , T/L , and W/P increase and at the same time R and U fall, labour productivity will rise. In other words, it is expected that β_1 , β_2 , β_3 , β_4 , and β_5 will have positive signs, whereas the elasticities for R and U (β_6 , and β_7) have a negative expected sign (for the theoretical justification of β_i see Section I).

An important step before estimating the productivity model is to determine the time series properties of the data. This is an important issue since the use of non-stationary data in the absence of cointegration can result in spurious regression results. To this end, three widely-used unit root tests, *i.e.* the Augmented Dickey-Fuller (ADF) test, the nonparametric Phillips-Perron (PP) test, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS, 1992) test, have been adopted to examine the stationarity, or otherwise, of the time series data. In this paper the lowest value of the Akaike Information Criterion (AIC) has been used as a guide to determine the optimal lag length in the ADF regression. These lags are added to the ADF regression to ensure that the error term is white noise. By using the PP test, one can ensure that the higher-order serial correlations in the ADF equation have been handled properly. In other words, the ADF test corrects for higher order autocorrelation by including lagged differenced terms on the right-hand side of the ADF equation, whereas the PP test corrects the ADF t -statistic by removing the serial

correlation in it. This nonparametric correction uses the Newey-West heteroskedasticity autocorrelation consistent estimate and is robust to heteroskedasticity and autocorrelation of unknown form.

In addition to the ADF test and the PP test, a KPSS test (Kwiatkowski, Phillips, Schmidt, and Shin, 1992) has also been calculated for all the variables. Unlike the ADF and PP tests, the KPSS test has the null of stationarity, and the alternative indicates the existence of a unit root. The KPSS simply assumes that a time series variable (say y_t) can be decomposed into the sum of a deterministic trend, a random walk, and a stationary error term in the following way:

$$y_t = \beta t + \xi_t + \varepsilon_t \quad (4)$$

where w_t (a random walk) is given by $\xi_t = \xi_{t-1} + u_t$.

One can now test for the stationarity of y_t by testing $\sigma_u^2 = 0$. This test involves two steps: first one should run an auxiliary regression of y_t on an intercept and a time trend t and save the OLS residuals (say e_t) and compute the partial sums $S_t = \sum_{i=1}^t e_i$; and second, compute the following KPSS statistic:

$$\text{KPSS} = T^{-2} \sum_{t=1}^T S_t^2 / s^2(l) \quad (5)$$

where $s^2(l) = T^{-1} \sum_{t=1}^T e_t^2 + 2T^{-1} \sum_{s=1}^l w(s,l) \sum_{t=s+1}^T e_t e_{t-s}$. Following KPSS, the Bartlett window, where $w(s, l) = 1-s/(l+1)$, has been used to correct for heteroscedasticity and serial correlation.

Given that there are only between 32-35 annual observations for the various variables studied in this paper, the unit root test results should be taken with a pinch of salt as all these tests are appropriate for large samples.

Let's assume that all the variables in equation (3) are I(1) and the resulting residuals are I(0). According to Engle and Granger (1987), it can then be stated that there exists a corresponding error-correction mechanism (ECM or e_t) model of the following form:

$$\begin{aligned} \Delta \ln \left(\frac{Y_t}{L_t} \right) = & \gamma_0 + \sum_{i=0}^p \gamma_{1i} \Delta \ln \left(\frac{K_1}{L} \right)_{t-i} + \sum_{i=0}^p \gamma_{2i} \Delta \ln \left(\frac{K_2}{L} \right)_{t-i} + \sum_{i=0}^p \gamma_{4i} \Delta \ln \left(\frac{S}{L} \right)_{t-i} + \sum_{i=0}^p \gamma_{3i} \Delta \ln \left(\frac{T}{L} \right)_{t-i} \\ & + \sum_{i=0}^p \gamma_{5i} \Delta \ln \left(\frac{W}{P} \right)_{t-i} + \sum_{i=0}^p \gamma_{6i} \Delta \ln(R)_{t-i} + \sum_{i=0}^p \gamma_{7i} \Delta \ln(U)_{t-i} + \sum_{i=1}^p \delta_i \Delta \ln \left(\frac{Y}{L} \right)_{t-i} + \theta e_{t-1} + v_t \end{aligned} \quad (6)$$

where γ_{ji} are the estimated short-term coefficients; θ represents the feedback effect or the speed of adjustment whereby short-term dynamics converge to the long-term equilibrium path indicated in equation (3); δ_i denotes for the estimated coefficients of the lagged dependent variable to ensure that v_t or the disturbance term is white noise; e or ECM is obtained from equation (3), and Δ indicates the first-difference operator.

The general-to-specific methodology can be used to omit insignificant variables in equation (6) on the basis of a battery of maximum likelihood tests. In this method, joint zero restrictions are imposed on explanatory variables in the unrestricted (general) model to obtain the most parsimonious and robust equation in the estimation process.

However, one may argue that the Engle-Granger is an appropriate method if there are only two variables in the cointegration equation. In other words, if there are more than two variables, it is possible that there could exist more than one cointegrating relationship between the variables, rendering the Engle-Granger two step procedure inadequate. To address this issue the multivariate Johansen cointegration technique was initially used to determine the number of cointegrating vectors. However, given the lack of long and consistent time series data, the Johansen method is also inappropriate, as the cointegration results, with only 31 observations, were very sensitive to the lag length, the

inclusion or exclusion of the intercept term, or a trend in the cointegration equation, and/or the VAR specification. Therefore, one can use either a more sophisticated econometric technique with a longer (but less reliable) time series or a simpler technique with shorter (but more accurate) time series data. Since Madden and Savage (1998) have already tried the first alternative in their trade-off, the author of this paper has chosen the second option.

