Innovation activity in South Africa

Measuring the returns to R&D

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Andre Steenkamp,[1] Mark Schaffer,[2] Wayde Flowerday,[3] and John Gabriel Goddard[4]

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Abstract: Improvements in productivity are necessary to effectively increase economic growth in the long term. The literature emphasizes a positive correlation between firm-level innovation and productivity gains. It is unsurprising, then, that policy makers and researchers widely acknowledge that innovation is one of the major drivers of productivity growth, and is therefore of critical importance to the competitiveness and growth of firms. Research and development (R&D) expenditure is used extensively as a proxy for innovation in the literature. Here, we use a production function approach to estimate the return to R&D in South African manufacturing firms for the period 2009–2014 using South African firm-level data. We find that the return to R&D in South African manufacturing firms is high compared to OECD countries. This analysis has been undertaken several times for OECD countries, but far less frequently for non-OECD countries. These findings therefore are not just novel for South Africa, but for the development economics literature more generally, and raise important insights for innovation policy in South Africa.

Keywords: innovation, returns to R&D, total factor productivity, technological change
JEL classification: O30, O38, C23, C81, D24

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1 Introduction

The only way to effectively increase economic growth in the long term is through improvements in productivity. In the long run, productivity is everything: a country's ability to improve its standard of living over time depends almost entirely on its ability to raise output per worker (Krugman 1992, cited in Lin and Tang 2013). The literature emphasizes a positive correlation between firm-level innovation and productivity gains, although evidence for developing countries has been less conclusive. It is unsurprising, then, that policy makers and researchers widely acknowledge that investment in innovation is one of the major drivers of productivity growth, and is therefore of critical importance. The major finding in growth accounting literature is based on Robert Solow's (1957) famous residual, interpreted as the consequence of innovation and improvements in technology. The now-standard explanation is that technological progress is the key contributor to economic growth, whereas increases in the factors of production such as capital and labour are not as important for growth (Kortum 2008). Based on this premise, evidence on the sources of technological change and channels of innovation are important for informing policy that can assist firms to engage more actively in innovation processes. This matters because firms that introduce business and technology innovations can achieve greater productivity through various channels, including: improved operations, new and higher value-added products and services, entry into new markets, and better use of existing capacity and resources. These innovations are then diffused across sectors as competitors copy best practice, which raises the overall productivity of the economy.

According to Lin and Tang (2013), innovation is essential to transition towards higher value-added economic activity and achieve sustained growth; and investment in research and development (R&D) is key to innovation. This paper aims to enhance our understanding of the dynamics of innovation practice and technology absorption in South Africa at the firm level by estimating the returns to R&D expenditure in the manufacturing sector. This research is novel in that it is one of the first papers to measure the returns to R&D using firm-level data in a developing country. This is done by: (1) estimating the intensity of R&D expenditure across South African manufacturing firms; (2) estimating the elasticity of R&D expenditure with respect to output using a production function approach; and (3) combining these two estimates to derive the estimated return to R&D expenditure in the South African manufacturing sector from 2009 to 2014. This kind of analysis has been done many times for Organisation for Economic Co-operation and Development (OECD) countries, but far less frequently for developing countries, due in part to the lack of accessible firm-level data. Therefore our results are novel not just for South Africa but for the development economics literature more broadly. One reason for such interest in this topic is that R&D investment is important for improving the productivity and competitiveness of firms and the macro-economy. R&D can increase productivity by improving the quality or reducing the average production costs of existing goods or simply by widening the spectrum of final goods or intermediate inputs available (Hall et al. 2009). Second, investment in R&D and innovation more broadly is generally expensive and diverts resources away from other areas that may offer better short-run gains or profitability. Any investment in R&D and other innovation activities requires a long-term view of improving productivity for movement closer towards the productivity frontier at both a firm and economy-wide level.

