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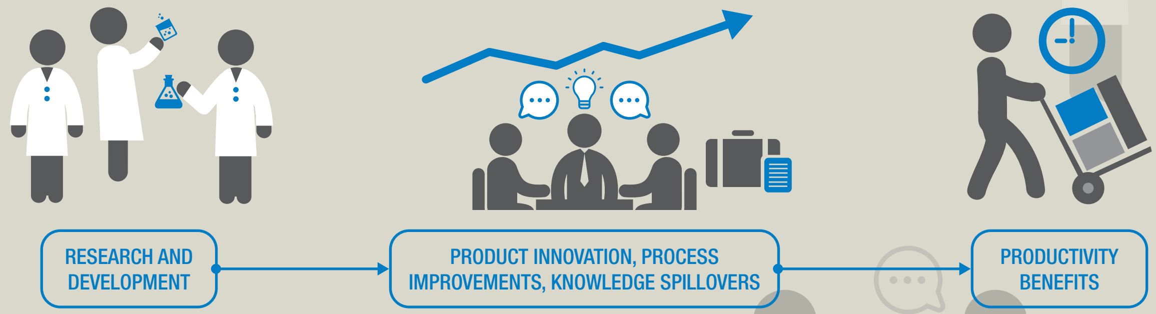
FEATURE ARTICLE

IMPACT OF RESEARCH & DEVELOPMENT ON PRODUCTIVITY

BACKGROUND

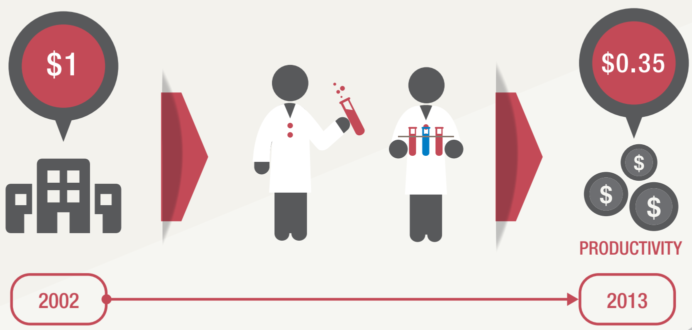
Research & Development (R&D) can bring about product innovation, process improvements and knowledge spillovers, resulting in productivity benefits.



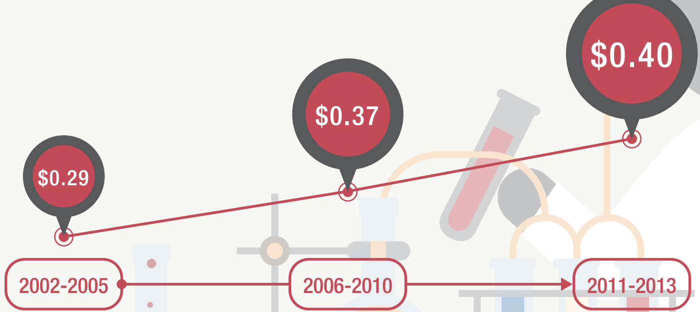
FINDINGS

At the overall economy level, a $1 increase in R&D stock was associated with an increase in multi-factor productivity of $0.28 and $1.01 in the short- and long-run respectively from 1978 to 2014.

At the firm-level, a $1 increase in R&D stock was found to raise productivity in a firm with a median value-added to R&D stock ratio by $0.35 from 2002 to 2013.



The dollar impact of R&D for the median firm has increased over time, from $0.29 in 2002-2005, to $0.37 in 2006-2010, and then to $0.40 in 2011-2013.



EXECUTIVE SUMMARY

- Studies in other countries have found that investments in Research and Development (R&D) can lead to productivity improvements. Our study quantifies the impact of R&D on productivity at both the overall economy and firm levels in Singapore.

- At the overall economy level, we find that R&D has a positive and significant correlation with productivity. In particular, between 1978 and 2014, a $1 increase in R&D stock was associated with an increase in multi-factor productivity of $0.28 and $1.01 in the short- and long-run respectively.[1]

- Similarly, our findings indicate that R&D has a positive and significant impact on productivity at the firm level. Over the period of 2002 to 2013, a $1 increase in R&D stock was found to raise productivity in a firm with a median value-added to R&D stock ratio by $0.35. Dividing this period into sub-periods that coincide with the Research, Innovation and Enterprise (RIE) funding tranches, we find that the dollar impact of R&D has increased over time, from $0.29 in 2002-2005, to $0.37 in 2006-2010, and then to $0.40 in 2011-2013.