One should bear in mind that if all the variables on the right-hand side of equation (3) are weakly exogenous with respect to the dependent variable, one can still rely on equation (4) representing short-term dynamics of the productivity model. In other words, as long as all the independent variables are weakly exogenous the Engle-Granger two-step procedure can be considered appropriate.

The next issue is how to test if a typical independent variable on the right hand side of an equation is weakly exogenous with respect to a dependent variable? In the rest of this section we briefly discuss weak exogeneity testing in a simplified model. As discussed later in this section, this simple model with two variables can be generalised to an equation with more than two regressors. For simplicity consider a two-variable regression of y on k . Following Hurn and Muscatelli (1992) it is assumed that the joint distribution of y_t and k_t is conditional normal with the following conditional means:

$$E[y_t | I_t] = \mu_t^y \tag{7}$$

$$E[k_t | I_t] = \mu_t^k \tag{8}$$

where the covariance matrix is

$$\Sigma = \begin{bmatrix} \sigma^{yy} & \sigma^{yk} \\ \sigma^{ky} & \sigma^{kk} \end{bmatrix} \tag{9}$$

The means and covariances depend on the information set, I_t . This information set includes past values of y_t and k_t and current and past values of some other valid conditioning variables, z_t .

Using the above relations, the expectation of y_t conditional on k_t can be written as

$$E(y_t | k_t) = \delta_t(k_t - \mu_t^k) + \mu_t^y \quad (10)$$

Note that in Equation (10) δ_t is the regression coefficient of y_t on k_t , which can be defined as $\sigma_t^{yk} / \sigma_t^{kk}$. Now if it is assumed that

$$y_t - E(y_t | k_t) = w_t \quad (11)$$

the conditional variance can be obtained by:

$$\text{var}[w_t] = \text{var}[y_t - E(y_t | k_t)] = \sigma_t^{yy} - \frac{(\sigma_t^{yk})^2}{\sigma_t^{kk}} \quad (12)$$

It is also assumed that the conditional mean of y_t and k_t is given as

$$\mu_t^y = \beta \mu_t^k + z_t' \gamma \quad (13)$$

Substituting Equation (13) into equation (10) yields

$$E(y_t | k_t) = \delta_t(k_t - \mu_t^k) + \beta \mu_t^k + z_t' \gamma \quad (14)$$

After substituting Equation (14) into equation (11), the following Equation is obtained:

$$y_t = \beta k_t + z_t' \gamma + (\delta_t - \beta)(k_t - \mu_t^k) + w_t \quad (15)$$

Equation (15) can then be used to test for weak exogeneity of k by estimating the conditional and the marginal models. The conditional model is the initial regression of y on k and the marginal model could be k as a function of a number of conditioning variables say z . According to Equation (15), k is weakly exogenous with respect to y_t only if μ_t^k , σ_t^{kk} and σ_t^{yk} do not enter the conditional model. This condition is satisfied if $\delta_t = \beta$. This condition simply means that the resulting residuals from the marginal model must be insignificant in

the conditional model. How can one generalise the Hausman weak exogeneity test if there are more than one explanatory variable on the right-hand side as in equation (3)? If there are more than one explanatory variable in the equation, this test involves three estimation stages. At the first stage one needs to regress each explanatory variable on the right-hand side of equation (3) on a number of conditioning variables. A conditioning variable (z) can include its own lagged values as well as the lagged values of other relevant variables, which in this example could be among the variables in equation (3). Then in the second stage the estimated stochastic residuals of each of these auxiliary equations should enter as a separate explanatory variable in equation (3). Finally a joint F or Wald test can be used to test a null hypothesis in which the coefficients of the computed residuals in equation (3) are all set equal to zero. If this joint hypothesis is not rejected, it can then be concluded that all the variables on the right-hand side of equation (3) are weakly exogenous and the OLS estimators are both consistent and efficient. For a detailed discussion of weak exogeneity testing see Hausman (1978).

According to Hamilton (1994, p.590), when there are more than two variables (say $y_{1t}, y_{2t}, y_{3t}, \dots, y_{nt}$), the OLS Engle-Granger estimation of the long-term relationship can still provide a consistent estimate of the cointegrating vector as long as the resulting residuals from $y_{1t} = f(y_{2t}, y_{3t}, \dots, y_{nt})$ are not correlated with any other non-stationary linear combinations of $(y_{2t}, y_{3t}, \dots, y_{nt})$.

III. EMPIRICAL RESULTS AND POLICY IMPLICATIONS

Australian labour productivity, proxied by output (GDP in 1999-2000 prices) per hour worked, rose substantially from \$21.9 in 1970 to \$38.4 in 2001, an average increase

of 1.8 per cent per annum. What are the sources of this productivity growth? Figures 1 to 8 in Appendix show the plots of labour productivity and its major determinants as far back as the data were available. The sources of the data have also been stated below each figure. A cursory or informal inspection of these graphs reveals some interesting facts which are consistent with the earlier theoretical postulates and findings in the literature outlined in section I. Labour productivity (GDP/L) has risen while K_1/L , K_2/L , S/L , T/L , and W/P have demonstrated a pronounced overall upward trend, and R and U a general downward pattern.

