The Impact of R&D on the Singapore Economy: An Empirical Evaluation

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Abstract

Much of the literature on the impact of R&D on economic performance is founded on the advanced countries, where the intensity of R&D expenditure has been relatively high and stable for many years. In this paper, we provide empirical estimates of the impact of R&D on the economic growth of a Newly Industrialised Economy, Singapore, where R&D expenditure intensity has been low initially, bur rising rapidly in recent years. The Cobb-Douglas based analysis provided empirical evidence that R&D investment in Singapore had a significant impact on its total factor productivity performance in the last 20 years and established a long-term equilibrium relationship between R&D investments and TFP. However, compared to the OECD nations, the impact of R&D investment on economic growth in Singapore is not as strong, as evidenced by lower estimated elasticity values. The long run elasticity of output with respect to R&D was computed to be 8.1% for Singapore compared to long run elasticities of over 10% estimated by other researchers for OECD countries. This suggests that Singapore still has some way to go in catching up with the advanced nations in terms of R&D productivity. This not only means increasing the level of R&D intensity in Singapore but also more efficient exploitation of domestic R&D activity.

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1. Introduction

While there is by now a significant body of empirical literature on the link between R&D expenditure and productivity growth, much of this literature is founded on the advanced countries, where the intensity of R&D expenditure has been relatively high and stable for many years. Research and development contributes to economic growth by expanding the resource base and enabling more efficient use of existing resources (Fagerberg, 1994; Grossman and Helpman, 1991; Jones, 1995 and Stokey, 1995). In this paper, we provide empirical estimates of the impact of R&D on the economic growth of a Newly Industrialised Economy, Singapore, where R&D expenditure intensity has been low initially, bur rising rapidly in recent years.

2. R&D and Productivity Growth

2.1 Approaches to Measuring Impact of R&D on Productivity Growth

Much of the empirical work in this area has been done at the firm or industry level. An early survey of the literature by Mansfield (1972) concluded that R&D expenditures contributed substantially to output growth in a variety of industries in the USA and Japan. More recently, Nadiri (1993) and Link and Siegel (2003) provided summaries of studies that investigated the effect of R&D investment on productivity, primarily at the firm and industry levels in advanced countries such as USA, Japan, France and Germany. The studies in this tradition typically use a Solow-like (1957) model, with a simple Cobb-Douglas production function to link output to R&D

investment. Output is treated as a function of conventional labor and capital inputs plus the stock of R&D. Based on assumptions of constant returns to scale with respect to the conventional inputs and equilibrium in product and input markets, productivity growth in the form of Total Factor Productivity (TFP) growth is defined and estimated. Domar (1961, p.712) characterised TFP measured in this way as a residual, accounting for “increases in output not accounted for by explicitly recognized inputs.” This residually measured TFP growth, termed the “Solow residual”, is then tested for any significant relationship with R&D expenditure, following the growth accounting approach pioneered by Denison (1962) and later summarized by Kendrick and Grossman (1980).

Another approach is adopted in the interrelated factor demands model, with R&D capital stock being treated as a factor of production and affecting demand for other factors of production. Studies such as Bernstein and Nadiri (1989) concluded that changes in R&D affect demand for labor, energy and physical inputs, with the pattern of substitutions and complementarities differing by industry. R&D investment increases demand for capital but decreases demand for labor and materials.

More recently, researchers have begun to examine growth that is endogenously determined by technical change resulting from R&D decisions of profit-maximizing agents. Verspagen (1992) and Ruttan (1997) provide surveys of such innovation and R&D based endogenous growth models. The latest class of models developed in this tradition has arisen from the works of Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992). In the spirit of Solow (1956), technical change is a major contributor to productivity growth in this line of research. However, in the

Solow-type models, long-run growth depends on the growth rate of inventions, which is exogenously determined. In contrast, in the Romer/ Grossman-Helpman/ Aghion-Howitt models, productivity growth results from intentional innovation by rational, profit-maximizing agents and is therefore endogenously determined.

2.2 Empirical Studies on Impact of R&D on National Level Productivity Growth

This paper returns to the basic Cobb-Douglas based analysis summarized by Nadiri (1993). Using national level data, this paper attempts to empirically establish the impact of R&D investment on total factor productivity in Singapore. While many studies have adopted this approach using firm and industry level data, studies at the aggregate national level are relatively uncommon. As shown by Griliches (1991), estimates of R&D effects on productivity are dependent on the level of aggregation of the data used. Due to the existence of R&D spillover effects, macroeconomic effects cannot be directly inferred from firm or industry level estimates. To accurately gauge the macroeconomic effects of R&D investment, macroeconomic level data must be directly used.

Lichtenberg (1992) represents an early effort to examine the macroeconomic effect of R&D using national level data. Using cross-sectional data from 98 countries (although sample size was reduced to a minimum of 38, based on data availability for specific model specifications), Lichtenberg estimated directly a non-linear production function that included the rates of investment in labor, physical capital and research as regressors. The results show that privately-funded R&D investment has positive significant effects on the level and growth rate of productivity. Additionally, it was found that the rate of return to private R&D investment is seven times larger than the return to investment in equipment and structures.