- Our findings thus suggest that continued investments in R&D can help to raise productivity in the years ahead.

The views expressed in this paper are solely those of the authors and do not necessarily reflect those of the Ministry of Trade and Industry or the Government of Singapore.[2]

INTRODUCTION

Research & Development (R&D) can bring about product innovation, process improvements and knowledge spillovers that enable firms to offer new and improved products, as well as lower production costs.[3] These could in turn lead to improvements in productivity, thereby contributing to sustainable economic growth and higher wages.

R&D has been an integral part of our economic strategy. The Government supports R&D through 5-year Research, Innovation and Enterprise (RIE) funding tranches, with the three most recent plans being the Science & Technology (S&T) Plan 2005, the S&T Plan 2010, and the RIE Plan 2015. The budgets for these plans have steadily increased, from $6 billion for the period of 2001-2005 to $13.6 billion in 2006-2010, and $16.1 billion in 2011-2015.

R&D expenditure in Singapore has also risen steadily over the years. Gross Expenditure on R&D (GERD) increased from $4.6 billion in 2005 to $7.6 billion in 2013, at a compounded annual growth rate (CAGR) of 6.5 per cent. Over this period, Business Expenditure on R&D (BERD) accounted for about 60-70 per cent of the GERD, while Public Expenditure on R&D (PUBERD)[4] accounted for the remaining 30-40 per cent [Exhibit 1].

Given our growing investments in R&D, this study aims to quantify the impact of R&D on productivity in Singapore, both at the economy-wide and firm levels. This would allow us to better understand the economic benefits of R&D.

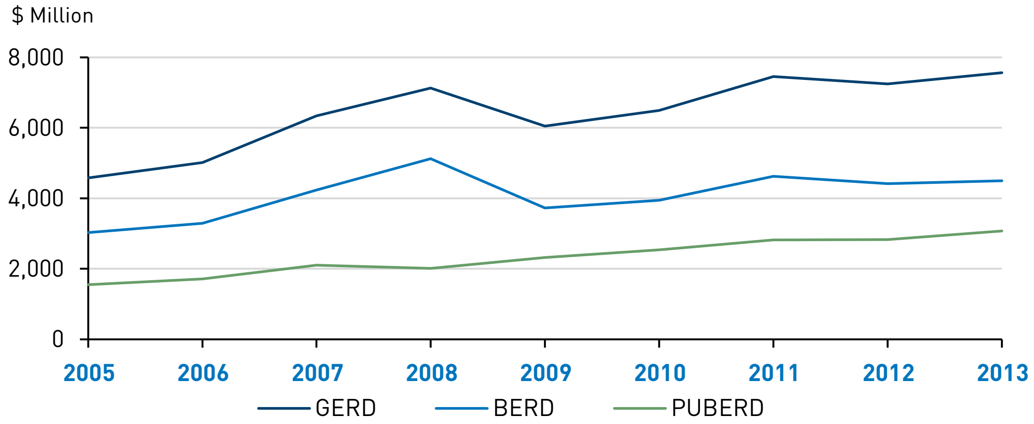
[1] *The dollar impact of R&D on productivity reported in this study is in constant 2010 market prices, i.e., in real terms.*

[2] *We would like to thank Yong Yik Wei and Andy Feng for their helpful comments and suggestions. We would also like to acknowledge the statistical support received from Sherilyn Lim (Research and Statistics Unit, Agency for Science, Technology and Research). All errors belong to the authors.*

[3] *See Hall, Mairesse, and Mohnen (2010).*

[4] *The public sector comprises government organisations, public research institutes, and higher education institutes.*

Exhibit 1: GERD, BERD and PUBERD (2005-2013)



Source: Agency for Science, Technology and Research

IMPACT OF R&D ON PRODUCTIVITY IN THE OVERALL ECONOMY

Literature Review

At the economy-wide level, several studies have found a positive relationship between R&D stock and multi-factor productivity (MFP). MFP measures how efficiently inputs, usually capital and labour, are used in production. Improvements in MFP may arise from new technologies or improvements in the methods of production.