Our empirical strategy for estimating the returns to R&D in South Africa is essentially comparative. We obtain estimates of R&D intensity and elasticity that we can compare to those obtained in previous studies, largely relating to firms in OECD countries. In summary, we find that: (1) R&D intensity, as measured by the R&D expenditure to sales ratio, in South African manufacturing firms is considerably lower than that observed in studies from other countries; (2) the elasticity of output with respect to R&D is within the range observed in previous studies; and (3) as a simple matter of arithmetic, items (1) and (2) imply that the estimated return to R&D in South Africa is high compared to that found in other countries.[1] Intuitively this makes sense, given the low prevalence, persistence, and intensity of R&D expenditure among South African manufacturing firms. These findings are not out of line with international experience, which shows that developing countries generally invest much less in R&D as a share of gross domestic product (GDP) than developed countries. In addition, Schumpeterian economists argue that countries further away from the technological frontier should have higher rates of return, given the strong potential gains from technological catch-up.

The rest of the paper is structured as follows. In Section 2, we draw on the literature discussing the role of technological change and survey studies which estimate the return to R&D. In Section 3, we discuss the data that are used in the analysis and definitions of the main variables. We outline our approach to estimating the return to R&D in Section 4, which is followed by a descriptive summary of the data. Section 6 discusses the intensity of R&D expenditure in South Africa. Results from the econometric analysis are presented and discussed in Section 7, followed by concluding remarks in Section 8.

2 Literature review

2.1 The role of technological change in generating growth at the technological frontier

The role of technological change in generating growth at the technological frontier is of paramount importance in the context of the global economy, which is becoming increasingly digitized and globalized. Whether or not it can generate catch-up growth in countries that are industrializing and not (yet) at the technological frontier is an important consideration for policy makers, especially in light of the global productivity slowdown over the past 10–15 years. There has been much debate on the determinants of the global productivity slowdown during the 2000s, and the role of technological change has been central in the discussion. According to Andrews et al. (2016),[2] a striking feature of the global productivity slowdown is not so much lower productivity growth at the global frontier, but rather rising labour productivity at the global frontier coupled with increasing labour productivity divergence between the global frontier and laggard or 'non-frontier' firms. Further, the productivity divergence remains after controlling for differences in capital deepening and mark-up behaviour, which suggests that divergence in measured total factor productivity (TFP) may in fact reflect technological divergence in a broad sense—namely digitalization, globalization, and the rising importance of tacit knowledge driving productivity gains at the global frontier. Andrews et al. (2016) suggest that increasing TFP divergence could reflect a slowdown in the diffusion process due to increasing costs for laggard firms of moving from an economy based on production to one based on ideas. The results suggest that structural changes in the global economy, such as digitalization and globalization, could have contributed to the slowdown in diffusion via two channels: 'winner takes all' dynamics, whereby technological leaders take advantage of digitalization and globalization to capture rising shares of the global market, and to stalling technological diffusion, due to increasing difficulties experienced by laggard firms in catching up with the leaders.

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[1] Since the return to R&D is the elasticity times the inverse of the R&D intensity ratio.

[2] See www.oecd.org/global-forum-productivity/events/GP_Slowdown_Technology_Divergence_and_Public_Policy_Final_after_conference_26_July.pdf.

Despite recent evidence of laggard firms in developing countries finding it increasingly difficult to 'catch up' to the global frontier, there are several historical examples in which catch-up growth has occurred in different countries and at different periods in history. Innovation and R&D played an important role in enabling these countries to transition over time from less-developed countries, lagging behind the global frontier, into industrial and technology leaders at the global frontier. For example, from around 1880 to 1910, both the United States and Germany 'caught-up' to Great Britain, which was at the frontier of industrial and technological development at the time. Great Britain had led the first Industrial Revolution from 1750 to 1850 and was considered to be at the frontier of technological development, before being overtaken by the United States and Germany in the late nineteenth and early twentieth centuries. The United States once again pushed the technology frontier from 1945 to 1990. These transition periods, in which countries graduate to the frontier, often reflect (among other things) change in the sources of innovative leadership. By the late nineteenth century, the development of national institutions that supported the institutionalization of R&D contributed to the catch-up growth experienced in the United States and Germany.