Birdsall and Rhee (1993) used cross-country regressions of data from both OECD and developing countries. They found that R&D activity (expenditure) and economic growth are positively correlated only countries in the OECD while there was no significant relationship in the case of developing countries. Even for OECD countries, the study found no evidence that R&D activity causes growth. These findings suggest that R&D activities contribute to productivity only once a country attains a threshold level of economic prosperity.

Goel and Ram (1994) used data from a cross-section of 52 countries in the late 1970s and early 1980s to assess the effect of research & development (R&D) outlays on economic growth. The variables in the growth model include labor, capital, & R&D expenditure. The estimated impact of R&D outlays on economic growth is positive & large, but its statistical significance is low.

Coe and Helpman (1995) and Engelbrecht (1997) used country-level data to establish a relationship between R&D expenditures and TFP in OECD countries (and Israel, in the case of Coe and Helpman, 1995), paying particular attention to international R&D spillovers from foreign R&D capital. Coe et al. (1997) extended this analysis to developing countries by estimating the elasticities of TFP in 77 developing countries with respect to R&D capital stock in 22 industrialized economies.

Madden et al. (2001) adopts the methodology of Coe et al. (1995) to examine the role of R&D in the technological progress of 16 OECD and 6 Asian countries. However, this paper includes domestic R&D capital stocks as contributors to TFP growth in the Asian countries. The Asian countries in this study included three Newly Industrialized Economies (Singapore, Taiwan and Korea) and three lower-income developing economies (India, Indonesia and Thailand). Using data from 1980 to 1995, the study estimated a positive and significant relationship between TFP and domestic R&D capital. Interestingly, this paper found that the impact of domestic R&D on TFP was around 6 times higher in the Asian countries (elasticity estimated to be 0.3) than in the OECD countries (elasticity estimated to be 0.05) in the sample. The estimates for domestic R&D elasticity were obtained by grouping all 6 Asian countries in one collective bloc. However, country-specific elasticities for foreign R&D were computed. Foreign R&D was found to have insignificant impact on TFP in Singapore.

A more recent study using national aggregate data was conducted by Guellec and van Pottelsberghe de la Potterie (2001). In this study, the authors estimated the effects of R&D investments on productivity growth using panel data of 16 OECD countries over the period 1980 to 1998. They separated the contribution of public sector, private sector and foreign R&D investment in this analysis. The results establish that all three forms of R&D investment are positively and significantly related to productivity.

Fraumeni and Okubo (2004) modified the USA National Income and Product Accounts (NIPA) framework by capitalizing R&D and constructed a R&D satellite account. This new set of data was applied to a Cobb-Douglas formulation of the sources of economic growth, following the tradition of studies by researchers such as

Denison (1985) and Jorgenson et al. (1987). Using USA time-series data from 1960 to 2000, it was found that the contribution of R&D investment to GDP growth averaged between 2% to 7% under alternative scenarios. In all cases, the contribution of R&D to economic growth was found to be significant.

3. R&D Investment and Innovation in Singapore

Much of the available empirical work focused on advanced countries where R&D intensities had been relatively high and stable for a number of years. For example, average growth in business R&D capital stock for the most of 16 OECD countries covered by Guellec and Pottelsberghe de la Potterie (2001) ranged between 4% and 7% for the period 1980-1998. This contrasts with average growth rate of above 15% for R&D capital stock in Singapore in the last 15 years.

Singapore has achieved remarkable economic growth over the last 40 years, with GDP growth averaging over 8% between 1965 and 2002. However, much of the growth in the first 3 decades had been driven directly by Direct Foreign Investment (Wong, 2003). It is only in the last 15 years that Singapore had begun to invest significantly in R&D activity. As can be seen from **Table 1**, Singapore's R&D expenditure was negligible in the early 1980's, accounting for less than 0.5% of GDP, but has since risen rapidly to reach 2.1% of GDP by the year 2001. This is only slightly lower than the GERD to GDP ratios in advanced nations such as USA and Japan and compares favorably with the ratios for South Korea and Taiwan (**Table 2**). Private sector contribution to GERD also rose from less than 60% in the 1980s to around 62% to 64% in the 1990s. The number of research scientists and engineers (RSEs) also rose in tandem with R&D spending, increasing from 8.5 RSEs per 10,000 labor force in 1978 to 87.6 by 2001.

4. Methodology

4.1 Basic Framework for Computing Total Factor Productivity

There are two main methodological approaches used to estimate the contribution of R&D to economic growth. The first approach is to estimate a production function directly over time, which includes explanatory variables representing knowledge capital and other likely key influences on productivity. The second approach calculates total factor productivity (TFP) in a growth accounting framework, and regresses TFP over time on the knowledge stocks and other possible explanators of total factor productivity. Both approaches can be derived from the production function of the generic form:

$$Q = f(L, K, A) \qquad (1)$$

Following Solow (1957), we adopt the popular and convenient Cobb-Douglas functional form:

$$Y = AK^{\alpha} L^{\beta} \qquad (2)$$

Where:

Y = output

A = productivity;

K = stock of physical capital;

L = labor employed.

If productivity can be explained by the stock of knowledge capital and other factors, then the productivity equation can be written as:

$$A = BS^{\gamma} Z^{\phi} \quad (3)$$

Where:

S = stock of knowledge capital and

Z = other factors affecting measured productivity (e.g. stock of foreign R&D; education attainment of workforce)

B = proportionality constant.