Prior to undertaking a thorough empirical investigation of the sources of Australian labour productivity growth, it is essential to determine the time series properties of the data. As mentioned above, in order to make robust conclusions about stationarity or otherwise of the data the ADF, the PP, and the KPSS tests are utilised. The empirical results of the ADF and PP unit root tests are summarised in Table I in Appendix. According to both tests, all of the eight variables employed in equation (3) are integrated of order one, $I(1)$, and they become stationary after first differencing. Table II in Appendix presents the results of the KPSS test for trend stationarity with up to 8 truncation lags (l). As seen from Table II, irrespective of the number of truncation lags, the calculated KPSS statistics are greater than the 5 per cent critical value of 0.146 for all the variables except for $\log(R_t)$. Therefore, it can be concluded that in most cases (7 out of 8 variables) the null is rejected and these variables are not trend stationary. However, when the KPSS test statistic for level stationarity was calculated for $\log(R_t)$ (not reported here but available from the author upon request), it was found that this variable was not level stationary although Table II shows that the null of trend stationary for this variable

cannot be rejected. Given the fact that in most cases the problem of serial correlation for annual time series data is likely to be of order 1 and/or 2, a maximum upper bound of 2 truncation lags (l) will be enough to ensure that autocorrelation is corrected in the KPSS test. In this study a maximum truncation lag of up to 8 is allowed and it is observed that the rejection of the null (for 7 out of 8 variables) is not subject to reversal using different truncation lags.

Since all the variables in equation (3) are $I(1)$, the Engle-Granger two-step procedure can be used to examine if this equation represents a long-term relationship. Before undertaking this procedure, consider Figure 7 closely: this Figure plots the union membership rate (U) in Australia during the 1968-2001 period. It seems that U has sharply declined since 1991. The Australian Bureau of Statistics (ABS, 2000) argues that this break in U relates to several factors such as: a) the amalgamation of unions that occurred in the 1990s; b) a move towards enterprise bargaining initiated by the introduction of the Accord Mark VI between the Commonwealth Government and the Australian Council of Trade Unions (ACTU). In order to capture this policy regime shift, a slope dummy variable affecting the estimated coefficient for U or β_7 , will be incorporated into equation (3). This Dummy variable (D) takes the value of 1 in the 1992-2001 period and zero otherwise.

Using the ordinary least square (OLS) estimation method, Table II in Appendix presents the empirical econometric results for equation (3) using the annual time series data from 1970 to 2001. All the estimated coefficients are statistically significant at least at the 5 per cent level and have the expected theoretical signs. This equation also performs extremely well in terms of goodness-of-fit statistics. The adjusted R^2 is as high

as 0.9982 and the overall F test rejects the null hypothesis at the one per cent level. Furthermore, this equation passes a battery of diagnostic tests and shows no sign of misspecification.

A joint F -test has also been used to determine if all the independent variables in equation (3) are weakly exogenous with respect to the dependent variable. At the first stage each explanatory variable in equation (3) is regressed on a number of conditioning variables which may include its own lagged values and the lagged values of the other seven variables in equation (3). Then the estimated stochastic residuals of each of these auxiliary equations have been inserted as a separate regressor in equation (3). Finally, after reestimating equation (3), a Wald test is used to test a null hypothesis in which the coefficients of the estimated residuals are all set equal to zero. The Wald test results indicate that all the variables on the right hand side of equation (3) are weakly exogenous with respect to the dependent variable, or $\ln(Y/L)$, except for the real wage rate. Given that $F = 0.93$ [probability=0.50], the null hypothesis of weak exogeneity is not rejected for all but W/P. Because of space limitations, the weak exogeneity test results are not reported here but they are available from the author upon request. Due to the simultaneity problem between W/P and GDP/L, both the 2SLS and OLS methods have been employed to estimate the long-term productivity model. However, as seen from Table III in Appendix, the 2SLS estimators are very close to the OLS estimates. Thus, it really does not make much difference which estimates are used in this analysis.

Given that a) all the variables in equation (3) are I(1); b) the resulting stochastic residuals are stationary, or I(0); and c) the independent variables are weakly exogenous, it can be concluded that equation (3) represents a cointegrating vector. Comment on the

magnitudes of the estimated long-term parameters of the productivity model, or equation (3), will be considered below.

In terms of the magnitude of the estimated elasticities, Table III in Appendix shows that if the real capita stock per hour worked in the non-ITT sector and the ITT sector increases by 10 per cent, the labour productivity will rise by 2.52 per cent 0.77 per cent, respectively. One may argue that why the productivity elasticity for ITT is low. However as emphasised by Parham *et al.* (2001), the ITT-related productivity gains are usually indirect: the use of ICT equipment (hardware, software) changes what businesses do and how they do it.

It is also found that an increase in the real wage rate by say 10 per cent, *ceteris paribus*, can boost productivity by 1.7 per cent. The value of the estimated wage rate elasticity (1.7 per cent) is consistent with other studies in the literature. Based on a study using manufacturing data for 22 OECD countries, Madsen and Damania (2001) have recently found that a 10 per cent rise in real wages increases the marginal productivities of labour and capital by 1.8 per cent.

Furthermore, the negative coefficient for U implies that a move towards a decentralised wage bargaining system, where unions play a less important role in wage setting, would improve productivity. It should be noted that the dummy variable, affecting the estimated slope coefficient of the union membership rate (U), is highly significant. The estimated coefficient for this dummy variable (-0.006) indicates that during 1970-1991 a 10 per cent increase in U could reduce the aggregate productivity by 0.72 per cent, whereas from 1992 to 2001 this rise in U would reduce labour productivity by 0.78 per cent: -0.06 relates to the slope dummy variable and -0.72 pertains to the

coefficient for $\ln(U)$. Thus, the negative impact of U during the post-1992 period is slightly greater than that of the pre-1992 period.

The reported results in Table III also clearly indicate that trade openness (proxied by T/L) and investment in human capital (proxied by S/L) can further improve labour productivity with an estimated long-run elasticities of 0.11 and 0.04, respectively. Finally the long-term elasticity of the real exchange rate is about -0.05 indicating that as Australia becomes more internationally competitive (proxied by a fall in R) productivity will increase. See Table III in Appendix. It is interesting to note that Madden and Savage (1998) found that the major long-term determinants of Australian labour productivity were only fixed capital and ITT capital (proxied by the total number of telephone lines).

