FEATURE ARTICLE

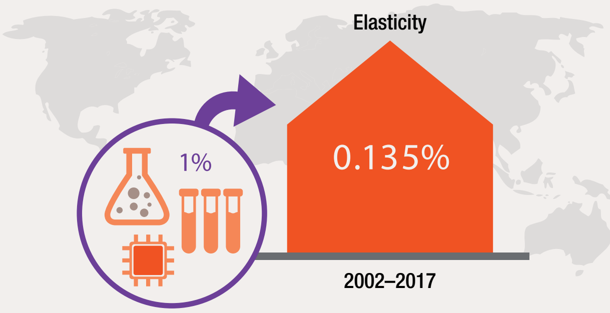
RETURNS TO RESEARCH AND DEVELOPMENT (R&D) AMONG FIRMS IN SINGAPORE

INTRODUCTION

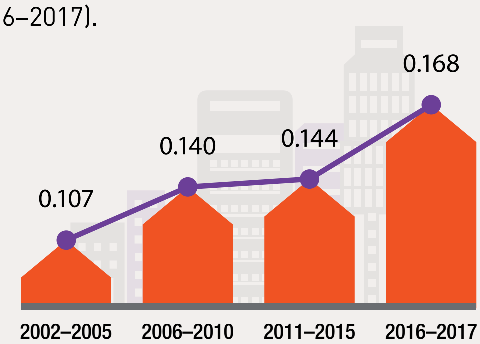
Research and Development (R&D) plays a key role in Singapore's ambitions to be an innovation-driven and value-creating economy. At the macroeconomic level, apart from enhancing the competitiveness of existing industries, R&D lays the foundation for Singapore to develop new capabilities in industries of the future. At the sectoral and firm levels, R&D investments can stimulate innovations in product offerings and production processes. These innovations can in turn raise productivity, thereby supporting sustainable economic and wage growth.

FINDINGS

Over the period of 2002 to 2017, a 1 per cent increase in R&D stock raised firm-level productivity by 0.135 per cent on average, which compares favourably with that found in other advanced economies.

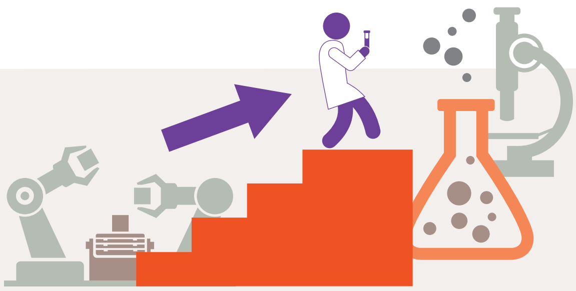


The elasticity of R&D has increased over time, from 0.107 for Science & Technology Plan 2005 (2002–2005) to 0.168 for the first two years of Research, Innovation and Enterprise Plan 2020 (2016–2017).



POLICY TAKEAWAY

These findings suggest that the government should continue to leverage R&D investments, along with other efforts under the Industry Transformation Maps, to raise the productivity of firms and industries in Singapore. Our efforts to raise the R&D and innovative capacity of our firms will be key to the transformation of our industries and Singapore's next phase of growth.



EXECUTIVE SUMMARY

- Leveraging a panel dataset from the Agency for Science, Technology and Research's (A*STAR) annual R&D survey, this study provides an overview of Singapore's R&D landscape. It also examines the impact of R&D investments on firm-level productivity in Singapore, and how this impact has changed across the various Science and Technology (S&T) and Research, Innovation and Enterprise (RIE) Plans.

- Our study finds that there are positive returns to firm-level productivity from R&D investments. Over the period of 2002 to 2017, a 1 per cent increase in R&D stock in a firm led to a 0.135 per cent increase in productivity on average. In dollar terms, a $1 increase in R&D stock raised productivity in a median firm (defined as having a median value-added to R&D stock ratio) by $0.24. The elasticity and dollar impact of R&D have also increased across the S&T and RIE Plans. Specifically, the elasticity rose from 0.107 for S&T Plan 2005 (2002-2005) to 0.168 for the first two years of RIE Plan 2020 (2016-2017). Meanwhile, the dollar impact rose from $0.20 in 2002-2005 to $0.28 in 2016-2017.

