Table I.2.1. Source of Labor Productivity Growth, by Industry

	1987-2000	1990-1995	1995-2000
Agriculture			
Labor productivity growth	3.1%	2.8%	3.5%
TFP	2.6%	2.1%	3.7%
Capital deepening	0.5%	0.7%	-0.2%
Hardware	0.1%	0.1%	0.1%
Software	0.0%	0.0%	0.1%
Mining			
Labor productivity growth	5.6%	5.7%	5.2%
TFP	1.4%	1.8%	0.3%
Capital deepening	4.2%	3.9%	5.0%
Hardware	0.1%	0.1%	0.1%
Software	0.1%	0.1%	0.1%
Manifacturing			
Labor productivity growth	2.8%	3.2%	2.3%
TFP	1.1%	1.3%	0.6%
Capital deepening	1.7%	1.8%	1.8%
Hardware	0.4%	0.4%	0.5%
Software	0.3%	0.3%	0.3%
Electricity, gas and water			
Labor productivity growth	7.5%	7.8%	6.3%
TFP	2.9%	3.5%	1.0%
Capital deepening	4.6%	4.3%	5.3%
Hardware	0.8%	0.4%	1.6%
Software	0.1%	0.1%	0.1%
Construction			
Labor productivity growth	0.4%	0.7%	1.3%
TFP	-0.6%	-0.9%	1.4%
Capital deepening	1.1%	1.6%	-0.1%
Hardware	0.7%	0.7%	0.8%
Software	0.5%	0.5%	0.4%
Wholesale trade			
Labor productivity growth	2.7%	1.9%	5.4%
TFP	1.9%	1.1%	4.2%
Capital deepening	0.8%	0.7%	1.2%
Hardware	0.3%	0.2%	0.3%
Software	0.4%	0.4%	0.3%

Table I.2.1. Source of Labor Productivity Growth, by Industry (Concluded)

	1987-2000	1990-1995	1995-2000
Retail trade			
Labor productivity growth	1.0%	1.1%	2.3%
TFP	-0.6%	-0.4%	0.5%
Capital deepening	1.5%	1.5%	1.8%
Hardware	0.7%	0.6%	0.8%
Software	0.4%	0.5%	0.3%
Accom., cafes and restaurant			
Labor productivity growth	-1.0%	-1.4%	1.4%
TFP	-1.8%	-2.3%	0.8%
Capital deepening	0.8%	0.9%	0.6%
Hardware	0.4%	0.3%	0.5%
Software	0.3%	0.3%	0.2%
Transport and storage			
Labor productivity growth	2.1%	2.2%	2.5%
TFP	1.1%	1.1%	1.9%
Capital deepening	1.0%	1.1%	0.6%
Hardware	0.4%	0.5%	0.4%
Software	0.3%	0.4%	0.3%
Communication services			
Labor productivity growth	7.6%	7.9%	6.4%
TFP	4.3%	4.9%	3.2%
Capital deepening	3.3%	3.0%	3.2%
Hardware	0.7%	0.5%	1.1%
Software	0.7%	0.7%	0.4%
Finance and insurance			
Labor productivity growth	5.2%	4.4%	6.4%
TFP	2.0%	1.3%	2.9%
Capital deepening	3.2%	3.2%	3.5%
Hardware	1.2%	1.0%	1.3%
Software	1.4%	1.2%	1.8%
Cultural and rec.services			
Labor productivity growth	-0.8%	-0.6%	-0.9%
TFP	-3.3%	-2.8%	-4.3%
Capital deepening	2.5%	2.2%	3.5%
Hardware	0.6%	0.5%	0.9%
Software	0.4%	0.4%	0.3%

II. Technology Transfer and R&D: A Cross-Country Regression[1]

A. Introduction

1. A considerable part of the debate on the "new economy" has been centered on the issue of the benefit of being a producer versus a user of frontier technology.[2] A view that has attracted a good deal of attention especially among market analysts is that Australia is an "old economy" and is unlikely to benefit from the productivity gains associated with the "new economy" because of its small ICT production base. Their view has been challenged by those who call attention to the widespread diffusion of ICT throughout the Australian economy. In their view, new technologies (either embodied in capital goods or disembodied, such as those associated with international R&D and patenting) can be imported from abroad, and the existence of a domestic production is not a necessary condition to claim "new economy" credentials. Indeed, Chapter I confirms that Australia has greatly benefited from adopting new technologies, and that it is well placed to take further advantage from ICT capital accumulation in the future.