Since the estimated residuals from the long-term productivity model are $I(0)$, one can use the Engle and Granger representation theorem (1987) to estimate the short-term productivity model, or equation (4). Table IV in Appendix presents the results for the vector error correction model which captures the short-term dynamics of the labour productivity model. The general-to-specific methodology have been adopted in estimating equation (6) by omitting insignificant lagged variables and undertaking a battery of maximum likelihood tests. Joint zero restrictions have been imposed on insignificant explanatory variables in the unrestricted (or general model) to obtain the most parsimonious and robust equation in the estimation process. The parsimonious short-term model of productivity includes all of the long-term determinants of labour productivity except for S/L and U . In other words, the results reported in Table IV indicate that the short-term sources of productivity are the capital stock per hour worked in both the ITT and non-ITT sectors, trade openness, international competitiveness, and

the real wage rate. All the estimated coefficients are statistically significant at the 1 per cent level and have the expected signs. In terms of goodness-of-fit statistics, though expressed in $\Delta \ln$, with an adjusted R^2 of 0.81, this equation performs extremely well. As with equation (3), this equation also passes each and every diagnostic tests. Table IV also reveals that the feed-back coefficient (or adjustment speed) is as high as -0.887 meaning that in every year 88 per cent of the divergence between the short-term productivity from its long-term path is eliminated.

In the short term, it can be stated that investment, openness to trade, international competitiveness, and wage rises are the main driving forces productivity changes. Therefore, the inward-looking protectionist stance will impede Australian productivity performance. However, in the long-term, in addition to these factors, Australian labour productivity also depends on the extent to which the government is determined to invest more in human capital and expedite labour reforms.

Since W/P was not weakly exogenous with respect to GDP/L , one may also be interested in the relationship between the wage rate and labour productivity. In this paper it is found that there is a bi-directional causation among these two variables. Table V in Appendix presents a log-linear equation specifying the nominal wage rate as a function of labour productivity, and the unionisation rate. As mentioned earlier, one should note that there is a simultaneity problem between this equation and the equation for labour productivity presented in Table IV. Due to this simultaneity problem, these equations have been estimated by both the 2SLS and OLS methods. The 2SLS estimators were very close to the OLS estimators. See Table III. The null hypothesis that the estimated coefficient for $\ln(P_t)$ is equal to 1 in the equation for the nominal wage rate was also

tested. Given a calculated F and chi-square value of 94.9, the null was easily rejected and as a result the equation for the wage rate has been estimated in nominal terms.

According to Table V in Appendix, both the union membership rate and particularly labour productivity have a significant positive impact on the nominal wage rate with estimated elasticities of 0.50 and 2.4, respectively. The estimated elasticity of $\ln(P_t)$ is highly significant but far below unity, indicating that with a 10 per cent rise in the consumer price index, *ceteris paribus*, the nominal wage rate will increase by only 6.3 per cent.

IV. CONCLUSION

In this paper the short-term and the long-term drivers of Australia's labour productivity surge have been examined by using consistent, and in some cases recently compiled, annual time series data from 1970 to 2001. The Engle-Granger two-step procedure and the Hausman weak exogeneity test are employed to estimate and validate empirically the short- and long-term productivity models.

The empirical results are broadly consistent with previous studies. It is found that in the long-term policies aimed at: a) accelerating various types of investments in human capital, the ITT and non-ITT sectors; b) promoting trade liberalisation, and international competitiveness; and c) using the wage rate as a stimulant in a decentralised wage bargaining system, will improve labour productivity. For example, *inter alia*, it is also found that an increase of say 10 per cent in the real wage rate, *ceteris paribus*, can boost productivity by 1.7 per cent.

It seems that in the long-term a move towards a decentralised enterprise bargaining system, where unions play no active role in setting wages, has been a

significant source of productivity, particularly after 1992. Australia's labour productivity growth in the short-term is mainly determined by the growth rate of the real stock of capital in the ITT and non-ITT sectors, trade openness, international competitiveness, the real wage rate, as well as an error correction mechanism. However, the long-term productivity performance depends, not only on these short-term determinants, but also on the effectiveness of the educational system and the government's success in undertaking consequential reforms in the labour market.

In sum, if Australia is to continue experiencing a high productivity growth at its 1990s rate, the economy should invest more in human, physical and ITT capital. Microeconomic reforms can also make the economy more adaptable and less vulnerable to any external shocks. The reduction of barriers to competition and removal of impediments (*e.g.* the impact of unionisation) to innovation will pave the way for a long-term sustainable growth of productivity.