- These findings suggest that the government should continue to leverage R&D investments, along with other efforts under the Industry Transformation Maps, to raise the productivity of firms and industries in Singapore. Our efforts to raise the R&D and innovative capacity of our firms will be key to the transformation of our industries and Singapore's next phase of growth.

*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 (MTI), A*STAR or the Government of Singapore.*[1]

1. INTRODUCTION

Research and Development (R&D) plays a key role in Singapore's ambitions to be an innovation-driven and value-creating economy. At the macroeconomic level, apart from enhancing the competitiveness of existing industries, R&D lays the foundation for Singapore to develop new capabilities in industries of the future. At the sectoral and firm levels, R&D investments can stimulate innovations in product offerings and production processes. These innovations can in turn raise productivity, thereby supporting sustainable economic and wage growth.

In view of the important role of R&D in the Singapore economy, this study examines the impact of R&D on the multi-factor productivity – productivity henceforth – of firms that conduct R&D, and how this impact has changed across the Science and Technology (S&T) and Research, Innovation and Enterprise (RIE) Plans over the years.

The rest of the paper is organised as follows. Section 2 provides an overview of R&D in the Singapore economy. Section 3 briefly reviews the literature related to the impact of R&D on firm-level productivity. Section 4 outlines the data source and empirical methodology used to estimate the impact of R&D on firms' productivity. Section 5 presents the results, and the final section concludes.

2. OVERVIEW OF R&D IN THE SINGAPORE ECONOMY

Against the backdrop of rapid technological advancements, it is critical for Singapore to invest in R&D in order to build up our S&T capabilities, and support our development as a knowledge-intensive and innovative economy. Reflecting Singapore's commitment to do so, the National Science and Technology Board (NSTB), subsequently renamed as the Agency for Science, Technology and Research (A*STAR), was established in 1991.[2]

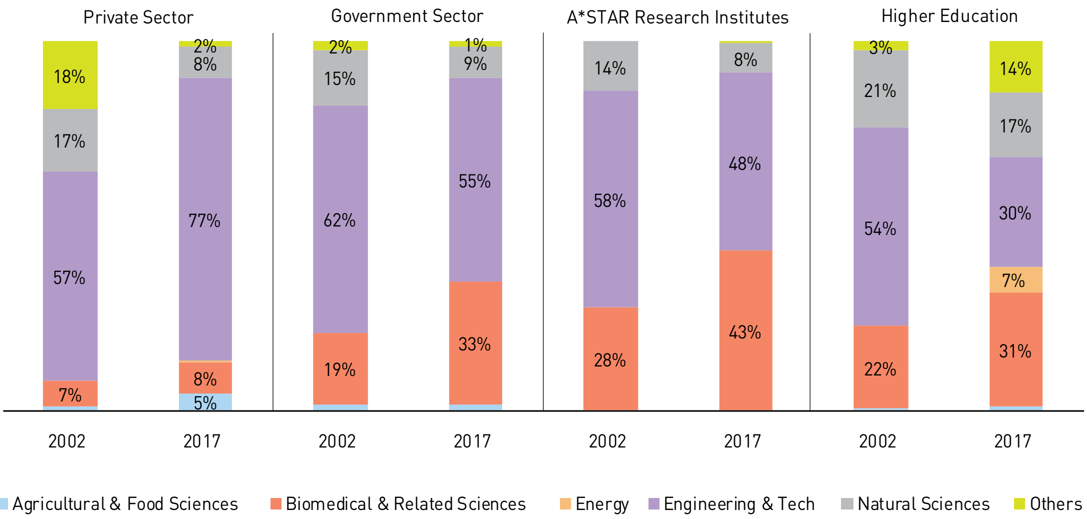
1 *We would like to thank Ms Yong Yik Wei for her useful suggestions and comments. We would also like to acknowledge the statistical support from A*STAR's Research and Statistics Unit.*
2 *For more details on the NSTB and A*STAR, see Hang et al. (2016), Thampuran (2017) and Yeoh (2017).*