Around 1870, Germany was primarily a rural-based economy, and most workers were engaged in agriculture-related industry. Through the late nineteenth and early twentieth centuries, Germany underwent rapid industrialization that propelled it to the technological frontier. Key to this transition was the establishment of technical training institutes and the importation of British technology (i.e. machine tool technology) that was used for reverse engineering and training of German craftsman, who then disseminated the technology in German industry (Freeman 1995). The transfer of technology was highly successful and set Germany up well to overtake Great Britain. However, the major institutional innovation that propelled Germany ahead was the establishment of the in-house industrial R&D department.[3] During the latter part of the nineteenth century and the first half of the twentieth century, specialized R&D laboratories became common features of most large firms in the manufacturing industries (Freeman 1995). Many aspects of Germany's current innovation system have their origins in the nineteenth and twentieth centuries, such as its apprenticeship schemes and universities, research institutes, and large and innovative industrial companies (e.g., BASF, Daimler AG, Sanofi-Aventis Deutschland, Siemens). Germany developed one of the best technical education and training systems in the world, which many argue was one of the main factors in Germany overtaking Great Britain in the latter half of the nineteenth century, and the foundation for the superior skills and higher productivity of the German labour force in the twentieth century (Freeman 1995).

In the global east, Japan, followed by South Korea, achieved extraordinary success in technological and economic catch-up in the twentieth century. Initially, Japan's success was attributed to high levels of copying, imitating, and importing of foreign technology, which was reflected in Japan's high deficit in transactions for licensing and know-how imports during the 1950s and 1960s (Freeman 1995). However, this explanation became insufficient when Japanese products and processes started to out-perform American and European products and processes in more and more industries, even though the import of technology remained an important source of advancement. Japan's later success was explained more in terms of R&D intensity, especially as Japanese R&D was highly concentrated in the fastest-growing industries, such as electronics (Freeman 1995).[4] Leading Japanese electronics firms surpassed American and European firms not

[3] First introduced in 1870 by the German dyestuffs industry, which first realized that it could be profitable to put the business of research for new products and development of new chemical processes on a regular, systematic, and professional basis (Freeman, 1995).

[4] In the 1970s, Japanese R&D expenditures as a proportion of industrial net output surpassed those of the United States in the 1970s and total civil R&D as a share of GNP surpassed the United States in the 1980s (Freeman, 1995).

just in domestic patenting, but in patents taken out in the United States. Japan's national innovation system during the 1970s and 1980s was characterized by quantitative and qualitative factors, including: a high GERD/GNP[5] ratio of 2.5 per cent, with a very low proportion in military/space R&D; a high proportion of total R&D expenditure concentrated at the enterprise level and company-financed (approximately 67 per cent); strong integration of R&D, production, and importation of technology at the enterprise level; strong incentives to innovate at the enterprise level, involving both management and workforce; and intensive experience of competition in international markets (Freeman 1995). Many argue that the strongest feature of Japan's system of innovation that contributed to rapid development was the integration of R&D, production, and technology imports at the firm level (Baba 1985; Freeman 1987; Takeuchi and Nonaka 1986).

In the 1980s, both Brazil and South Korea were considered 'newly industrializing countries'. Over this period, GNP in the East Asian countries grew at an average annual rate of around 8 per cent, but in many Latin American countries, including Brazil, this fell to less than 2 per cent (Freeman 1995). In the case of Brazil and South Korea, some key contrasting features emerged, which explain in part the deviation in the trajectory of growth. In South Korea, R&D as a percentage of GNP was 2.1 per cent in 1989 compared to Brazil's 0.7 per cent in 1987. The share of industry or enterprise R&D was also considerably higher in South Korea, 65 per cent of total R&D in 1987, compared to only 30 per cent in Brazil in 1988 (Freeman 1995). In addition, South Korea developed a significantly better education system, more accessible telecommunication infrastructure, and was able to diffuse new technologies more robustly. Many studies have shown that technology diffusion at a broad level has positive impacts on productivity in industry and has been shown to be as important as R&D investments for innovative performance in many cases (OECD 1997). For example, technology diffusion was found to have had a greater impact on productivity growth in Japan than direct R&D expenditures in the period 1970–1993 (OECD 1997). The intense use of advanced machinery and equipment in production contributed even more to the improvement of the technology intensity of Japan's economy than did research spending (OECD 1996, cited in OECD 1997). Technology diffusion has played a crucial role in the development of these economies, and is an important accompaniment to direct R&D expenditure in the overall national innovation system. Emerging trends that suggest that technology diffusion is becoming increasingly difficult in the global economy are of concern for countries that lag behind the global frontier, given the important role it has played in the growth and development of economies that are today at or near the technology frontier.