2. This paper addresses the following question: Even assuming that new technologies (either embodied in capital goods, such as computers, or disembodied, such as those associated with patenting) can be imported from the technological "leaders," does the existence of a domestic base of innovation help in facilitating the transfer of technology and making it more efficient?[3] This question has clear policy implications as Australia considers its approach to supporting innovation following the Innovation Summit in 2000.

3. This paper's findings support the view that R&D plays an important role in the "catch–up" process. Specifically, using a panel of 14 OECD countries during 1981–1997, this paper concludes that an increase in the rate of growth of R&D expenditure raises the rate at which new technologies may be transferred to an economy which is still catching up to the technological frontier. The main policy implication for Australia is that strenghtening

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[1] Prepared by Roberto Cardarelli (x38059), who is available to answer questions.

[2] With reference to the US, these two different positions can be identified with the studies of Gordon (2000), who attributes the recent acceleration of labor productivity growth only to the ICT producing sector, and those of Oliner and Sichel (2000) and Nordhaus (2001), who find evidence of a post-1995 acceleration of total factor productivity growth outside the ICT producing sector.

[3] A large number of studies within the OECD have addressed the interaction between R&D and productivity growth (see OECD, 2000, for a comprehensive review). In particular, one recent contribution by Verspagen (2001) shows that R&D seems to have a crucial part in the catching–up process and that recent trends suggest that the absorption of foreign technology increasingly requires more active efforts, with technological differences between countries translating more easily into growth rate differentials.

domestic innovation capacity and setting sound incentives for R&D is likely to pay off in the future and can contribute to sustaining the current pace of economic growth.[4]

4. The rest of the paper is organized as follows. The next section presents the theoretical framework and the data used in the estimation (Annex 1 contains the detailed description of the sources of data and of the methodology followed in estimating levels and rates of growth of total factor productivity). Section C presents the results of the panel data estimation, and section D concludes.

B. Methodology and Data

5. The key hypothesis of interest in this paper is whether an increase in R&D raises the rate at which new technologies may be transferred to an economy which is behind the technological frontier. This hypothesis is tested by estimating an equation which is the reduced–form of a "β–convergence" productivity model (Bernard and Jones, 1996), according to which total factor productivity (TFP) in country j is a function of country–specific innovation (γ_j) and of the technology transfer from the frontier country F (the U.S.), which is a function of the productivity gap between the two countries:[5]

[1] $$\ln\left(\frac{TFP_t^j}{TFP_{t-1}^j}\right)=\gamma_j(\xi_j)+\lambda_j(\xi_j)\ln\left(\frac{TFP_{t-1}^j}{TFP_{t-1}^F}\right)$$

6. The two terms γ_j and λ_j are assumed to be log–linear function of economic variables (ξ_j) that are generally thought to affect the economy's ability to assimilate existing technologies or generate innovations. In addition to R&D activity, the econometric estimation considers education, openness to trade, and an indicator of labor market flexibility. The last two variables may be interpreted as proxies for the structural reforms that

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4 According to the *2001 Economic Report of the President,* the US Federal Government increased funding for basic research at a 2 percent annual real rate in the last 6 years and supplies over half of all basic research funds in the country. Besides providing direct funding, government policies in the US have created a favorable climate for private R&D through the tax code (one of the most favorable among OECD countries) and though encouraging the formation of strategic technology alliances among private sector firms. Partly as a consequence of these policies, private sector real spending on basic R&D in the US has grown at an astounding average annual rate of 17 percent since 1991.