Concomitantly, the government's investment in R&D has increased over the years. The first National Technology Plan (1991-1995) had a budget of $2 billion, which doubled to $4 billion in the second National S&T Plan (1996-2000). In the four most recent S&T and RIE Plans, the funding continued to increase, to $6 billion in S&T Plan 2005 (2001-2005), $13.5 billion in S&T Plan 2010 (2006-2010), $16 billion in RIE Plan 2015 (2011-2015), and $19 billion in RIE Plan 2020 (2016-2020).

In tandem with the government's efforts to promote R&D, Gross Expenditure on R&D (GERD) in Singapore rose from $0.8 billion in 1991 to $9.1 billion in 2017, representing a compounded annual growth rate (CAGR) of 10.0 per cent. The increase in GERD was supported by growth in both Business Expenditure on R&D (BERD) and Public Expenditure on R&D (PUBERD)[3]. The former rose from $0.4 billion to $5.4 billion (or 10.1 per cent per annum) over the same period, while the latter increased from $0.3 billion to $3.7 billion (or 9.9 per cent per annum). As a share of Gross Domestic Product (GDP), GERD (BERD) climbed from 0.96 per cent (0.56 per cent) to 1.94 per cent (1.16 per cent) between 1991 and 2017. By 2017, BERD accounted for around 60 per cent of GERD.

Given Singapore's capabilities in the manufacturing sector (e.g., electronics, precision engineering, aerospace and marine), a sizeable share of R&D expenditure in the private sector (or BERD) has remained in Engineering and Technology (Exhibit 1).[4] Similarly, Engineering and Technology remains a key focus of PUBERD (i.e., R&D expenditure in the government sector, A*STAR research institutes and higher education), although the share of PUBERD in Biomedical & Related Sciences has also seen a significant increase over the years. The latter reflects the government's efforts to develop the Biomedical Sciences (BMS) sector as a new engine of growth.[5] At the same time, within the higher education sector, new areas of research such as Energy have also become more prominent in recent years.[6]

Exhibit 1: R&D Expenditure by Areas of Research and Institutional Sector, 2002 and 2017



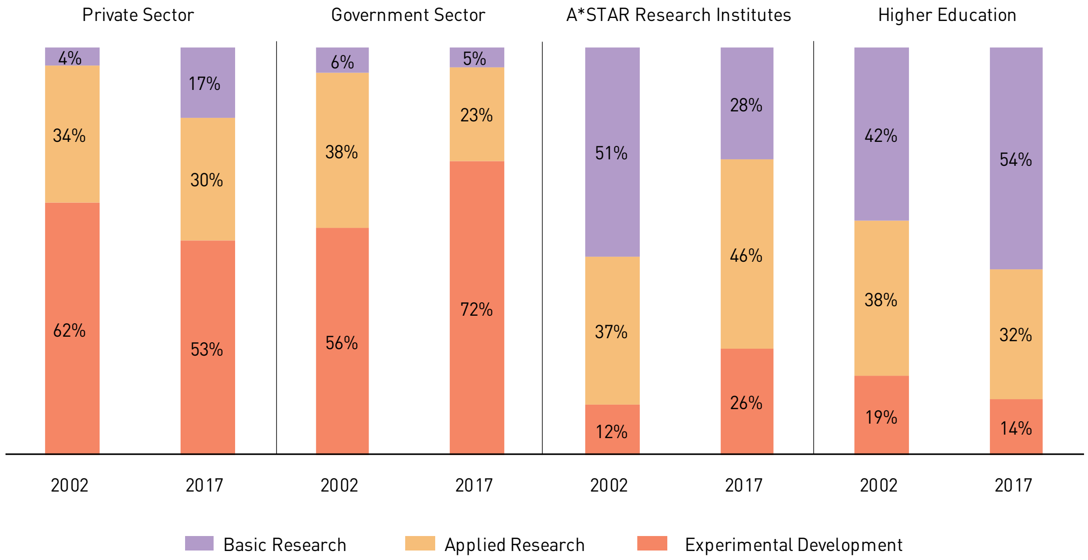
Source: A*STAR R&D Survey

Note: The "Others" category includes research which does not fall within the core areas, including research on education and supply chain management.