Substituting (3) into (2) gives

$$Y = BK^{\alpha} L^{\beta} S^{\gamma} Z^{\phi} \quad (4)$$

In the production function approach, a log linear version of equation (4) would be estimated directly:

$$\text{Log } Y = \log B + \alpha \log K + \beta \log L + \gamma \log S + \phi \log Z \quad (5)$$

Estimation of equation (5) provides unconstrained estimates of each of the parameters of the production function. The estimate of γ would provide a direct estimate of the percentage increase in output obtainable from one percent increase in knowledge stocks, holding all other factors constant.

However, statistical estimation of equation (5) is often made difficult and imprecise because of severe multicollinearity between the explanatory variables[1]. As such, and following the tradition of many studies cited by Nadiri (1993), this paper adopts the second approach in which TFP is first computed in a social accounting framework.

Total factor productivity is that increase in output not explained by capital and labor inputs, on the assumption of constant returns to scale (i.e. $\alpha+\beta=1$ in equation (5)) and of perfect competition in the markets for capital and labor. Under these assumptions, the values of α and β can be taken from observed factor shares. Thus total factor productivity in this sense can be calculated from available data. Hence, in the total factor productivity approach, equation (5) would be re-written as:

$$\text{Log } Y - \alpha \log K - \beta \log L = \log B + \gamma \log S + \phi \log Z \qquad (6)$$

[1] Regression analysis using this unconstrained model yielded the following standardised estimated coefficients: α = -0.287 (p=0.208), β = 0.529 (p=0.000), γ = 0.758 (p=0.002). However, the collinearity diagnostics were highly indicative of multicollinearity. The VIF values ranged from 30.3 to 138.2. The last Condition Index is at 532 and is associated with variance proportions above 0.90 for Log K and Log S.

The expression on the left hand side describes exactly the definition of TFP as the increase in output (log Y) that is not explained by changes in capital (log K) and labor (log L). Hence, we arrive at the following equation:

$$TFP = \log B + \gamma \log S + \phi \log Z \tag{7}$$

Hence observations on TFP, computed in a social accounting framework, can be regressed on the observable right hand side variables.

R&D expenditures are often expected to yield output after some lags of time. Thus, equation (7) is treated more appropriately as a long run relationship. The residuals from estimating equation (7) may be tested to establish the existence of a co-integrated long run equilibrium relationship between TFP and its determinants, log S and log Z.

4.2 Short Term Error Correction Reprsentation

According to the *Granger Representation Theorem*, a set of cointegrated variables will have an error correction model (ECM) representation. The ECM describes the short-run relationship between the cointegrated variables and can also be expressed as an autoregressive distributed lag (ADL) model (see Davidson and MacKinnon (1993) for proof that the ECM representation in Engel and Granger (1987) is a special case of an ADL model). If TFP, log S and log Z are cointegrated, assuming a ADL(x,y) form, the short-run relationship is

$$TFP_t = \beta + \lambda_1 TFP_{t-1} + \ldots + \lambda_x TFP_{t-x} + \gamma \log S_t + \ldots + \gamma_y \log S_{t-y} + \phi \log Z + \ldots + \phi_y \log Z_{t-y} \quad (8)$$

4.3 Other Computed Indicators

4.3.1 Mean Lag

The **mean lag** of R&D capital is the weighted average of all the lags involved with weights given by the relative size of the respective γ coefficients. It characterizes the speed of the adjustment process in output growth to increases in R&D capital stock. Formally, for the model described in equation (8):

$$\text{Mean lag} = \Sigma\, i\gamma_i / \Sigma\gamma_i \quad (9)$$

Or

$$\text{Mean lag} = \lambda/(1-\lambda) \quad (9a)$$

4.3.2 Median Lag

The **median lag** is defined as the duration of the time lapse such that the proportion of the total lag effect of R&D capital on output is equal to half. The formula for computing the median lag for the model in equation (8) is

$$\text{Median Lag} = \log(0.5)/\log(\lambda) \quad (10)$$

where log(x) represents the Naperian logarithm of x.

4.3.3 Rate of Return

Using either the production function approach (estimating equation (5)) or the TFP approach (estimating equations (7) and (8)), estimates of the parameter γ can easily be converted from an elasticity measure to a **rate of return**, $\partial Y/\partial S$ which measures the marginal product of R&D capital stock S. $\partial Y/\partial S$ is the increase in output for a given increase in the stock of knowledge, other variables being held fixed.

$$\partial Y/\partial S = \gamma . (Y/S) \qquad (11)$$

It is noted that Y/S is the reciprocal of the stock of R&D capital as a proportion of GDP.

The internal rate of return IRR, defined as the interest rate that makes the net present value of research investments equals to zero, was calculated using the stream of marginal products (Davis, 1981 and Makki et al., 1999). The procedure is implemented by solving the following equation for the IRR that makes the present value of a dollar investment equal to zero:

$$\Sigma\ VMP_j(1+r)^{-j} - 1.0 = 0 \qquad (12)$$

The value of marginal product VMP_j is the marginal physical product of research R_t after j periods times the output price P, and r is the interest rate. In our computation we have assumed that P=1, implying that all marginal products are valued in term of the prices during the base year.