5 The steady state implication of this model is that countries with the lowest initial relative productivity level should also experience the highest rate of growth of relative TFP. Further, in steady–state, the productivity gap is absorbed and TFP levels differ only because of different country–specific rates of innovation, as: $\ln\left(\frac{TFP^j}{TFP^F}\right)=\frac{\gamma_j-\gamma_F}{\lambda_j}$

have been undertaken in many industrialized countries, including Australia which contributed, inter alia, to improving the ability and incentives to import and make use of new technologies. The main objective of the estimation is to show whether, once the contribution of these other economic variables is taken into account, R&D affects the rate at which the productivity gap with the "leader" economy is absorbed (through the technology transfer) λ_j[6] and/or the domestic rate of innovation γ_j. To take into account the possibility that it is the rate of change of R&D activity (rather than its level), that matters for TFP growth, equation [1] is estimated using both log levels and first differences of the R&D variables.

7. The analysis is based on a three measures for R&D activity: total gross expenditure on R&D (GERD), total R&D personnel as a share of total employment; and the number of resident patent applications. As far as the other variables are concerned, the choice of indicators is limited by the availability of sufficiently long time series data. The gross enrollment ratios in tertiary education has been used as a proxy for human capital.[7] The openness of the economy is proxied by the ratio of the sum of exports and imports to GDP. The degree of flexibility in the labor market is proxied by the number of working days lost in disputes. Also, a cyclical variable (the rate of change in the consumption of electricity) is introduced in order to control for the impact of changes in capacity utilization on the rate of growth of TFP[8].

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[6] In Cameron, Prouding and Redding (1997), another channel is the quantity of the technological know–how that can be transferred from the leading economy, as the productivity gap on the right hand side of [1] is multiplied by a parameter ω_j not necessarily equal to 1 ($\omega_j \in (0,1]$). Both the theoretical and empirical results are not sensitive to this generalization, and in what follows this effect is not identified separately (being observationally equivalent to the effect of domestic innovation, γ_j).

[7] Tertiary education corresponds to the ISCED levels 5, 6 and 7 and is provided at universities, teachers' colleges, higher professional schools, which requires, as a minimum condition of admission, the successful completion of secondary education or evidence of the attainment of an equivalent level of knowledge. Clearly, some caution is required when using this indicator for inter–country comparison, since the countries do not always classify degrees and qualifications at the same ISCED levels, even if they are received at roughly the same age or after a similar number of years of schooling. Further, this indicator only measures levels of educational attainment i.e., the quantity of schooling, and does not necessarily capture the quality of the education.

[8] It is worth stressing that the objective of this paper is not to "explain" productivity growth. Such an ambitious objective would require conducting the analysis at an industry or firm level. The omission of variables that are generally supposed to play a role in the productivity growth story can be justified in view of this observation. For example, foreign direct investment is certainly an important channel of technology transfers across countries, and is likely to affect productivity growth and catching–up. The omission of this variable, however,

(continued)

8. The estimation uses panel data for 14 OECD countries[9] between 1980–1997. However, the labor market variable is not available for 4 countries (Denmark, Japan, Netherlands and Norway), while for Germany only pre–unification data are available. Since tertiary education data covers only the post–unification period for Germany, in the regression which uses labor market and education variables Germany too drops out, and the total number of countries considered falls to 9.

9. TFP levels are calculated as the Solow residuals, that is, residuals from a neoclassical growth accounting equation (derived from a constant return to scale production function and based on the hypothesis of perfect competition). However, for this exercise, neither capital nor labor is adjusted for changes in quality, due to data limitations.[10] In particular, the stock of capital does not reflect the "capital services" methodology presented in Chapter I, and labor productivity is estimated as output per employee. Total factor productivity, therefore, incorporates embodied technological progress and the improvement in labor quality. However, while the latter effect should be captured by the human capital variable, the lack of quality–adjusted capital should not be a cause of concern, as the main objective of the estimation is to check whether R&D affects the transfer of new technologies from the frontier country, including those embodied in capital assets.