In terms of the strategic focus areas, R&D expenditure in the private and government sectors has mostly focused on Experimental Development and Applied Research, while that in the A*STAR research institutes and higher education sector has been more diverse (Exhibit 2). The focus of the private and government sectors on more downstream research (i.e., Experimental Development and Applied Research) is aligned with their aim to operationalise R&D.

3 *PUBERD comprises R&D spending by the universities, A*STAR research institutes and the government sector.*
4 *Data with detailed breakdown into the various segments of R&D spending is only available from 2002 onwards.*
5 *In 2000, the government launched the BMS initiative, with a budget of $1.48 billion, to create a conducive innovation ecosystem with research infrastructure and top scientists (see Thampuran & Kong, 2016; Thampuran, 2017). In the same year, the Biomedical Research Council (BMRC) was established to promote public sector R&D and nurture Singapore's talent base in the BMS sector. Reflecting the aim to grow BMS research in Singapore, new research institutes, including the Genome Institute of Singapore (first known as the Singapore Genomics Programme in 2000), the Bioinformatics Institute (2001), and the Institute of Bioengineering and Nanotechnology (2003) were formed in the initial years.*
6 *To support R&D in the energy sector, research institutes were set up in the universities, including the National University of Singapore's Solar Energy Research Institute of Singapore (SERIS) in 2008 and the Nanyang Technological University's Energy Research Institute @NTU (ERI@N) in 2010.*

Exhibit 2: R&D Expenditure by Strategic Focus Areas and Institutional Sector, 2002 and 2017

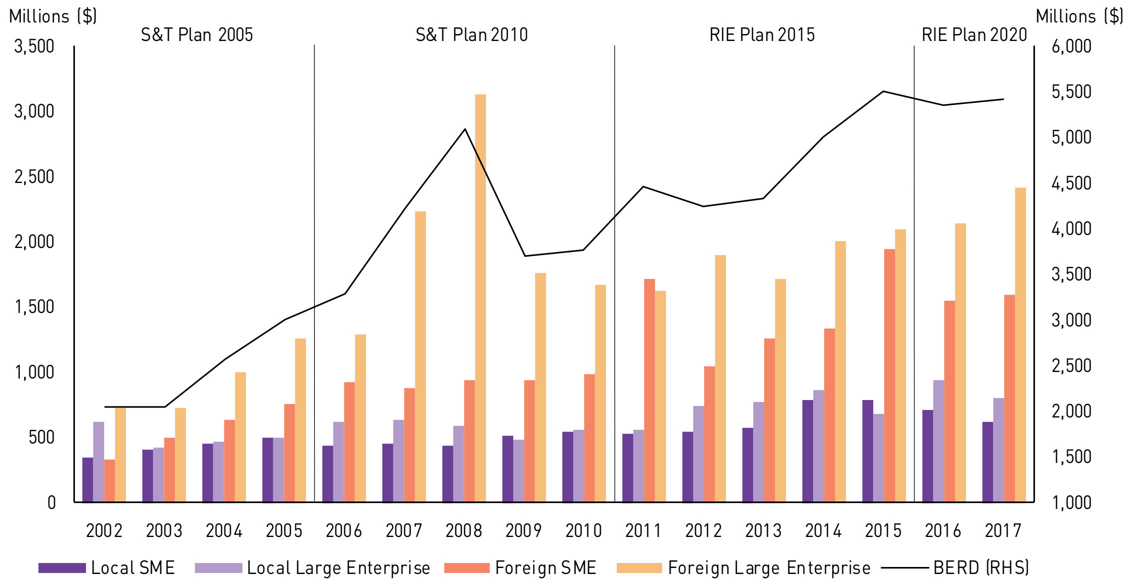


Source: A*STAR R&D Survey

Note: Basic research is defined as that which advances knowledge, or/and produces a broad base of knowledge likely to form the basis of the solution to problems. Applied research refers to original investigation directed primarily towards a specific practical objective, and aims to give operational form to ideas. Experimental development draws on knowledge gained from research to produce new or improve existing products/processes.