For example, Coe and Helpman (1995) found that a 1 per cent increase in R&D stock was associated with a 0.2 per cent increase in MFP in G7 countries[5], and a 0.08 per cent increase in non-G7 OECD economies over the period of 1971 to 1990. In the case of Singapore, Toh and Choo (2002) and Ho, Wong and Toh (2009) found the elasticity over the period of 1978-2001 to be between 0.01 per cent and 0.02 per cent in the short run, and between 0.05 per cent and 0.08 per cent in the long run.

Data and Empirical Methodology

To examine the relationship between R&D stock and productivity at the economy-wide level in Singapore based on more recent data, we use annual MFP[6] and R&D capital stock data from the Department of Statistics (DOS), spanning the years 1978 to 2014.

We adopt a growth accounting framework based on a Cobb-Douglas production function, as is commonly done in the literature (see equation 1). The logarithmic form of MFP is shown in equation 2.

$$Y = AL^{\alpha} K^{\beta} = (BS^{\gamma})L^{\alpha}K^{\beta} \quad (1)$$

Where
Y = Output
A = MFP = BS^{γ}
B = Non-R&D factors that affect MFP
S = R&D capital stock
L = Labour
K = Physical capital stock

$$\log MFP = \log B + \gamma \log S \quad (2)$$

[5] *The G7 countries are the United States, United Kingdom, France, Germany, Canada, Italy and Japan.*

[6] *More specifically, we construct an annual MFP index from MFP growth provided by DOS.*

Similar to Toh and Choo (2002) and Ho, Wong and Toh (2009), we use an Auto-Regressive Distributive Lag model based on equation 2 to derive a short- and long-run relationship between R&D capital stock, *S*, and MFP over time *t* (equation 3).[7]

$$\log MFP_t = \alpha + \beta_1 \log MFP_{t-1} + \beta_2 \log S_t + \varepsilon_t \quad (3)$$

Results and Discussion

Over the period of the study, we estimate that a 1 per cent increase in R&D stock was associated with a 0.03 per cent increase in MFP in the short run (i.e., the same year in which the R&D investment was made) [Exhibit 2]. Given the lagged effect of R&D on productivity, the long run elasticity is larger, with a 1 per cent increase in R&D stock associated with a 0.108 per cent increase in MFP [Exhibit 3].[8] In dollar terms[9], a $1 increase in R&D stock was associated with a $0.28 and $1.01 increase in MFP in the short- and long-run respectively.

Exhibit 2: Regression Results

	1978-2014
β_1	0.724***
β_2	0.030***
Adjusted R^2	0.970

* p<0.10 ** p<0.05 *** p<0.01

Exhibit 3: Impact of R&D stock on MFP in the short- and long-run

	Short-run	Long-run
β_2	0.030	0.108
Dollar impact ($)	0.28	1.01

Our elasticity estimates are slightly higher than that found in earlier studies for Singapore (e.g., Toh and Choo, 2002), suggesting an improvement in the translation of R&D investments to productivity improvements in recent years.

IMPACT OF R&D ON PRODUCTIVITY AT THE FIRM LEVEL

Next, we examine the impact of R&D at the firm level using micro-econometric analysis. Unlike the earlier analysis which examined R&D at the economy-wide level, this analysis focuses on the impact of R&D conducted by firms on their own productivity.

[7] *We find that log MFP_t and log S_t are cointegrated, and can thus be represented in this form. Dummies for recession years (1998, 2001, 2009) are also included in the equation.*

[8] *The long-run elasticity of MFP with respect to R&D stock is equal to $\beta_2/(1-\beta_1)$.*

[9] *The dollar impact of R&D is equal to the elasticity of productivity with respect to changes in R&D stock multiplied by the ratio of the average GDP to average R&D stock from 1978 to 2014.*

Literature Review

Firm-level studies overseas have found a positive relationship between R&D stock and productivity. For instance, a 1 per cent increase in R&D stock was estimated to have led to a 0.09 per cent increase in productivity in US firms in 1966-1977 (Griliches and Mairesse, 1984), 0.07 per cent in the case of French manufacturing firms in 1980-1987 (Hall and Mairesse, 1995), and 0.09 per cent in the case of German manufacturing firms in 1979-1989 (Harhoff, 1998).[10] For Singapore, Toh and Choo (2002) showed that the elasticity of productivity to R&D stock was 0.04 per cent in the short run and 0.12 per cent in the long run in 1996-2001.