2.2 South Africa's low ratio of R&D expenditure to GDP and weak productivity growth

Innovation is inherently difficult to measure at both the firm and macro level, given the various inputs and processes that contribute to its output. These inputs are very often intangible in nature and as a result difficult to measure and report for tax purposes. Innovation should be analysed using a wide lens, although a detailed analysis of certain components of the innovation process, such as R&D expenditure, is important as it is critical for new-to-the-world innovation, but also for building absorptive capacity in companies. Expenditure on R&D is used extensively as a proxy for innovation in the literature. R&D is required to foster innovation across various spheres of the economy, by improving the capability for developing new products and processes and improving existing ones. This is crucial for improving competitiveness and growth. The *Frascati Manual* (OECD 2015) defines research and experimental development as:

[5] Gross domestic expenditure on R&D/gross national product.

> Research and experimental development (R&D) comprise creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge.

Furthermore, for an activity to be classified as R&D it must satisfy five core criteria, which are to be met, at least in principle, every time an R&D activity is undertaken, whether on a continuous or occasional basis. The activity must be: novel, creative, uncertain, systematic, and transferable and/or reproducible (OECD 2015).

Figure 1 illustrates the positive relationship between a country's level of economic development (proxied by GDP per capita) and the intensity of innovation (proxied by R&D expenditure as a share of GDP). In general, countries that are more developed have a higher national R&D intensity compared to less-developed countries. Zimmermann (2015) argues that countries that have substantially expanded their R&D activities often achieve higher GDP growth, as is the case for South Korea, Finland, Spain, and Austria. An increase of 1 percentage point in the rate of R&D growth leads to a rise in GDP growth of around 0.05–0.15 percentage points in the subsequent year (Zimmermann 2015). However, the relationship between R&D and economic development is complex because of causality issues. Doing more R&D can assist a country in becoming richer over time, but if a country has already exploited catch-up growth, then it is natural for such a country to be doing original R&D since that country is already at the frontier. Over the period 2000–2014, several advanced economies increased their share of R&D expenditure to GDP quite markedly: Germany increased from 2.4 to 2.9 per cent; Japan increased from 3.0 to 3.6 per cent; South Korea increased from 2.2 to 4.3 per cent; Australia increased from 1.5 to 2.2 per cent; Belgium increased from 1.9 to 2.5 per cent; and Denmark increased from 2.3 to 3.1 per cent (World Bank Development Indicators 2017). Several developing countries also increased their share of R&D expenditure to GDP over the same period: Mexico's share increased from 0.3 per cent to 0.5 per cent in 2014; Turkey increased from 0.5 to 1 per cent; both Turkey and Russia increased their shares from 1 to 1.2 per cent over the same period. In 2014, China had a relatively high share of R&D expenditure to GDP at 2 per cent, even though its GDP per capita was one of the lowest among the group of comparison countries in Figure 1. Among its BRICS[6] peers, China had the highest R&D intensity in 2014, having increased its share of R&D expenditure to GDP from 0.9 per cent in 2000 to 2 per cent in 2014. In comparison, by 2015, India's share of R&D expenditure to GDP was only 0.6 per cent (2000: 0.7 per cent).

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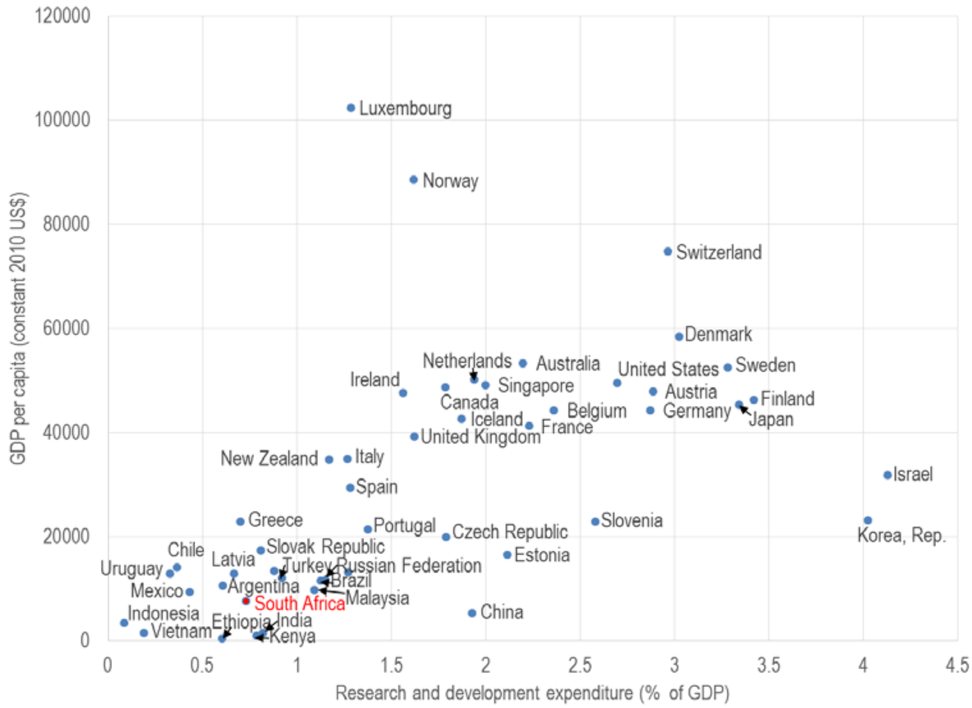
[6] BRICS is the acronym for an association of five major emerging national economies: Brazil, Russia, India, China, and South Africa.