Table II.1. TFP Growth Rates and TFP Levels Relative to the United States

	TFP growth			Relative TFP		
	1981-90	1990-97	1995-97	1981-90	1990-97	1995-97
Australia	0.50	1.28	1.43	78.13	78.00	78.87
Canada	0.13	0.42	0.52	85.95	79.81	78.01
Denmark	0.50	1.63	1.21	60.39	56.74	57.20
Finland	2.19	2.71	3.65	58.62	62.66	64.35
France	1.85	0.75	0.76	75.91	76.32	74.93
Germany	1.17	-0.68	0.79	77.25	68.87	66.66
Ireland	3.73	3.82	5.68	56.46	67.55	69.01
Italy	1.10	0.80	0.95	68.88	68.54	67.53
Japan	1.90	0.63	1.32	69.35	69.47	67.91
Netherlands	1.30	1.04	0.65	76.81	77.82	76.68
New Zealand	0.98	0.57	0.24	59.43	57.98	57.99
Norway	0.11	1.96	1.07	54.74	52.60	52.69
Spain	1.76	0.72	0.39	68.00	68.57	66.89
United Kingdom	2.35	1.90	1.16	61.74	66.29	67.52
United States	1.12	0.97	1.10	100.00	100.00	100.00

Source: See Annex II.1.

10. Table II.1 shows that estimated TFP levels lie below that of U.S. for each country in the sample, for the whole period considered. It shows that Australia pulled ahead of other countries, and now has TFP levels second only to that of the U.S. At the same time,

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is not a serious drawback in the present context, where the objective is to use cross–country panel data regressions to shed some light on the relative importance of R&D on the speed of these transfers. At the econometric level, allowing the intercept to vary across country should absorb country-specific (exogenous) effects that are not captured by regressors.

[9] These are: Australia, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Spain, UK

[10] The data sources and the methodology followed to derive relative TFP levels are reported in Annex 1.

Table II.2 shows that Australia lags behind most of the other countries in the sample in terms of R&D expenditure and, to a lesser extent, in terms of the share of R&D personnel over total employment (although it is ahead of the U.S. for the latter variable).[11] As for the other economic variables, over the period 1990–1997 Australia had one of the highest gross tertiary enrolment ratios in the sample (second only to Canada and U.S.), while the impact of the labor market and trade reforms over the 1990s is evidenced by the decline in the number of days lost for industrial disputes and by the rapid increase in the degree of openness of the economy compared to the previous decade.

Table II.2. R&D Indicators and Other Variables Affecting TFP

	GERD		RES		PAT		EDU		OPEN		LAB	
	1981-90	1990-97	1981-90	1990-97	1981-90	1990-97	1981-90	1990-97	1981-90	1990-97	1981-90	1990-97
Australia	1.2	1.5	1.0	1.2	1.7	1.5	28.8	57.6	26.5	29.4	-0.10	-0.12
Canada	1.4	1.6	1.0	1.1	0.3	0.2	72.4	91.0	44.9	52.4	-0.12	-0.05
Denmark	1.3	1.7	0.9	1.2	0.5	0.5	30.5	42.6	53.6	51.2	-	-
Finland	1.6	2.2	1.1	1.8	2.7	2.4	37.0	61.6	47.2	47.8	-0.04	-0.01
France	2.2	2.3	1.4	1.5	0.7	0.4	31.1	47.0	37.7	36.6	-0.11	-0.05
Germany	2.6	2.4	1.7	1.5	8.0	6.8	31.6	40.7	50.3	42.9	-0.26	-
Ireland	0.8	1.2	0.7	0.9	0.2	0.2	23.4	35.9	98.2	110.8	-	-0.27
Italy	1.1	1.1	0.8	0.9	-	0.7	26.7	38.8	35.7	34.5	-0.12	-0.16
Japan	2.7	2.9	1.8	1.8	62.7	63.4	29.0	34.0	19.9	15.9	-	-
Netherlands	2.0	2.0	1.4	1.6	0.6	0.4	32.5	45.3	98.5	91.0	-	-
New Zealand	1.0	1.0	0.7	0.8	0.3	0.2	34.4	54.4	45.7	45.6	-0.09	-0.42
Norway	1.4	1.7	1.0	1.2	0.2	0.2	32.0	52.2	52.0	51.2	-	-
Spain	0.6	0.8	0.6	0.8	0.5	5.1	29.0	43.3	29.7	33.0	-0.02	-0.08
United Kingdom	2.2	2.0	1.3	1.2	5.1	3.6	23.1	41.7	42.3	42.0	-0.17	-0.24
US	2.6	2.6	0.8	0.9	16.6	18.9	63.8	80.0	14.4	16.9	-0.13	-0.03

Source: See Annex II.1.