Focusing on R&D spending in the private sector, it can be seen that the increase in BERD over the years was supported primarily by higher R&D spending by foreign enterprises (Exhibit 3). Between 2002 and 2017, BERD for foreign small and medium-sized enterprises (SMEs) and foreign large enterprises increased by 10.9 per cent per annum and 8.3 per cent per annum respectively. While the BERD of local enterprises also rose during this period, it was at a slower pace of 3.8 per cent per annum for local SMEs and 1.6 per cent per annum for local large enterprises.

Exhibit 3: BERD by Firm Type, 2002-2017

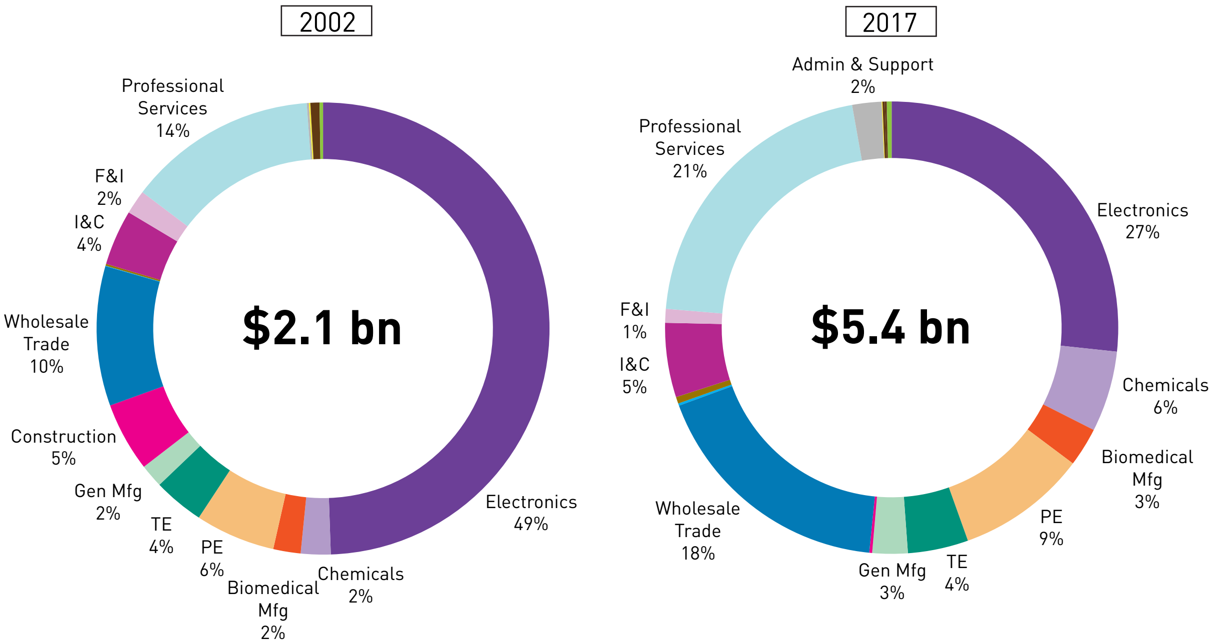


Source: A*STAR R&D Survey

Note: Exhibit 3 draws on firm-level data from A*STAR's annual R&D survey between 2002 and 2017. As such, it only captures the last four years of S&T Plan 2005 and the first two years of RIE Plan 2020.