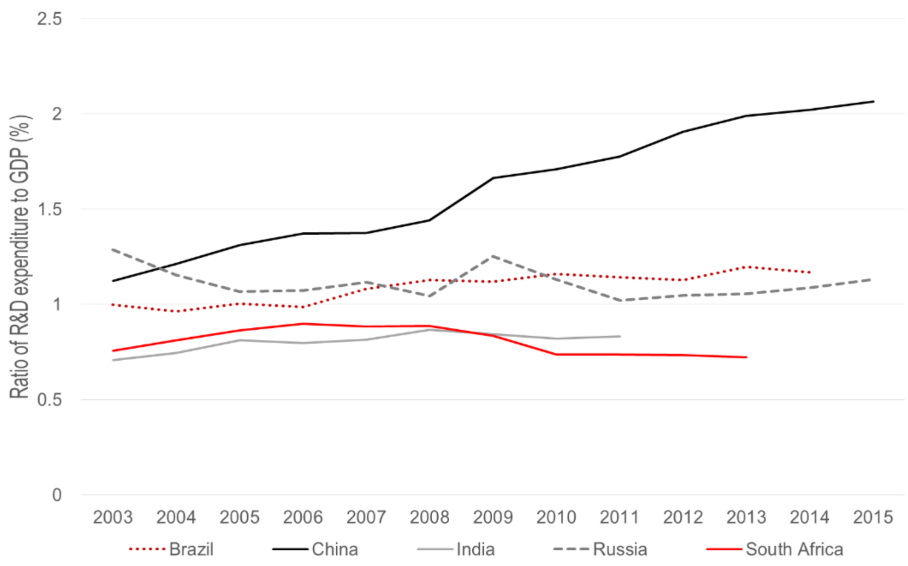
Figure 1: National R&D intensity versus GDP per capita in 2012



Source: World Development Indicators, 2017.

In South Africa, R&D expenditure relative to GDP declined marginally over the period 2004–2012 (Figure 2). The ratio of R&D expenditure to GDP in South Africa—0.72 per cent in 2013—was the lowest among the BRICS countries (e.g., China 1.99 per cent; Brazil 1.19 per cent; Russia 1.06 per cent). The Human Sciences Research Council (HSRC) estimated that South Africa spent 0.73 per cent of its GDP on R&D in 2013/2014 according to its R&D survey, which compares unfavourably to an OECD average of 2.4 per cent.

Figure 2: R&D expenditure as a percentage of GDP



Source: World Development Indicators, 2017.

Most OECD countries are operating at the world technological frontier, where scope for rapid growth through technology diffusion and catching up is mostly gone. On the contrary, South Africa should be growing faster than the OECD area and more in line with its emerging market peers as it industrializes and grows, in part through adopting world-best technology. South Africa, however, is caught in a cycle of declining TFP growth and stagnant GDP growth, at around 1 per cent. TFP growth in its broadest sense is really technological change. While it is argued to be an imperfect measure of innovation activity, it is a useful measure to ascertain an estimate of the level of investment in innovation. When looking at trends in TFP growth over the period 1990–2015, South Africa mostly lagged behind its BRICS peers, and since 2010 even experienced a contraction in TFP growth. A lack of diversification of South Africa's export basket over the period 1994–2015 also suggests that product innovation is weak. As a result, South Africa would appear to be lagging in technological progress relative to its emerging market peers. This is further reflected by the low share of high-technology exports as a percentage of manufactured exports compared to BRICS peers.