APPENDIX

TABLE I
Time series properties of the data employed

Variable	Available data	MacKinnon critical value		ADF test Optimal lag (i)	ADF <i>t</i> - statistic	Phillips- Perron <i>t</i> - statistic	Statistical inference
		10%	5%				
$\ln(\text{GDP}_t/L_t)$	1966-2001	-3.20	-3.54	0	-2.98	-3.01	I(1)
$\Delta \ln(\text{GDP}_t/L_t)$	1966-2001	-3.21	-3.55	2	-3.41**	-5.70*	
$\ln(K_{1t}/L_t)$	1966-2001	-3.20	-3.54	2	-0.86	-0.94	I(1)
$\Delta \ln(K_{1t}/L_t)$	1966-2001	-3.20	-3.54	1	-4.52*	-3.85*	
$\ln(K_{2t}/L_t)$	1966-2001	-3.20	-3.54	2	1.76	2.65	I(1)***
$\Delta \ln(K_{2t}/L_t)$	1966-2001	-3.20	-3.54	1	-3.20**	-2.36	
$\ln(S_t/L_t)$	1966-2001	-3.20	-3.54	0	-1.15	-1.33	I(1)
$\Delta \ln(S_t/L_t)$	1966-2001	-3.20	-3.54	0	-4.65*	-4.67*	
$\ln(T_t/L_t)$	1966-2001	-3.20	-3.54	2	-0.52	-1.52	I(1)
$\Delta \ln(T_t/L_t)$	1966-2001	-3.20	-3.54	1	-6.75*	-8.12*	
$\ln(W_t/P_t)$	1965-2001	-3.20	-3.53	1	-2.35	-1.63	I(1)
$\Delta \ln(W_t/P_t)$	1965-2001	-3.20	-3.54	0	-4.22	-4.20*	
$\ln(R_t)$	1970-2001	-3.21	-3.56	0	-2.59	-2.79	I(1)
$\Delta \ln(R_t)$	1970-2001	-3.21	-3.56	3	-6.03*	-4.09*	
$\ln(U_t)$	1968-2001	-3.21	-3.56	2	1.16	1.80	I(1)
$\Delta \ln(U_t)$	1968-2001	-3.21	-3.56	1	-4.88*	-4.73*	

Notes: 1) * and ** indicate that the corresponding null hypotheses are rejected at 5% and 10% significant levels, respectively; 2) *** denotes that this conclusion is based on the ADF test statistic only.

TABLE II
KPSS statistics for null of trend stationarity

Variable	Available data	Lag truncation parameter (<i>l</i>)									
		0	1	2	3	4	5	6	7	8	
$\ln(\text{GDP}_t/L_t)$	1966-2001	0.58	0.416	0.346	0.289	0.257	0.235	0.219	0.208	0.201	
$\ln(K_{1t}/L_t)$	1966-2001	0.806	0.559	0.439	0.369	0.324	0.235	0.27	0.254	0.243	
$\ln(K_{2t}/L_t)$	1966-2001	0.522	0.403	0.333	0.295	0.272	0.292	0.248	0.24	0.233	
$\ln(S_t/L_t)$	1966-2001	0.596	0.422	0.337	0.289	0.259	0.258	0.228	0.22	0.217	
$\ln(T_t/L_t)$	1966-2001	0.619	0.451	0.366	0.311	0.275	0.24	0.233	0.222	0.214	
$\ln(W_t/P_t)$	1965-2001	0.607	0.422	0.333	0.282	0.251	0.25	0.217	0.209	0.205	
$\ln(R_t)$	1970-2001	0.151	0.511	0.103	0.103	0.11	0.231	0.128	0.13	0.127	
$\ln(U_t)$	1968-2001	0.742	0.517	0.409	0.346	0.306	0.279	0.26	0.248	0.24	

Note: 5% critical value for the null is 0.146.

TABLE III

Empirical results for the long-term productivity, $\ln(GDP_t/L_t)$, model

Variable	Estimated elasticities	<i>t</i> -statistics*	Prob.	Expected signs
Intercept				
OLS	2.904	9.9	[0.000]	
2SLS	2.900	10.1	[0.000]	
$\ln(K_{1t}/L_t)$				
OLS	0.252	3.5	[0.002]	+
2SLS	0.252	3.6	[0.002]	
$\ln(K_{2t}/L_t)$				
OLS	0.077	2.9	[0.009]	+
2SLS	0.077	2.9	[0.009]	
$\ln(S_t/L_t)$				
OLS	0.037	2.1	[0.049]	+
2SLS	0.038	2.2	[0.039]	
$\ln(T_t/L_t)$				
OLS	0.110	3.9	[0.001]	+
2SLS	0.109	4.5	[0.000]	
$\ln(W_t/P_t)$				
OLS	0.173	5.7	[0.000]	+
2SLS	0.171	6.8	[0.000]	
$\ln(R_t)$				
OLS	-0.047	-2.9	[0.009]	-
2SLS	-0.046	-2.9	[0.008]	
$\ln(U_t)$				
OLS	-0.072	-2.0	[0.050]	-
2SLS	-0.072	-2.1	[0.043]	
$D*\ln(U_t)$				
OLS	-0.006	-4.6	[0.000]	-
2SLS	-0.006	-4.5	[0.000]	

Order of integration of stochastic residuals: I(0)

Goodness-of-fit statistics:

Adjusted $R^2=0.9982$ Overall F statistic $F(8,23) = 2187$

Diagnostic tests:

DW	2.18	
AR 1-2	$F(2, 21) = 0.27$	[0.77]
ARCH 1	$F(1, 21) = 0.15$	[0.47]
Normality	$\chi^2(2) = 1.50$	[0.47]
White χ^2	$F(16, 6) = 0.24$	[0.99]
RESET	$F(1, 22) = 1.39$	[0.25]

Notes: a) * indicates that the standard errors of coefficients have been corrected by the Newey-West HAC method before calculating t -ratios; b) figures in square brackets show the corresponding probabilities; c) the diagnostic tests are calculated using the OLS results.