4.4 Constructing Capital Stock Data

Economic studies of the impact of R&D have adopted either a stock approach, with variables such as R&D and capital employed expressed in terms of stocks, or a flow approach, with relevant variable expressed in terms of R&D expenditures flows and relationships sought between the flow variables. A good deal of economic theory suggests that relationships should be sought between stock rather than flow variables, but such a methodology raises difficult questions about how such stock variables are to be constructed.

In this paper, following many studies such as Mohnen et al. (1986), the R&D capital stock is constructed by applying the perpetual inventory method, a similar approach to that used when constructing physical capital stocks. The R&D capital stock in any period may be expressed as:

$$S_t = (1-\delta)\ S_{t-1} + R_{t-1} \qquad (13)$$

Where

S_t = Stock of R&D capital at time t (in constant prices)

R_t = Expenditure on R&D during period (in constant prices)

δ = Depreciation rate of knowledge.

In the perpetual inventory method, a critical factor is the value of the stock in the initial period, from which the inventory begins. This initial period value may either be calculated or assumed. We adopt a suggestion by Griliches (1980) that the initial stock of R&D capital may be calculated according to the following procedure.

$$S_o = R_o/(g + \delta) \tag{14}$$

Where:

S_o = stock of R&D capital at the beginning of the first year for which R&D expenditure data (in constant prices) is available.

R_o = expenditure on R&D (in constant prices) during the first year for which it is available.

G = the average annual logarithmic growth of R&D expenditure over the period for which published R&D data were available, and

δ = the depreciation rate of knowledge.

Nadiri (1993) noted that the depreciation rate to generate stock of R&D capital is often arbitrarily determined. Typically, researchers conduct sensitivity analysis to ensure that the estimation results are not significantly changed when using different depreciation rates. Many empirical studies use depreciation rates of the order of 10 to 15 per cent per annum. Bernstein and Nadiri (1989) and Mohnen et al. (1986) used a depreciation rate of 10% in their studies using firm level data. Also using firm level data, Jaffe (1986) assumed a 15% depreciation rate. Guellec and van Pottelsberghe de la Potterie (2001), in their study using national level data for 16 OECD countries, assumed a depreciation rate of 15%.

5. Analysis Using Singapore Data

Annual data on GDP and R&D Expenditure in Singapore for the years 1978 to 2001 were used in the derivation of TFP values and the estimation of both the short run and long run equations relating GDP growth to R&D capital stock. Data on GDP were obtained from the Singapore Department of Statistics, while data on R&D expenditure were taken from the annual National R&D Survey conducted by the Agency for Science, Technology and Research (A*STAR). As indicated previously, the R&D capital stock is computed using the perpetual inventory method.

In this paper, the reported results are derived based on the assumption that the depreciation rate for R&D capital stock is 10%. **Table 3** shows the computed stock of R&D capital in Singapore from 1978 to 2001, using this depreciation rate. Sensitivity analysis of the regression results with respect to different depreciation rates was conducted to ascertain the robustness of the analysis and interpretation. The regression results indicate that the estimated coefficients are not sensitive to the depreciation rates. Depreciation rates ranging from 10% to 20% were used in the sensitivity analysis. Regressions results and computations based on a 20 percent depreciation rate are reported in the **Appendix 1**.

The following variables were tested for possible effect on measured productivity:

Z_1 = proportion of labor force with post secondary and tertiary education [to proxy human capital effect]

Z_2 = proportion of labor force whose occupation are associated professionals, technicians and professionals [another variable to proxy human capital effect]

Z_3 = stock of foreign direct investment as a proportion of domestic capital stock [to proxy foreign R&D, hence attempt to measure spillover effect]

The above variables are found not significant in influencing the TFP in the case of Singapore. This reduces the long-run equation (7) to the following form:

$$TFP = \log B + \gamma \log S \tag{7a}$$

5.1 Long Run Relationship between R&D and Productivity

Table 4 shows the regression results from estimating equation (7a). A unit root test was conducted on the residuals from estimating this equation and the results show that TFP and log(S) are cointegrated, i.e. there exists a linear combination of TFP and Log(S) that yields a stationary series. This establishes a long run relationship between R&D capital stock and growth in output as measured by TFP.

5. 2 Short Run Relationship between R&D and Productivity

A short run error correction model was constructed, of the general ADL(x,y) form as shown in equation (8). We began with ADL model with lag length of 3 and "tested-down" to a model ADL(1,0) given by:

$$TFP_t = \beta + \lambda\, TFP_{t-1} + \gamma \log S_t \tag{8a}$$

The regression results for equation (8a) are reported in **Table 5** and the estimated coefficients are given in equation form below.

$$\mathbf{TFP_t = 0.0965 + 0.8366 * TFP_{t-1} + 0.013298 * logS_t}$$

5.3 Estimating Impact of R&D on GDP

In the short run, one percent increase in the stock of R&D capital will lead to a 0.013 percent increase in the Gross Domestic Product (GDP). However, in the long run, one percent increase in the stock of R&D capital will lead to a 0.0814 percent increase in the GDP.[2] This is at least six times as much as the short run impact, reflecting that there is significant lagged effect in the contribution of R&D to GDP. Taking 2001as an example, one percent increase of R&D capital stock will amount to $122 million. This will yield a contemporaneous increase in GDP amounting to $1803 million. That is $14.78 of GDP for every dollar increase in R&D. In the long run, when the lagged effects are taken into account, the increase in GDP will be $11,289 million which is tantamount to $92.53 of GDP for every dollar increase in R&D.