The number of trade patents is also lower than in the other BRICS countries. The exception is the mining and fuels subsectors, which have patents and R&D comparable to South Africa's competitors—the United States, Canada, and Australia. Fostering innovation depends on effective intellectual property (IP) rights protection, as it is difficult to have innovation without the protection of ideas. In the 2016/2017 Global Competitiveness Report, South Africa ranked 21st out of 138 countries for IP rights protection, which suggests that a sound legislative framework to support investment in innovation is in place. This raises the question as to why R&D activity is so low compared to South Africa's peers. Given the importance of R&D for raising productivity and competitiveness in the long run, remaining stuck at a low level of R&D and broader innovation activity is undesirable.

The role of innovation at the firm level is critical to achieving the government's policy goals of reindustrializing the economy and expanding exports to achieve higher economic growth, lowering South Africa's unemployment rate, and reducing inequality by raising average living standards. The South African government recognizes the important role that the innovation process can play in achieving these goals, and as a result introduced, among other measures, the R&D Tax Incentive in November 2006 to encourage firms to undertake R&D. South Africa is one of several countries that use a tax-based incentive to stimulate private-sector R&D. The use of R&D tax incentives has gained popularity globally. As of 2016, 29 of the 35 OECD countries, 22 of the 28 European Union countries, and a number of non-OECD economies provide tax relief on R&D expenditures (OECD 2017). Several advanced economies also used their R&D incentives as part of their response to the global economic crisis, evidenced by specific adjustments introduced between 2009 and 2011 to counter reduced private-sector R&D, and R&D that was migrating to emerging economies.

The Department of Science and Technology (DST) administers the Research and Development (R&D) Tax Incentive Programme under section 11D of the Income Tax Act, 1962 (Act No. 58 of 1962), in order to promote private-sector investment in scientific or technological R&D. It shares responsibilities for the delivery of the incentive with the South African Revenue Service (SARS) and the National Treasury. The incentive offers, among other benefits, a 150 per cent tax deduction for approved R&D expenditure and can be accessed by companies of all sizes across all sectors of the economy. From 1 October 2012, the procedure for administrating the R&D Tax Incentive changed from a retrospective to pre-approval procedure, which, based on anecdotal evidence, has resulted in application backlogs, increased application complexity, and a general need to simplify the administrative process. The incentive is part of a package of policy instruments to promote R&D and innovation in the country, which the DST supports and oversees, including the following:

- The Council for Scientific and Industrial Research (CSIR) is responsible for R&D in areas including health, energy, advanced manufacturing, and mining. Its mining research and technology development programme aims to improve the competitiveness of local mining equipment manufacturing firms. It assists them to develop products required for narrow reef, hard rock mining and to develop technological solutions that will increase safety and productivity, reduce costs, and ultimately extend the working lives of mines.
- The Technology Innovation Agency (TIA) funds strategic technological innovation, emerging technologies, and knowledge innovation products with the aim of commercializing them.
- The Technology for Human Resources in Industry Programme (THRIP) fosters R&D collaboration between private-sector companies and universities and science councils.
- The construction of MeerKAT, precursor to the Square Kilometre Array (SKA), has led to job creation and diversification of the economy in the Northern Cape through DST's technology localization strategy, which requires 75 per cent local content in construction. SKA is the department's main infrastructure project and key contributor to current and future R&D.
- The Support Programme for Industrial Innovation (SPII) aims to promote technology development in South African industry through provision of financial assistance for the development of innovative products or processes.

Despite these efforts, South Africa needs to significantly increase investment and growth in R&D and broaden innovation activity. The minister of science and technology recently announced a new R&D expenditure target of 1.5 per cent of GDP by 2019, more than double the current spend.