TABLE IV

Empirical results for the short-term productivity growth, $\Delta \ln(\text{GDP}_t/L_t)$, model

Variable	Estimated elasticities	<i>t</i> -statistics*	Prob.	Expected signs
Intercept	-0.003	-1.4	[0.167]	
$\Delta \ln(K_1/L_t)$	0.280	6.6	[0.000]	+
$\Delta \ln(K_2/L_t)$	0.125	3.5	[0.002]	+
$\Delta \ln(T/L_t)$	0.176	4.2	[0.000]	+
$\Delta \ln(W/P_t)$	0.222	6.0	[0.000]	+
$\Delta \ln(R_{t-1})$	-0.053	-2.8	[0.012]	-
ECM _{t-1}	-0.887	-7.8	[0.000]	-

Order of integration of stochastic residuals: I(0)

Goodness-of-fit statistics:
Adjusted $R^2=0.8097$
Overall F statistic $F(6,22) = 21$

Diagnostic tests:

DW	2.5	
AR 1-2	$F(2, 20) = 1.8$	[0.19]
ARCH 1	$F(1, 20) = 0.01$	[0.92]
Normality	$\chi^2(2) = 2.41$	[0.30]
White Xi^2	$F(12, 9) = 0.4$	[0.93]
RESET	$F(1, 21) = 0.04$	[0.84]

Notes: a) * indicates that the standard errors of coefficients have been corrected by the Newey-West HAC method before calculating *t*-ratios; b) figures in square brackets show the corresponding probabilities; and c) the estimated method is OLS.

TABLE V
Empirical results for the nominal wage rate, $\ln(W_t)$, model

Variable	Estimated elasticities	<i>t</i> -statistics	Prob.	Expected signs
Intercept	-11.1	-15.9	[0.000]	
$\ln(\hat{GDP}_t/L_t)$	2.41	11.6	[0.000]	+
$\ln(U_t)$	0.48	9.7	[0.000]	+
$\ln(P_t)$	0.63	15.3	[0.000]	+

Order of integration of stochastic residuals: I(0)

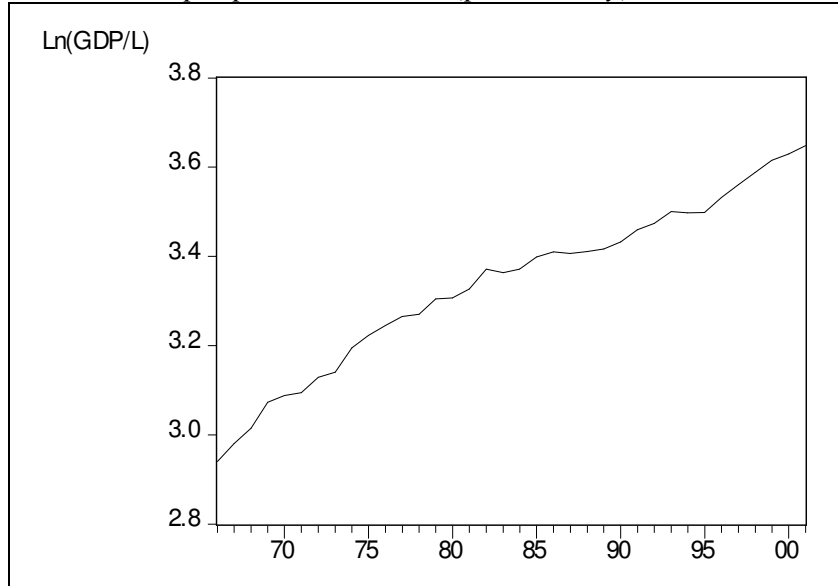
Goodness-of-fit statistics:
Adjusted $R^2=0.9988$
Overall F statistic $F(3,28) = 8425$

Diagnostic tests:

DW	1.70	
AR 1-2	$F(2, 26) = 0.29$	[0.74]
ARCH 1	$F(1, 26) = 0.40$	[0.53]
Normality	$\chi^2(2) = 1.64$	[0.43]
White χ^2	$F(6, 21) = 0.87$	[0.53]
White $\chi^2 * X_j$	$F(9, 18) = 0.76$	[0.65]
RESET	$F(1, 27) = 0.23$	[0.23]

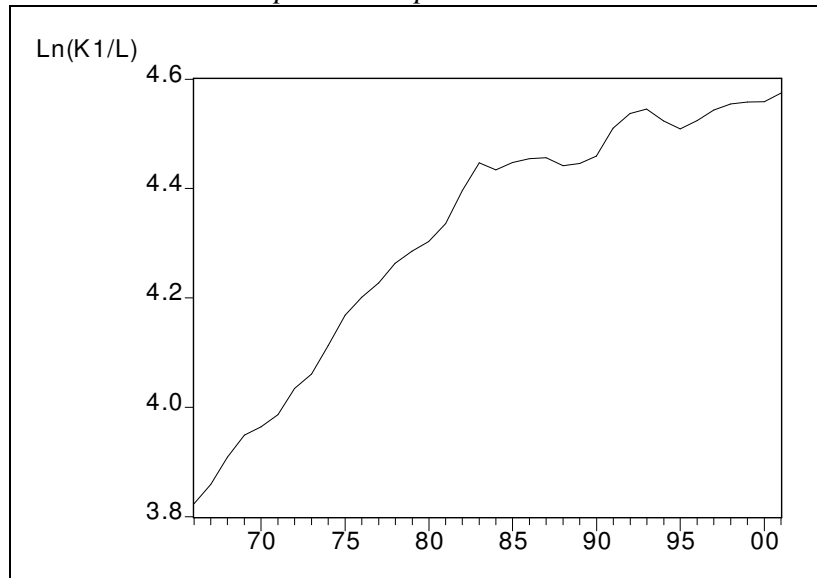
Notes: a) figures in square brackets show the corresponding probabilities; and b) the estimation method is 2SLS.