5.4 Other Indicators of R&D Impact on Growth

Table 6 summarizes the mean lag, median lag and internal rates of return for R&D capital investments over the last 5 to 10 years.

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[2] The long run elasticity of GDP with respect to S is given by $\gamma/(1-\lambda)=0.0133/(1-0.837)=0.0814$. This is similar to the estimated value of $\gamma = 0.080$ in the long-run cointegration equation.

The mean lag and median lag measure the speed at which GDP responds to changes in R&D capital stock. Shorter periods for the mean and median lag would indicate a faster adjustment process for GDP in response to growth in R&D capital. The internal rate of return (IRR) provides a measure of the profitability in investing resources in R&D. The IRR on R&D investment can be contrasted to the cost of borrowing funds to finance an investment project. If the IRR on R&D capital investment is higher than the interest rate charged for borrowing, then that project is considered profitable.

From **Table 6**, the mean lag is estimated to be 5.1 years, while the median lag is 3.9 years. Thus the half-life of R&D investment is 3.9 years; in other words, it will take 3.9 years for half the effect from R&D to be realized in terms of GDP growth. The mean lag shows that on average, it takes 5.2 years for R&D capital to have an impact on GDP. As an indication of the magnitude of the impact, the internal rate of return computed over the last five years was 5.9%. This contrasts with a longer-term internal rate of return of 8.2% over the last 10 years. These rates of return compare against market rates of between 5 and 6 percent for bank loans and other sources of debt funding. R&D investment is profitable, especially in the long run as it yields higher returns than the cost of funds.

The long-term elasticity of output with respect to R&D was computed to be 8.14%. Compared to many of the industry and firm level estimates summarized by Nadiri (1993), this elasticity value is very low. However, Nadiri notes that the elasticities and rates of return derived from time-series data are often smaller than those obtained from cross-sectional data. As earlier discussed, Griliches (1991) had also stated that elasticity estimates are sensitive to the level of data used.

5.5 Comparing Singapore with Other Countries

How, then, does Singapore's elasticity of output with respect to R&D compare against the estimated elasticities of other countries in studies using national level data? The 8.14% computed for Singapore is lower than the long run elasticities estimated by Guellec and van Pottelsberghe de la Potterie (2001) across 16 OECD countries (13.2% for private R&D and 17.1% for public R&D). However, this figure of 8.14% is consistent with Lichtenberg's estimate of 7% for the elasticity of GNP with respect to private R&D, where the estimate is derived using cross-sectional data from 53 countries. As Lichtenberg's study covered many developing as well as advanced OECD countries, our finding for Singapore is consistent with the interpretation that the productivity impact of R&D in less developed countries has been lower than for advanced countries, as suggested by Birdsall and Rhee (1993).

Table 7 summarizes the comparable estimated parameters for Singapore vis a vis other countries for which equivalent studies have been done. R&D capital in Singapore appears to be less productive than in OECD countries, in terms of the responsiveness of output to research capital. Both the short and long term elasticities of output with respect to R&D are higher in the OECD countries. The mean lag for R&D in OECD countries is 4.55 years; on average, it takes 4.55 years for R&D to have an impact on the GDP of OECD nations. This compares with a higher mean lag value of 5.12 years for Singapore. The corresponding half-life figure, as measured by median lag, is also lower among OECD countries.

One possible explanation for the lower productivity of R&D investment in Singapore is the relatively lower level of private sector R&D activities in this country, compared to the advanced OECD nations. In 2000, the government's share in total R&D expenditure was 38% in Singapore, compared to an average of 34% in the OECD countries[3]. For some of the larger OECD countries, the share of government spending in R&D expenditure was even lower: USA (31%), Japan (27%) and Germany (32%). In his cross-country study, Lichtenberg (1992) suggested that the marginal product of government-funded research capital is much lower than that of private sector research capital. Countries with higher government share in R&D spending exhibited significantly lower productivity growth. In this present study, we have not explored the comparative returns on government funded R&D versus private sector R&D due to multicollinearity between the two time-series and data-point constraints.

The collated results presented in **Table 7** are in contrast to Madden et al. (2001) who found that the impact of domestic R&D on TFP was six times higher in a block of 6 Asian countries than in two groups of advanced OECD nations: a G7 group and a non-G7 OECD group. However, we note that annual data in Madden et al. was collected by group and the lack of homogeneity in the six Asian countries, notably the inclusion of South Korea with its high GDP level and R&D intensity comparable to that of advanced OECD nations. The observation of higher domestic R&D elasticity in the Asian countries collectively may not be applicable to the specific case of Singapore as a single country.

[3] Source for OECD data: OECD STI Directorate, *Main Science and Technology Indicators*

6. Conclusions

This paper provided empirical evidence that R&D investment in Singapore had a significant impact on its total factor productivity performance in the last 20 years. The analysis established a long-term equilibrium relationship between R&D investments and TFP. Compared to the OECD nations, the impact of R&D investment on economic growth in Singapore is not as strong, as evidenced by lower estimated elasticity values. This is not entirely surprising, as concerted effort in investing in R&D capital in Singapore is a recent phenomenon.