Over time, the composition of firms' R&D spending by industry has become more diversified (Exhibit 4). In line with the strategic technology domains proposed in recent RIE Plans (e.g., Services and Digital Economy, Urban Solutions and Sustainability) (see Low, 2017), firms in selected services have contributed more to BERD over the years. Notably, between 2002 and 2017, the share of BERD increased significantly for firms in the professional services (14 per cent to 21 per cent) and wholesale trade (10 per cent to 18 per cent) sectors. By contrast, the contribution to BERD by firms in the electronics cluster fell from 49 per cent to 27 per cent over the same period.[7]

Exhibit 4: BERD by Industry, 2002 and 2017



Source: A*STAR R&D Survey

Note: The following abbreviations were used in Exhibit 4 – Finance & Insurance (F&I), Information & Communications (I&C), General Manufacturing Industries (Gen Mfg), Transport Engineering (TE), Precision Engineering (PE), and Biomedical Manufacturing (Biomedical Mfg).

3. LITERATURE REVIEW

Internationally, studies have found that R&D investments have a positive impact on firms' productivity, although the estimated returns vary across economies, industries and time periods examined. For instance, a 1 per cent increase in R&D stock was estimated to increase the productivity of UK manufacturing firms by 0.02 per cent in 1990-2000 (Griffith et al., 2006), US firms by 0.06 per cent in 1964-1990 (Hall, 1993), and German manufacturing firms by 0.09 per cent in 1979-1989 (Harhoff, 1998). More recent work estimated that a 1 per cent increase in R&D stock led to a 0.15 per cent increase in productivity on average among firms in the OECD in 2006-2007 (Kancs & Siliverstovs, 2016).

For Singapore, Fan et al. (2015) found that R&D conducted by firms had a positive and significant impact on firm-level productivity. Specifically, they estimated that a 1 per cent increase in R&D stock raised firm-level productivity by 0.13 per cent on average over the period of 2002 to 2013. In dollar terms, a $1 increase in R&D stock in a firm with a median value-added (VA) to R&D stock ratio increased productivity by $0.35. Across the S&T and RIE Plans, they found that the elasticity of productivity with respect to changes in R&D stock rose, from 0.10 per cent in 2002-2005, to 0.13 per cent in 2006-2010, and 0.15 per cent in 2011-2013.[8] The dollar impact of R&D also followed a similar trend, increasing from $0.29 in 2002-2005, to $0.37 in 2006-2010, and $0.40 in 2011-2013.

7 *In absolute levels, BERD by firms in the electronics cluster continued to increase, from $1.02 billion in 2002 to $1.45 billion in 2017 (or 2.4 per cent per annum).*

8 *Due to data availability, Fan et al.'s (2015) study only covered the last four years of S&T Plan 2005 and the first three years of RIE Plan 2015.*

4. DATA AND EMPIRICAL METHODOLOGY

To update earlier estimates of the impact of R&D on the productivity of firms that conduct R&D in Singapore, this study uses an anonymised unbalanced panel dataset compiled from A*STAR's annual National Survey of R&D over the period of 2002 to 2017. The dataset contains information on firms' R&D expenditure, profits, net fixed asset investments, employment and industry classification, among others.

Our sample for the study covers 1,724 private firms which conducted in-house R&D for at least two years during the period of analysis. Similar to the approach by Fan et al. (2015), we excluded R&D service providers (i.e., firms classified under SSIC2015 72) from the analysis as their R&D expenditure would have directly contributed to the bulk of their VA.[9]

Consistent with other firm-level studies, a Cobb-Douglas production function, augmented with R&D capital stock (which represents knowledge capital), is assumed for each firm[10]:

$$Y = AL^{\alpha}K^{\beta}S^{\gamma} \tag{1}$$

Where Y = Firm's VA
A = Efficiency parameter (proxy for technological progress)
L = Labour
K = Physical capital stock
S = R&D capital stock

A fixed effects regression is then run, based on the logarithmic form[11] of equation 1:

$$\log Y_{it} = \beta_s \log S_{it} + \beta_L \log L_{it} + \beta_k \log K_{it} + \beta_x X_{it} + c_i + \textstyle\sum_t \theta_t d_t + \varepsilon_{it} \tag{2}$$