2.3 Estimating the returns to R&D using firm-level data

There is a rich literature on measuring the contribution of R&D to TFP growth across a range of model specifications and estimation methods, which Hall et al. (2009) summarize, and from which we largely draw. The predominant approach that economists have taken to measure the return to firms' investment in R&D econometrically is the familiar growth accounting framework, adapted with various measures of R&D investment or capital at various levels of aggregation (Hall et al. 2009). According to Peters et al. (2013), this work has been built for decades around the knowledge-production function developed by Griliches (1979). In this framework, firm investment in R&D creates a stock of knowledge within the firm that enters into the firm's production function as an additional input along with physical capital, labour, and materials (Peters et al. 2013). The marginal product of this knowledge input provides a measure of the return to the firm's investment in R&D and has been the focus of the empirical innovation literature (Peters et al. 2013). To attain an estimate of the rate of return to R&D capital using the approach we take, it is necessary to estimate the intensity of R&D and the elasticity of output with respect to R&D capital.

The R&D intensity ratio is defined as the ratio of R&D capital to sales or revenue. In Mairesse and Hall (1996), the R&D intensity ratio for a sample of 1,232 French manufacturing firms in 1985 was 2.26 per cent, representing 56 per cent of industrial R&D recorded in that year. The highest ratios were in aircraft and other transport (9.41 per cent), electronics, computers, and instruments (6.04 per cent), pharmaceuticals (2.92 per cent), rubber and plastics (2.69 per cent), and electrical machinery (2.24 per cent). The lowest were in paper and printing (0.49 per cent) and primary metals (0.5 per cent). In that same year, the R&D to sales ratio for a sample of 1,073 manufacturing firms in the United States, representing about 67 per cent of industrial R&D, was 2.93 per cent. The highest ratios were recorded in electronics, computers, and instruments (7.06 per cent), pharmaceuticals (5.56 per cent), chemicals (3.73 per cent), and aircraft and other transport (3.6 per cent). The lowest were in food (0.95 per cent), textiles and leather (0.9 per cent), and primary metals (1.12 per cent). In a study by Canada's Department of Finance in 2005, it was found that the R&D intensity ratio in the Canadian economy in 1999 was around 2 per cent, 2.5 per cent in the manufacturing sector, and 1.6 per cent in the services sector (Iorwerth 2005). Within the manufacturing sector in 1999, telecommunications equipment, pharmaceutical and medicine, and other electronic equipment had the highest R&D intensity ratios of approximately 19, 13.5, and 13 per cent respectively. According to Statistics Sweden (2017), the average R&D intensity ratio across all industries in 2015 was 1.5 per cent (excluding financial enterprises), and 2.6 per cent for goods producing enterprises (closely related to manufacturing). For service-producing enterprises, this ratio was lower, at 0.8 per cent in 2015. Lin and Tang (2013) found that in 2007, the average R&D intensity ratio for Chinese manufacturing firms was less than 0.2 per cent; only two industries in the electronics sector had an R&D intensity over 1 per cent. However, this would have increased in recent years as the overall Chinese economy had an R&D expenditure to GDP ratio of approximately 2 per cent in 2015.

The elasticity of output with respect to R&D measures the responsiveness of output to a change in the level of R&D capital used in production after controlling for other production inputs (i.e. capital and labour). Studies that follow a production function approach to measuring R&D elasticity typically show estimates ranging from 0.01 to 0.25, and averaging around 0.08 (Hall et al. 2009). The return to R&D is the marginal product of R&D capital (ϱ), which measures the change in output resulting from an incremental increase in R&D capital. Estimates for the rate of return to R&D are mostly based on multiplying the estimated R&D elasticity by the average output to R&D capital ratio in the sample (Hall et al. 2009). Studies in developed economies have shown that the rate of return to R&D can be as high as 75 per cent, although it is more likely to be in the 20–30 per cent range (Hall et al. 2009). These results will be discussed in more detail in the next section.

Modelling setup, approaches

Model specifications are usually approximated by a Cobb–Douglas production function in the three inputs of fixed capital stock *C*, labour *L*, and knowledge capital *K*:

$$Y_{it} = A_{it} L_{it}^{\alpha} C_{it}^{\beta} K_{it}^{\gamma} e^{\varepsilon_{it}} \tag{1}$$

When applied to firm-level data, this framework relates output of a firm to either its stock of knowledge capital and/or investment in R&D. Under this theoretical framework, two major approaches have been followed: the primal approach and the dual approach.[7] In addition, Hall et al. (2009) point out that the market value or Tobin's q methodology is an important alternative approach taken in the literature, which relates the current financial value of a firm to its underlying assets, including knowledge or R&D assets. In some studies, additional information is added into the model such as producer behaviour and market structure to allow for scale economies, mark-up pricing in the presence of imperfect competition, and intertemporal R&D investment decisions (Hall et al. 2009).