Our findings extended the existing empirical literature on advanced countries to a NIE. The findings show that the positive impact of R&D on productivity performance may be generalized to countries other than the advanced OECD nations that have been the focus of most of the existing literature. However, the lower long-term elasticity estimates for Singapore in comparison to advanced countries suggest that Singapore still has some way to go in catching up with the advanced nations in terms of R&D productivity. This not only means increasing the level of R&D intensity in Singapore but also more efficient exploitation of domestic R&D activity.

References

Aghion, P. and P. Howitt (1992). A Model of Growth through Creative Destruction. *Econometrica*, 60, pp. 323-51.

Bernstein, J.I . and M.I. Nadiri (1989). Research and Development and Intraindustry Spillovers: An Empirical Application of Dynamic Duality. *Review of Economic Studies*, 56, pp. 249-69.

Birdsall, N. and C. Rhee (1993). Does Research and Development Contribute to Economic Growth in Developing Countries? Policy Research Working Paper No. 1221, Washington, D.C., The World Bank (November).

Coe, D. and E. Helpman (1995). International R&D Spillovers. *European Economic Review,* 39, pp. 859-87.

Coe, D., E. Helpman and A. Hoffmaister (1997). North-South R&D Spillovers. *Economic Journal*, 107, pp. 134-49.

Engelbrecht, H. (1997). International R&D Spillovers amongst OECD Economies. *Applied Economics Letters*, 4, pp. 315-19.

Davis, J. (1981). A Comparison of Procedures for Estimating Returns to Research Using Production Functions. *Australian Journal of Agricultural Economics*, 25, pp. 60-72.

Denison, E.F. (1985). *Trends in American Economic Growth, 1929-1982*. Brookings Institution, Washington D.C.

Domar, E.D. (1961). On measurement of technological change. *Economic Journal*, 71, pp. 709-29.

Fagerberg, J. (1994). Technology and International Differences in Growth rates. *Journal of Economic Literature*, 32, pp. 1147-1175.

Goel, R.K. and R. Rati (1994). R&D Expenditures and Economic Growth : A Cross Country Study. *Economic Development and Cultural Change*, 2, pp. 403-411.

Griliches, Z. (1980). R&D and Productivity Slowdown. *American Economic Review*, 70, pp. 343-348.

Griliches, Z. (1981). The Search for R&D Spillovers. NBER Working Paper no. 3769, National Bureau of Economic Research.

Grossman G.M. and E. Helpman, E. (1991). *Innovation and Growth in the Global Economy*. MIT Press, Cambridge, MA.

Guellec, D. and B. van Pottelsberghe de la Potterie (2001). R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries. STI Working Paper 2001/3, Directorate for Science, Technology and Industry, OECD, Geneva.

Jaffe, A. (1986). Technological Opportunity and Research Spillovers of R&D: Evidence from Firms' Patents, Profits and Market Value. *American Economic Review*, 76, pp. 984-1001.

Jorgenson, D.W., F.W. Gollop and B. Fraumeni (1987). *Productivity and the US Economic Growth*. Harvard University Presss, Cambridge.

Jones, C.I. (1995). R&D Based Models of Economic Growth. *Journal of Political Economy*, 103, pp. 759-784.

Kendrick, J.W. and E.S. Grossman (1980). *Productivity in the United States: Trends and Cycles*. The John Hopkins University Press, Baltimore, MD.

Lichtenberg, F.R. (1993). R&D Investment and International Productivity Differences. NBER Working Paper No. 4161, National Bureau of Economic Research.

Madden, G., S.J. Savage and P. Bloxham (2001). Asian and OECD International R&D Spillovers. *Applied Economics Letters*, 8, pp. 431-435.

Makki, S.S., S.T. Cameron, and L.G. Tweeten (1999). Returns to American Agricultural Research: Results from a Cointegration Model. *Journal of Policy Modeling*, 21, pp. 185-211.

Mansfield, E. (1972). Contribution of Research and Development to Economic Growth of the United States. Papers and Proceedings of a Colloquim on Research and Development and Economic Growth Productivity. National Science Foundation, Washington DC.

Mohnen, P., M.I. Nadiri and I. Prucha (1986). R&D, Production Structure and Productivity Growth in the US, Japanese and German Manufacturing Sectors. *European Economic Review*, 30, pp. 749-722.

Nadiri, I.N. (1993). Innovations and Technological Spillovers. NBER Working Paper 4423, National Bureau of Economic Research, Cambridge, MA.

Romer, P.M. (1990). Endogenous Technological Change. *Journal of Political Economy*, 98, pp. S71-S102.

Ruttan V.W. (1997). Induced innovation, Evolutionary Theory and Path Dependence: Sources of Technical Change. *Economic Journal*, 107, pp. 1520-1529.

Solow, R.M. (1956). A Contribution to the Theory of Economic Growth. *Q.J.E.*, 70, pp. 65-94.

Solow, R.M. (1957). Technical change and the aggregate production function. *Review of Economics and Statistics*, 39, pp.312-20.

Stokey, N.L. (1995). R&D and Economic Growth. *Review of Economic Studies*, 62, pp. 469-489.