FIGURE 1
Real output per hour worked (productivity) 1966-2001



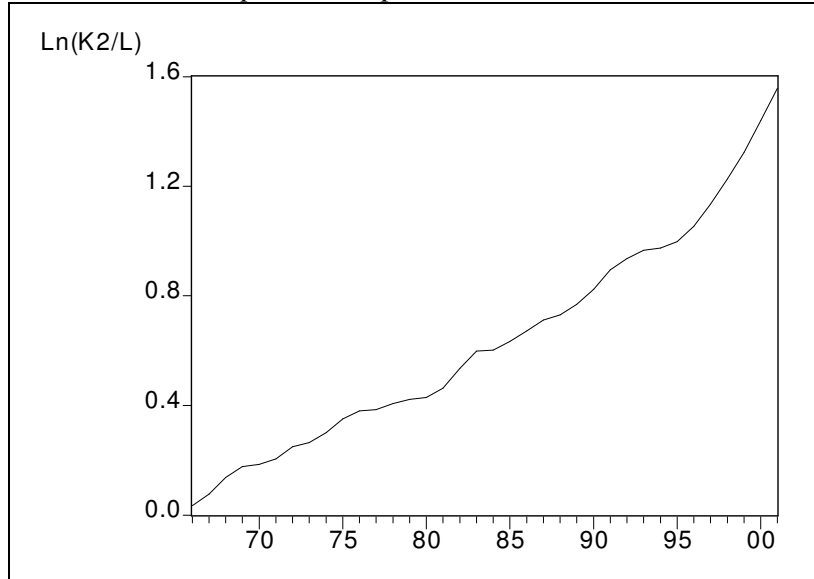
Sources: 1) GDP (\$m in 1999 prices): *Australian National Accounts*, ABS, cat. no. 5206.0; 2) L, or total hours worked (in million)=Average hours worked per week (AHW) times 52; 3) AHW: the 1966-1984 period, RBS-http://www.rba.gov.au/Statistics/op8_excel_files/4-12.xls; the 1985-2001 period, ABS, *Labour Force (HQ) Hours Worked and Average Hours Worked*, ABS, cat. no. 6291.0.40.001.

FIGURE 2
Real non-ITT capital stock per hour worked 1966-2001



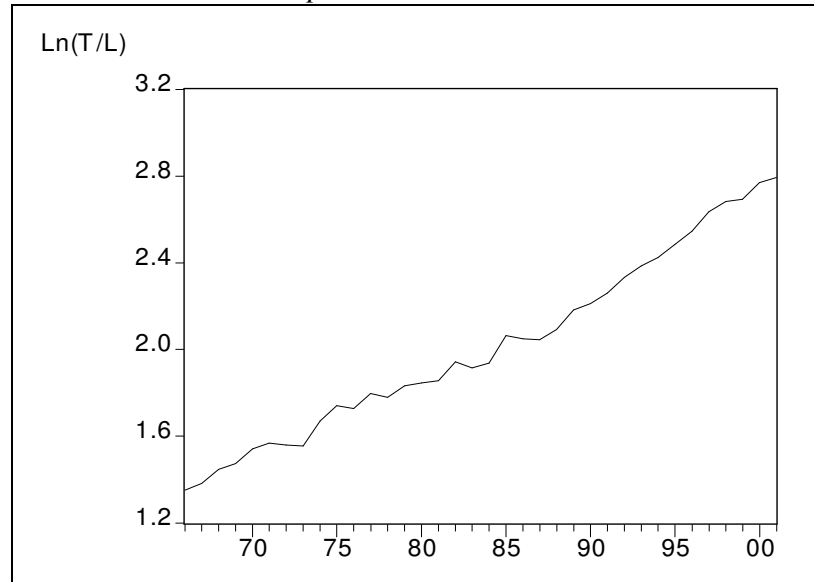
Sources: 1) K or total net capital stock (\$m in 1999 constant prices): ABS, *Australian System of National Accounts*, cat. no. 5204.0; 2) K_2 or net ITT capital stock (\$million in 1999 constant prices), an unpublished database compiled by ABS; 3) K_1 or total net non-ITT capital stock (\$million in 1999 constant prices) is then calculated as $K - K_2$.

FIGURE 3
Real ITT capital stock per hour worked 1966-2001



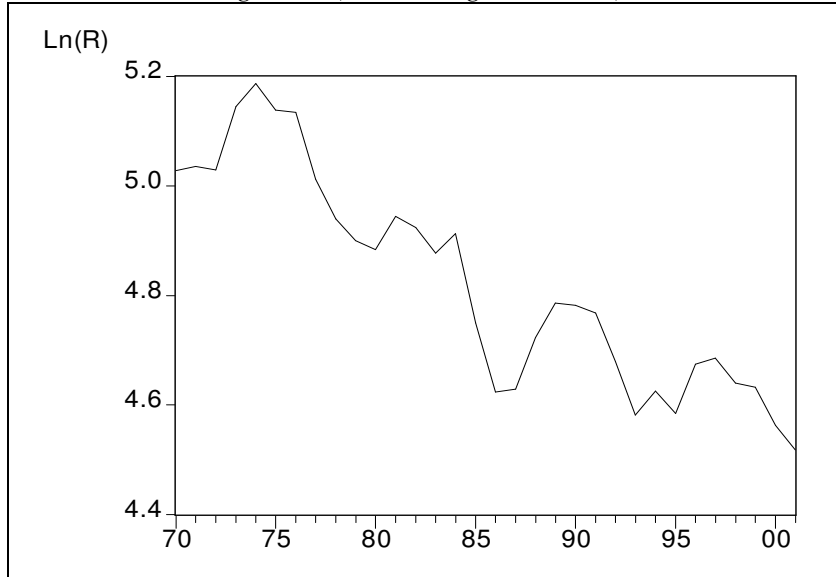
Source: K_2 , or real net ITT capital (\$m in 1999 constant prices) stock (information technology assets), an unpublished database compiled by the ABS.