Where Y_{it} is the VA of firm i at time t
S_{it} is the R&D stock of firm i at time t
L_{it} and K_{it} are the labour and physical capital stock[12] respectively in firm i at time t
X_{it} is a set of control variables comprising dummies for the area of research and industry, as well as interactions of year and industry dummies for firm i at time t
c_i is the fixed effects term for firm i
d_t is a dummy for year t
ε_{it} is an error term associated with firm i at time t

The regression controls for both observable (e.g., labour and physical capital stock) and time-invariant unobservable (e.g., management practices) characteristics of firms, as well as macroeconomic (e.g., economic cycles) and industry-specific (e.g., fixed asset requirements) factors that could affect VA across firms. As such, β_s , which measures the average impact of a firm's R&D stock on its VA, can also be interpreted as the average impact of the R&D stock on its productivity.[13] The dollar impact of R&D for a median firm (defined as one with a median VA to R&D stock ratio) is then estimated by multiplying β_s and the VA to R&D stock ratio of the firm.[14]

We also allow R&D to have varying effects on firm productivity across the four S&T and RIE Plans in 2002-2017:

$$\log Y_{it} = \textstyle\sum_j \beta_{sj} \log S_{it} \times \mathrm{Plan}_j + \sum_j \beta_{Lj} \log L_{it} \times \mathrm{Plan}_j + \sum_j \beta_{Kj} \log K_{it} \times \mathrm{Plan}_j + \beta_x X_{it} + c_i + \sum_t \theta_t d_t + \varepsilon_{it} \tag{3}$$

In addition to the variables defined in equation 2, Plan_j is a dummy for each S&T or RIE Plan j, where j = S&T Plan 2005 (2002-2005), S&T Plan 2010 (2006-2010), RIE Plan 2015 (2011-2015) or RIE Plan 2020 (2016-2017).[15]

9 *Firms with negative values for VA, non-R&D fixed assets and employment were excluded from the analysis.*
10 *See Annex A for the computation of the variables Y_{it}, S_{it}, L_{it} and K_{it}.*
11 *In line with the literature, we assume that the log of efficiency parameter (log A) is the sum of a firm-specific effect (c_i), a time effect (d_t) and other effects stemming from areas of research and industry.*
12 *In line with the literature, R&D employment and R&D capital stock are excluded from the computation of labour and physical capital stock to avoid double counting R&D inputs.*
13 *The impact on VA from an increase in R&D stock can be considered as the impact on multi-factor productivity as other factor inputs used in the production process (e.g., capital and labour) are already controlled for in the regression.*
14 *The dollar impact estimates are in chained 2015 dollars, with the latest GDP deflators used to deflate nominal VA.*
15 *As the analysis draws on firm-level data from A*STAR's annual R&D survey for the period of 2002-2017, it can only capture the last four years of S&T Plan 2005 and the first two years of RIE Plan 2020.*

5. RESULTS

Our findings suggest that there are positive and significant returns to firm-level productivity from conducting R&D (Exhibit 5). Specifically, we estimate that a 1 per cent increase in R&D stock raised firms' productivity by 0.135 per cent on average over the period of 2002-2017. In dollar terms, a $1 increase in R&D stock in a firm with a median VA to R&D stock ratio raised productivity by $0.24. Our elasticity estimate compares favourably with that found in other advanced economies.

Exhibit 5: Impact of R&D Stock on Firm-level Productivity

	2002-2017
β_s	0.135**
Dollar impact ($)	$0.24

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

Additionally, we find that the impact of R&D on firms' productivity increased across the four most recent S&T and RIE Plans (Exhibit 6). In particular, the estimated elasticity rose from 0.107 for S&T Plan 2005 (2002-2005), to 0.140 for S&T Plan 2010 (2006-2010), 0.144 for RIE Plan 2015 (2011-2015), and 0.168 for the first two years of RIE Plan 2020 (2016-2017). For a firm with a median VA to R&D stock ratio, the dollar impact of R&D followed a similar trend, rising from $0.20 in 2002-2005, to $0.24 in 2006-2010 and 2011-2015, and $0.28 in 2016-2017.