Verspagen, B. (1992). Endogenous Innovation in Neo-Classical Growth Models: A Survey. *Journal of Macroeconomics*, 14, pp. 631-662.

Wong, P.K. (2003). From using to creating technology: the evolution of Singapore's national innovation system and the changing role of public policy. In Lall, S. and S. Urata (eds.), *Competitiveness, FDI and Technological Activity in East Asia.*: Edward Elgar, Chelterham, UK.

Table 1: Singapore R&D Expenditures and Number of RSEs, 1978-2001

Year	**R&D Expenditure (S$ m)**	**R&D Expenditure as % of GDP**	**Private Sector Share of R&D Expenditure**	**RSEs (Headcount)**	**RSEs per 10,000 labour force**
1978	37.8	0.21	67.46	818	8.53
1979	48.3	0.24	63.35	927.6	9.09
1980	62.3	0.25	59.07	1,051.9	9.80
1981	81.0	0.28	54.57	1,193	10.34
1982	111.9	0.34	52.99	1,500.6	12.29
1983	154.7	0.42	51.39	1,894.6	15.14
1984	214.3	0.54	49.79	2,401	18.92
1985	256.9	0.66	53.29	2,683.1	21.73
1986	309.5	0.80	56.80	3,001.4	24.72
1987	374.7	0.87	60.21	3,361	26.53
1988	430.7	0.85	58.21	3,642.7	27.36
1989	495.7	0.85	56.18	3,963.5	28.43
1990	571.7	0.86	54.14	4,329	29.47
1991	756.7	1.02	58.41	5,218	34.23
1992	949.3	1.19	60.83	6,454	40.95
1993	998.2	1.07	62.00	6,629	41.64
1994	1175.0	1.10	62.66	7,086	42.96
1995	1366.6	1.16	64.50	8,340	49.00
1996	1792.1	1.40	63.24	10,153	58.08
1997	2104.5	1.50	62.46	11,302	61.74
1998	2492.3	1.81	61.63	12,655	67.68
1999	2656.4	1.87	62.90	13,817	73.26
2000	3009.50	1.89	62.00	18,302	87.37
2001	3232.70	2.11	63.26	18,577	87.64
Average % growth rate per annum					
1978-1985	31.5	17.8	-3.3	18.5	14.3
1985-1995	18.2	5.8	1.9	12.0	8.5
1995-2001	15.4	10.5	-0.3	14.3	10.2

Source: NSTB R&D Survey, various years

RSE figures for 1979, 1980, 1982, 1983, 1985, 1986, 1988, 1989 calculated by interpolation

Table 2: International Comparisons of R&D Expenditure as % of GDP

Country	**R&D Expenditure as % of GDP, 2000-2001**
USA	2.70
Japan	3.12
Singapore	2.11
South Korea	2.65
Taiwan	2.04

Source: *World Competitiveness Yearbook 2002*, IMD

Table 3: Stock of R&D Capital in Singapore, 1978 – 2001 (computed using 10% depreciation rate)

	S$ million		
	Private R&D Capital	Public R&D Capital	Total R&D Capital
1978	102.6	50.8	153.9
1979	121.3	59.6	181.2
1980	141.7	73.5	215.5
1981	161.6	92.2	254.1
1982	183.6	119	302.8
1983	216.8	157.2	374.1
1984	263.6	211.1	474.8
1985	331.1	290.1	621.3
1986	421.1	369.0	790.1
1987	542.2	451.4	993.6
1988	695.4	534.0	1229.5
1989	831.4	624.7	1456.1
1990	957.0	727.4	1684.4
1991	1075.1	844.1	1919.2
1992	1285.1	977.9	2263.1
1993	1576.1	1135.1	2711.2
1994	1828.5	1256.0	3084.6
1995	2120.2	1396.6	3516.8
1996	2466.0	1541.1	4007.0
1997	2951.4	1801.6	4753.1
1998	3487.3	2118.1	5605.5
1999	4133.1	2530.7	6663.8
2000	4802.7	2907.0	7709.7
2001	5482.8	3331.0	8813.9

TABLE 4 Testing Cointegration between TFP and log(S)

$$TFP = \log B + \gamma \log S$$

Dependent Variable: TFP **Method: Least Squares** **Depreciation rate for R&D Capital Stock = 10%**				
Sample: 1978 2001				
Included observations: 24				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	0.556	0.081	6.876	0.000
Log(S)	0.080	0.011	7.507	0.000
R-squared	0.71925	Mean dependent var		1.15417
Adjusted R-squared	0.70649	S.D. dependent var		0.12085
S.E. of regression	0.06547	Akaike info criterion		-2.53468
Sum squared residuals	0.09431	Schwarz criterion		-2.43651
Log likelihood	32.41619	F-statistic		56.36090
D-W statistics	0.30561	Prob(F-statistic)		0.00000
Cointegration Test : Between TFP and Log(S)#				
ADF Test Statistic	-2.90306	1% Critical Value*		-2.67429
		5% Critical Value		-1.9572
Result	Cointegrated			
*MacKinnon critical values for rejection of hypothesis of a unit root.				
#TFP and log(S) are tested to be non-stationary I(1) variables. Test used is the Augmented Dickey-Fuller Unit Root Test with Intercept. Using TFP and Log(S) in the levels, the null hypothesis of unit root was accepted. Using first differences of TFP and Log(S), the null hypothesis was rejected.				