Data and Empirical Methodology

We use an anonymised unbalanced panel dataset compiled from the annual National Survey of R&D conducted by the Agency for Science, Technology and Research (A*STAR) over the period of 2002 to 2013. The regression sample comprises 965 firms that conducted in-house R&D for more than one year during this period.[11] The dataset contains information on the firms' R&D expenditure, employment, profits, net fixed asset investments, and industry.

Similar to other firm-level studies, we assume a standard Cobb-Douglas production function for each firm, with R&D capital stock being a determinant of productivity:

$$Y = AL^{\alpha} K^{\beta} = (BS^{\gamma})L^{\alpha} K^{\beta} \qquad (4)$$

Where Y = Value-added of firm (VA)
A = MFP
B = Non-R&D factors that affect MFP
S = R&D capital stock
L = Labour
K = Physical capital stock

Our empirical model is derived by taking the logarithmic form of equation 4[12], and adding control variables:

$$\log Y_{it} = c_i + \sum_t \theta_t d_t + \beta_s \log S_{it} + \beta_L \log L_{it} + \beta_K \log K_{it} + \beta_X X_{it} + \varepsilon_{it} \qquad (5)$$

Where Y_{it} is firm i's VA at time t
c_i is the fixed effects term for firm i
d_t is a dummy for year t
S_{it} is firm i's R&D stock at time t
L_{it} and K_{it} are non-R&D employment and capital[13] respectively for firm i at time t
X_{it} is a set of control variables comprising dummies for area of research and industry, as well as interactions of year and industry dummies for firm i at time t
ε_{it} is an error term associated with firm i at time t

We run a fixed effects regression on equation 5. As the regression controls for both observable (e.g., non-R&D fixed assets and employment) and time-invariant unobservable (e.g., managerial quality) characteristics of the firms, as well as macroeconomic and industry-specific factors that could affect R&D expenditure across firms, β_S can be interpreted as the average impact of a firm's R&D stock on the productivity of the firm.

[10] These studies are cited as their empirical strategies are more comparable to ours. See Hall, Mairesse and Mohnen (2010) for a survey of the literature.

[11] We exclude R&D service providers (i.e., firms classified under SSIC2010 72) from our analysis, as their R&D expenditure would have directly contributed to the bulk of their VA.

[12] As a result, firms that had negative values for VA, non-R&D fixed assets and employment are excluded from the sample. See Annex A for the computation of the variables Y_{it}, S_{it}, L_{it}, and K_{it}.

[13] This removes the double-counting of labour and capital engaged in R&D. Schankerman (1981, p454) pointed out that "research labour and capital are double-counted, once in the available measures of traditional labour and capital and again in the research expenditure input". He showed that failing to correct for double-counting would result in the estimated coefficient of R&D being biased downwards.

In our second firm-level regression, we allow for R&D to have varying effects on firm productivity over the three sub-periods that coincide with the RIE funding tranches i.e., 2002-2005, 2006-2010, and 2011-2013:

$$\log Y_{it} = c_i + \sum_t \theta_t d_t + \sum_j \beta_{sj} \log S_{it} \times \text{tranche}_j + \sum_j \beta_{Lj} \log L_{it} \times \text{tranche}_j + \sum_j \beta_{Kj} \log K_{it} \times \text{tranche}_j + \beta_X X_{it} + \varepsilon_{it} \quad (6)$$

Where in addition to the variables defined in equation 5,

tranche_j is a dummy for period j, where j = 2002-2005, 2006-2010 or 2011-2013

Results and Discussion

Over the period of 2002 to 2013, we find that R&D conducted by firms had a positive and significant impact on firm-level productivity [Exhibit 4]. In particular, we estimate that a 1 per cent increase in R&D stock raised firm-level productivity by 0.127 per cent on average over this period. In dollar terms, a $1 increase in R&D stock in a firm with a median value-added to R&D stock ratio increased productivity by $0.35.[14] Our elasticity estimate compares favourably with those found in other countries (e.g., 0.09 per cent in Germany), although we note that these studies tend to be for earlier periods. It is also higher than the estimates found for Singapore in the earlier study by Toh and Choo (2002).