GERD: Nominal total R&D expenditure (as a percentage of GDP).
RES: Numbers of total R&D personnel (as a percentage of total employment).
PAT: Number of resident patent application (share of total).
EDU: Gross tertiary enrollment ratio.
OPEN: Ratio of Imports plus Exports over GDP.
LAB: Working days lost for industrial disputes, average annual rate of change.

C. Econometric Results

11. Turning to the econometric of equation [1], given the relatively small number of time series observations, a country–by–country set of regressions would leave very few degrees of freedom and compromise the efficiency of the estimates. Pooling observations across countries increases the numbers of degree of freedom and permits the exploitation of the

[11] In particular, the behavior of business R&D expenditure in Australia has been a cause of concern (see Maddock, 2000). After it reached a peak in 1995 (0.85 percent of GDP), business R&D fell by almost 15 percent in the following 4 years (to 0.65 percent in 1999). This was largely a consequence of the cut in the tax concession for business R&D from 150 percent to125 percent, and of the narrowing of the range of expenditure subject to such concessional treatment. Partly to correct this trend, in January 2001 a series of measures were announced to boost Australia's ICT innovation ability, involving a tax concession of 175 percent for additional R&D expenditure.

cross–country variation in the independent variables. The regressor coefficients are imposed to be the same across countries but the constant is allowed to vary and represents country–specific determinants of TFP growth that are not explicitly included in the equation. Within this fixed–effect pooled approach, a generalized least squares approach is followed, in order to deal with the likely existence of cross–section heteroskedasticity (possibly reflecting parameter heterogeneity). Further, to mitigate a possible endogeneity problem, all regressors are lagged one period.[12]

12. As the key objective of the exercise is to identify a possible relationship between R&D and the speed of technological absorption, initially equation [1] is estimated with only the relative TFP gap and the R&D interaction term as explanatory variables. Other variables (human capital, openness, and labor market flexibility) are then included, to check whether the relationship between TFP growth and R&D is robust to the inclusion of other factors that may affect TFP growth or is the spurious outcome of their omission. The final step of this specification strategy is to verify that the previous results are robust to the introduction of the country specific R&D term. If this is not the case, then one could deduce that R&D matters primarily because it affects the domestic rate of innovation, rather than the speed of catching–up.

13. The main result of the estimation is that only when R&D is proxied by the rate of change of R&D spending does there seem to be a relationship between R&D activity and the speed of technological transfer. Table II.3 shows the results of the regressions obtained with the log difference of GERD as a proxy for R&D. In the simplest specification (Specification I) the R&D interaction term has the correct sign (a negative coefficient implies a positive impact on productivity growth for all variables except the labor market proxy), but is insignificant at a 10 percent level. The relative productivity gap is both correctly signed and significant at a 10 percent critical level. After the introduction of the other variables (Specification II), the R&D interaction term is still correctly signed and becomes significant.[13] Further, all the other variables have the expected sign, even if they are all not

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[12] As an example of the endogeneity problem, the same R&D activity can be affected by a larger accumulation of human capital and/or by the more flexible labor market or the larger openness of the economy. No single econometric technique is likely to offer complete insulation against possible endogeneity problems. Moreover, the nature of the sample, and in particular the relatively small number of observations, prevents the adoption of the conventional remedy for this problem, namely, the use of instrumental variables estimation (with the lagged values of the independent variables as instruments).