TABLE 5 Short run Error Correction Model

$$TFP_t = \beta + \lambda\ TFP_{t-1} + \gamma \log S_t$$

Dependent Variable: TFP **Method: Least Squares** **Depreciation rate for R&D Capital Stock = 10%**				
Sample: 1978 2001				
Included observations: 24				
Variable	**Coefficient**	**Std. Error**	**t-Statistic[4]**	**Prob.**
C	0.0965	0.0736	1.3121	0.2036
TFP(-1)	0.8366	0.1094	7.6481	0.0000
Log(S)	0.0133	0.0104	1.2822	0.2138
R-squared	0.9258	Mean dependent var		1.1542
Adjusted R-sq	0.9188	S.D. dependent var		0.1209
S.E. of regression	0.0344	Akaike info criterion		-3.7825
Sum squared residuals	0.0249	Schwarz criterion		-3.6352
Log likelihood	48.3901	F-statistic		131.0727
D-W statistics[5]	1.1781	Prob(F-statistic)		0.0000
Breusch-Godfrey LM Test:[6] Chi -squared F-statistic	 4.3467 2.1011	 Prob(BG Chi- Squared) Prob(BG F-statistic)		 0.1138 0.1498

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[4] As the regression equation involves non-stationary time-series for dependent and independent variables, the estimated t-statistics are not valid. The t-statistics and associated probability values are reported for formality only. The purpose of estimating this ADL equation was not to establish the significance of regressors, but to obtain estimates for the elasticity coefficient, γ.

[5] The Durbin-Watson d-statistic is not appropriate for detecting autocorrelation in this equation, which includes a lagged value of the dependent variable as an explanatory variable. As an alternative test of autocorrelation, the correlogram of residuals, Q-statistic and the Breusch-Godfrey Lagrange Multiplier test were computed. The correlogram did not reveal any significant spikes and Q-statistics were not significant (at 5%) on any of the lags.

[6] Due to the small size of the sample, the Breusch-Godfrey LM test is preferred over the Durbin h test, as it has been suggested to be statistically more powerful in finite small samples. Additionally, Monte Carlo simulations has suggested that the F form of the BG test is more reliable than the chi-squared form for small samples. The null hypothesis for both BG test statistics is that there is zero serial correlation in the residuals. The null hypothesis cannot be rejected in this case.

Table 6: Mean Lag, Median Lag and Internal Rates of Return for Singapore R&D Capital Investment

Parameter	**Value**
Lambda λ	0.8366
Short Term Gamma γ (Short Term Elasticity of R&D Capital Stock)	0.0133
Long Term Gamma γ (Long Run Elasticity of R&D Capital Stock)	0.0814
Average (Y/S) over last 10 years	18.51
Average (Y/S) over last 5 years	14.54
Internal Rate of Return (over last 10 years)	8.24%
Internal Rate of Return (over last 5 years)	5.89%
Mean Lag	5.12 years
Median Lag	3.89 years

Table 7: Comparison of Parameter Estimates

Parameter	**Singapore**	**16 OECD Countries** (Guellec and van Pottelsberghe de la Potterie (2001))	**53 countries (Lichtenberg (1992))**
Lambda λ	0.8366	0.82	NA
Short Term Gamma γ (Short Term Elasticity of R&D Capital Stock)	0.0133	0.024 (private R&D) 0.028 (public R&D)	NA
Long Term Gamma γ (Long Run Elasticity of R&D Capital Stock)	0.0814	0.13 (private R&D) 0.17 (public R&D)	0.068 to 0.077
Mean Lag	5.12	4.55	NA
Median Lag	3.89	3.49	NA

Mean and Median Lag for 16 OECD countries are computed from model estimates reported in (Guellec and van Pottelsberghe de la Potterie (2001))

APPENDIX 1:

ERROR CORRECTION MODEL USING 20% DEPRECIATION FOR TOTAL R&D CAPITAL STOCK

$TFP_t = \beta + \lambda\ TFP_{t-1} + \gamma \log S_t$

Dependent Variable: TFP **Method: Least Squares** **Depreciation rate for R&D Capital Stock = 20%**				
Sample: 1978 2001				
Included observations: 24				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	0.0972	0.0740	1.3144	0.2029
Log(S)	0.8418	0.1069	7.8784	0.0000
TFP(-1)	0.0129	0.0102	1.2674	0.2189
R-squared	0.92571	Mean dependent var		1.1542
Adjusted R-sq	0.91863	S.D. dependent var		0.1209
S.E. of equation	0.03447	Akaike info criterion		-3.7808
Sum squared residuals	0.02496	Schwarz criterion		-3.6336
Log likelihood	48.37012	F-statistic		130.8376
D-W statistics	1.18046	Prob(F-statistic)		0.0000

Parameter Estimates

(Depreciation rate for R&D Capital Stock = 20%)

Indicator	**Value**
Lambda λ	0.8418
Short Term Gamma γ (Short Term Elasticity of R&D Capital Stock)	0.0129
Long Term Gamma γ (Long Run Elasticity of R&D Capital Stock)	0.0817
Mean Lag	5.3225
Median Lag	4.0251