Exhibit 4: Impact of R&D stock on firm-level productivity

	2002-2013
β_s	0.127***
Dollar impact ($)	0.35

* p<0.10 ** p<0.05 *** p<0.01

When we break down the period into sub-periods corresponding to the three RIE funding tranches, we find the elasticity of productivity with respect to changes in R&D stock to be increasing over the tranches, from 0.102 per cent in 2002-2005, to 0.134 per cent in 2006-2010, and then to 0.150 per cent in 2011-2013. The dollar impact of R&D also followed a similar trend, growing from $0.29 in 2002-2005, to $0.37 in 2006-2010, and then to $0.40 in 2011-2013 for the median firm[15] [Exhibit 5].

Exhibit 5: Impact of R&D stock on firm-level productivity over the RIE funding tranches

	2002-2005	2006-2010	2002-2013
β_s	0.102***	0.134***	0.150***
Dollar impact ($)	0.29	0.37	0.40

* p<0.10 ** p<0.05 *** p<0.01

[14] *The dollar impact of R&D is equal to the elasticity of productivity with respect to changes in R&D stock multiplied by the VA to R&D stock ratio.*

[15] *An increasing trend in dollar impact is also observed for firms with a 25th and 75th percentile value-added to R&D stock ratio.*

CONCLUSION

Our study suggests that investments in R&D have improved productivity at both the economy-wide and firm levels in Singapore. We also find that, at the firm-level, the dollar impact of R&D on productivity has increased over the years, from 2002-2005 to 2006-2010, and further in 2011-2013. This coincides with the increased support provided by the Government for industry-relevant R&D in the public sector under S&T Plan 2010 and RIE Plan 2015. By tapping on industry-relevant knowledge generated by the public sector, firms might have been able to make better R&D investment decisions that reaped higher returns in the later tranches. In addition, over time, firms may have become better at capturing value from the R&D done, leading to improved revenues and higher productivity.

Our findings imply that continued investments in R&D can help to raise the level of productivity in Singapore. To help firms that may not have the financial resources or technical expertise to conduct R&D, the Government has put in place schemes such as the Productivity and Innovation Credit, Research Incentive Scheme for Companies, and Capability Development Grant to help companies make R&D investments and thereby raise their productivity. Firms may also work with public institutions to meet their technological needs, for example, through Centres of Innovation and the Technology Adoption Programme.

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ANNEX A: COMPUTATION OF VARIABLES FOR FIRM-LEVEL STUDY

Value-added Y_{it}

First, to obtain nominal value-added, we sum up net operating profit after taxes, indirect taxes, manpower expenditure and depreciation of fixed assets. Next, to obtain real value-added Y_{it}, we deflate nominal value-added using the Gross Domestic Product (GDP) deflator by industry from DOS.

R&D Stock S_{it}

First, we derive the real R&D expenditure E_{it} by deflating nominal R&D expenditure using the Gross Fixed Capital Formation (GFCF) deflator. The GFCF deflator is derived by dividing GFCF at current market prices by GFCF at 2010 market prices, both obtained from DOS.

Next, consistent with literature, we use the perpetual inventory method to compute the R&D capital stock S_{it}, assuming a depreciation rate δ of 15 per cent (equations 7 and 8).[16]

$$S_{it} = S_{it-1} \times (1 - \delta) + E_{it} \tag{7}$$

Where S_{it} = R&D capital stock for firm i at time t
δ = Depreciation rate of R&D capital stock
E_{it} = Real R&D expenditure for firm i at time t

$$S_{it=0} = \frac{E_{it=0}}{g + \delta} \tag{8}$$

Where $S_{it=0}$ = R&D capital stock for firm i when it first entered the dataset
$E_{it=0}$ = Real R&D expenditure of firm i when it first entered the dataset
g = Growth rate of real R&D expenditure

We assume g to be 19 per cent, which is the estimated growth rate of BERD from 1990 to 2001, deflated using the GFCF deflator.

Physical Capital Stock K_{it}

We use net book value of fixed assets to proxy for total physical capital stock. We derive the real total physical capital stock by deflating nominal total physical capital stock using the net capital stock deflator. The net capital stock deflator is in turn derived by dividing net capital stock at current market prices by net capital stock at 2010 market prices, both obtained from DOS. Following Hall and Mairesse (1995), we deduct physical capital stock for R&D purposes from total physical capital stock to derive K_{it}, in order to correct for double counting.

Labour L_{it}

Following Hall and Mairesse (1995), L_{it} is total employment less R&D employment, to correct for double counting.

[16] *For example, see Griliches and Mairesse (1984) and Hall and Mairesse (1995).*