[13] As mentioned above, introducing the other variables results in restricting the number of countries from 14 to 9. This suggest that the results are sensitive the choice of countries in the sample. While some form of (pre–regression) analysis of the data would be required to evaluate the contribution of the different subset of countries to the regression results, and thus to identify the existence of different regimes, such an exercise is prevented here from the

(continued)

significant at the 10 percent level (except the trade variable). Finally, the introduction of the log differences of GERD as a separate term does not change the sign and significance of both the R&D interaction term and the relative productivity gap (Specification III). However, the log difference of GERD is correctly signed but insignificant, suggesting that R&D primarily affects the transfer of technology from abroad rather than the country–specific rate of innovation. Specification IV shows the final specification, obtained by eliminating the log–level of the labor variable, which was incorrectly signed and insignificant. All the other variables have the correct sign and are significant at a 5 or 10 percent critical level.[14]

14. While estimating [1] with the R&D expenditure variable gives some encouraging results, the same is not true when using the two other proxies for R&D, the R&D personnel (as a share of total employment) and the number of resident patent application.[15] In both cases, the R&D interaction term is either incorrectly signed and/or insignificant at the 10 percent threshold, or is accompanied by a wrongly signed productivity gap term, something which is clearly inconsistent with the model being estimated.

15. The lack of a relationship between these R&D variables and TFP growth is not a new result,[16] and can be explained by several factors. The first relates to the relevance of the measures to proxy innovation. Not all patents leads to innovative production or products (indeed, only few of them are valuable), and not all R&D personnel is involved in knowledge–producing activities and not all operate with the same efficiency. It is reasonable to expect that this problem is less severe when using an expenditure (dollar–denominated) measure of R&D.

16. Further, it can be argued that R&D spending and the number of patent applications do not capture the same aspects of technology accumulation. As they are the output of innovation activity, patents should be considered more as an indicator of the country ability

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relatively scarce number of observations available. Only one major outlier is eliminated from the initial database, the TFP rate of growth for Germany in 1991 (the unification year).

[14] In addition to the R^2 and the Durbin–Watson, the normality of the residuals is not rejected when tested through a Bera–Jarque test, while the F–test reject the hypothesis that all parameters are jointly zero. Further, for equation III and IV all fixed effects (the constant allowed to vary across countries) are significant at a 5 percent level.

[15] For sake of brevity these results are not shown in this chapter.

[16] Hall (2000) shows that, in work relating the market value of individual firms to innovation indicators, patents typically have less explanatory power than R&D expenditure measures. Using a panel of UK firms, Stoneman and Kwon (2000) estimate an equation where investments undertaken to change technologies depend on a number of variables that affect the speed of diffusion, and they also find that their model works better with R&D expenditure than with patents.

to develop new knowledge. On the other hand, a relatively large part of R&D spending is usually related to assimilating foreign technology and, therefore, could be expected to work better as a determinant of the speed of productivity catching–up (Verspagen, 2001).

17. The estimates reported in Table II.3 are consistent with other research that shows a relationship between the rate of change in R&D and the acceleration in TFP (see Bassanini et al, 2000). Using the coefficients reported in this table, it is possible to estimate that, for a country with a relative TFP level of 79 percent, like Australia in 1997, a 1 percent increase in total expenditure on R&D increases the rate of growth of TFP by between 0.1 and 0.4 percentage points in the first year (and by diminishing amounts thereafter).[17]

D. Conclusions

18. The objective of this paper was to address the question of the importance and relevance of R&D spending in raising productivity growth, and in earning "new economy" credentials. A large literature on the subject emphasizes the importance of international technological spillovers in determining productivity convergence, and the benefits associated with following the country on the technological frontier. At the same time, however, several studies stress that the absorption of foreign technology can greatly benefit from the development of domestic innovation and R&D abilities.

19. Using data on a panel of OECD countries for the period 1981–1997, this paper estimates a reduced–form productivity convergence model and finds that an increase in R&D expenditure positively affects the rate of technology transfer, and thus the speed of absorption of ICT from abroad. The main policy implication for Australia is that additional effort in developing domestic innovation capacity through setting the right incentives for R&D is likely to pay off richly in the future and can contribute to sustaining the current pace of productivity growth.

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[17] This estimate is based on the lower and upper bounds of the parameter estimates for the R&D interaction term in the different specifications of Table II.3.

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