FIGURE 4
Real trade per hour worked 1966-2001



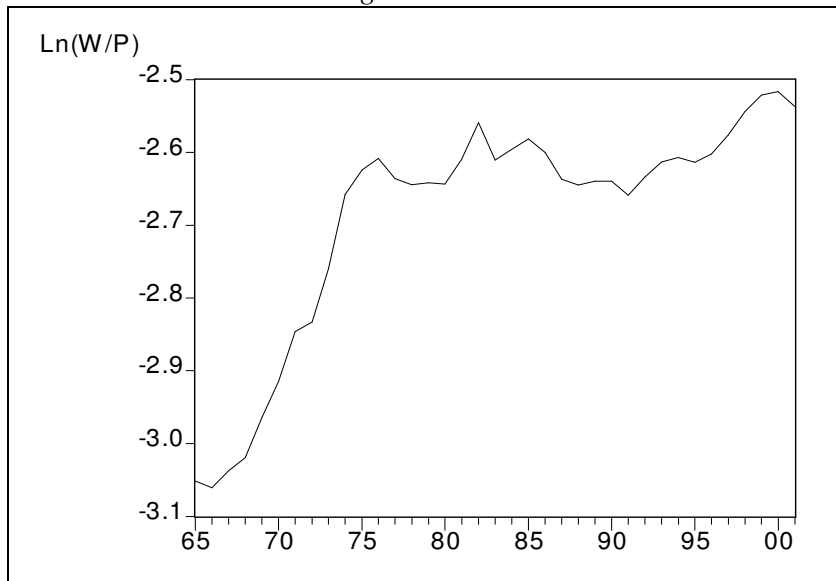
Source: T, or exports plus imports (\$m in 1999 constant prices), *Australian National Accounts*, ABS, cat. no. 5206.0.

FIGURE 5
Real exchange rate (trade weighted index) 1970-2001



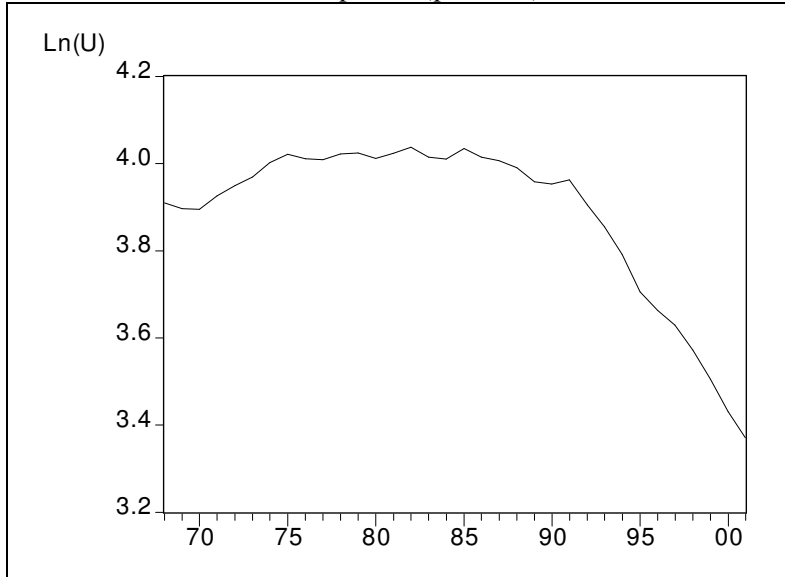
Source: Real exchange rate trade weighted index (1995=100), Reserve Bank of Australia, http://www.rba.gov.au/Statistics/real_exchange_rate_indices.xls

FIGURE 6
Real wage rate 1965-2001



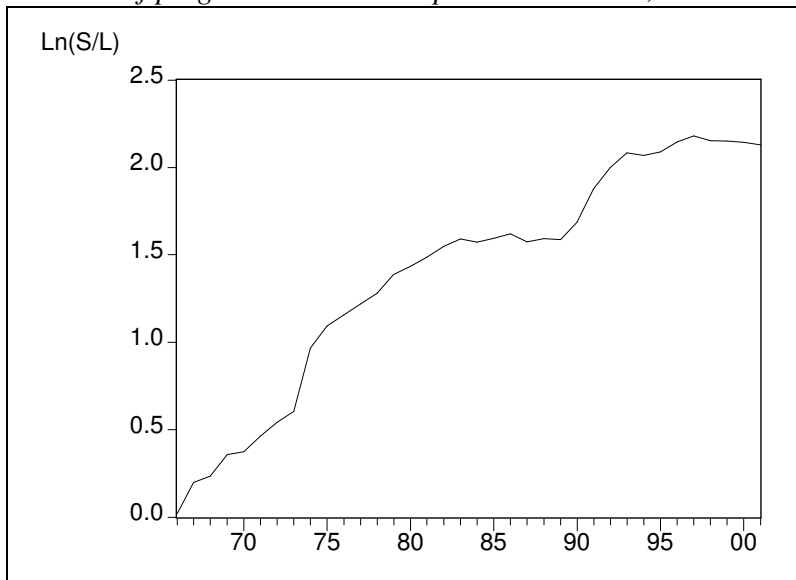
Sources: 1) W, or the nominal wage rate (\$), ABS, *Modellers Database*, cat. no. 1364.0.15.003; 2) P, or consumer price index (1990=100), ABS, *Consumer Price Index*, cat. no. 6401.0.

FIGURE 7
Union membership rate (percent) 1968-2001



Source: U, or the union membership rate (per cent), ABS, *Modellers' Database*, cat. no. 1364.0.15.003.

FIGURE 8
Number of postgraduate students per hour worked, 1966-2001



Source: S, or total number of postgraduate students (persons), Department of Education, Training and Youth Affairs (2001).

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