Exhibit 6: Impact of R&D Stock on Firm-level Productivity over the S&T and RIE Plans

	2002-2005	2006-2010	2011-2015	2016-2017
β_s	0.107***	0.140***	0.144***	0.168***
Dollar impact ($)	$0.20	$0.24	$0.24	$0.28

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

6. CONCLUSION

In summary, our study finds that R&D investments have been beneficial in improving firms' productivity. The estimated elasticity of productivity with respect to R&D stock is positive and significant, and compares favourably with that found in other advanced economies. The elasticity and dollar impact of R&D on productivity has also increased, in line with the focus on R&D with economic outcomes across the S&T and RIE Plans. In particular, the increase in government funding across the tranches, together with the growing emphasis on public-private partnerships (see Low et al., 2016), may have strengthened private firms' R&D capabilities and enabled their R&D investments to reap higher returns over time.

These findings also suggest that the government should continue to leverage R&D investments, along with other efforts under the Industry Transformation Maps, to raise the productivity of firms and industries. To encourage firms to grow their capabilities through R&D, the government has in place initiatives such as A*STAR's Growing Enterprises through Technology Upgrade (GET-Up) programme, and the Economic Development Board's Research Incentive Scheme for Companies. Firms, particularly SMEs, can also tap on laboratory facilities, technology consultancy, testing services and training courses in the Centres of Innovation to grow new innovative capabilities. Our efforts to raise the R&D and innovative capacity of our firms will be key to the transformation of our industries and Singapore's next phase of growth.

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ANNEX A: COMPUTATION OF VARIABLES

Following Fan et al. (2015), the key variables are defined as follows:

Value-added (VA) (Y_{it})
Nominal VA is the sum of net operating profit after taxes, indirect taxes, expenditure on manpower and depreciation of fixed assets. This is then deflated using GDP deflators by industry from the Department of Statistics (DOS) to obtain real VA.

R&D Stock (S_{it})
For real R&D expenditure, nominal R&D expenditure is deflated using the Gross Fixed Capital Formation (GFCF) deflator. This deflator is obtained by dividing GFCF at current market prices by GFCF in chained (2015) dollars. Both series are available from DOS.

Consistent with the academic literature, the perpetual inventory method is used to compute the R&D capital stock (S_{it}) (equations 4 and 5). We assume a deprecation rate (δ) of 15 per cent in line with the literature (e.g., Hall et al., 2010; Fan et al., 2015) and a growth rate (g) of 19 per cent. The latter is the estimated growth rate of real BERD from 1990 to 2001.

$$S_{it} = S_{it-1} \times (1-\delta) + E_{it} \tag{4}$$

Where S_{it} is the R&D capital stock for firm i at time t
δ is the depreciation rate of R&D capital stock which is assumed to be 15 per cent
E_{it} is the real R&D expenditure for firm i at time t

$$S_{it=0} = \frac{E_{it=0}}{g+\delta} \tag{5}$$

Where $S_{it=0}$ is the R&D capital stock for firm i when it first entered the dataset
$E_{it=0}$ is the real R&D expenditure for firm i when it first entered the dataset
g is the growth rate of real R&D expenditure which is assumed to be 19 per cent

Physical Capital Stock (K_{it})
Total physical capital stock is proxied using the net book value of fixed assets. This is deflated using the net capital stock deflator to obtain real total physical capital stock. The net capital stock deflator is the ratio of net capital stock at current market prices to net capital stock in chained (2015) dollars. Both series are available from DOS.

The physical capital stock (K_{it}) used in the analysis excludes the physical capital stock used for R&D purposes to avoid double counting the R&D physical capital stock.

Labour (L_{it})
Similarly, the labour stock (L_{it}) used in the analysis is total employment less R&D workers to avoid double counting R&D workers (as their remuneration is typically already captured under R&D expenditure).