There are numerous measurement issues raised in econometric studies of R&D and productivity. A key area of concern is how to separate out the R&D effect from other explanatory factors of

[7] The primal approach estimates a production function with quantities such as labour and capital as inputs. The dual approach estimates a system of factor demand equations derived from a cost function representation of technology (Hall et al., 2009). This approach assumes some kind of optimizing behaviour, such as profit maximization or cost minimization, and then makes use of the theorems of duality to derive factor demand and/or output supply equations.

productivity. Most studies measure output either by value added, sales, or gross output, each of which has advantages over the other. Cunéo and Mairesse (1984) and Mairesse and Hall (1994) find that the estimates of R&D elasticities do not differ substantially when using either value added or sales (excluding materials/cost of goods sold) as the dependent variable. Griliches and Mairesse (1984) find that when omitting materials as an input from an estimation where sales is the dependent variable, an upward bias in the R&D elasticity is likely because materials are correlated with R&D. The bias is more predictable in the cross-sectional dimension because the proportionality of materials to output is likely to hold, and is roughly equal to the estimated R&D elasticity multiplied by materials share in output (Hall et al. 2009).

According to Hall et al. (2009), three issues particularly relevant to R&D arise when attempting to correctly measure the elasticity of inputs in productivity analysis: (1) the R&D double-counting and expensing bias in the estimated returns to R&D; (2) the sensitivity of these estimates to corrections for quality differences in labour and capital; and (3) the sensitivity with respect to variations in capital utilization. The double-counting problem is that input factors such as labour, capital, and material costs are used in R&D activities, and hence R&D expenditures may be counted twice. A number of studies attempt to measure this bias and make adjustments to ensure that input factors such as labour and capital are cleared of their R&D components (Cunéo and Mairesse 1984; Hall and Mairesse 1995; Mairesse and Hall 1994; Schankerman 1981). Some of these studies find that there is a substantial downward bias in the R&D elasticity when the adjustments to the inputs for R&D are not corrected for in both the cross and time or within-firm dimensions. Some studies incorporate quality differences in labour and capital into the production function. Mairesse and Cunéo (1985), Mairesse and Sassenou (1989), and Crépon and Mairesse (1993) obtain lower R&D elasticities when different kinds of labour, corresponding to different levels of educational qualifications, are introduced separately into the production function. Hall et al. (2009) argue that even through first differencing controls for permanent differences across firms, it leaves too much cyclical noise and measurement error in the data, and therefore the within-firm rates of return to R&D are difficult to estimate. Some studies use long-differencing to remove part of this cyclical variation. Hall and Mairesse (1995) report more significant R&D elasticities (but not rates of return) using long differences rather than first-differenced data.

Recent developments in this literature break away from the familiar knowledge-production function approach to measuring the private returns from R&D investment. Peters et al. (2013) develop and estimate a dynamic, structural model of German manufacturing firms' decisions to invest in R&D and quantify the cost and long-run benefit of this investment. The dynamic model incorporates and quantifies linkages between the firm's R&D investment, product and process innovations, and future productivity and profits (Peters et al. 2013). Ski and Jaumandreu (2013) extend the traditional knowledge capital model of Griliches (1979) by developing a model of endogenous productivity change to examine the impact of investment in knowledge on the productivity of firms.

An additional source of bias to estimates of the elasticity and returns to R&D are other factors that contribute to technical progress, such as returns to scale and technical change not directly as a result of R&D. Hall et al. (2009) remark that controlling for time-invariant firm effects, the elasticities and rates of return to R&D tend to be higher when constant returns to scale is imposed or when factor elasticities are replaced by observed factor shares (see Cunéo and Mairesse 1984; Griliches 1986; Griliches and Mairesse 1984, 1990; Hall and Mairesse 1995). In addition, it is argued that it is preferable to include time dummies when doing analysis at the firm level to account for variations across time that may have little relationship to the R&D–productivity relationship, such as macro-economic conditions, errors in deflators, or other economy-wide measurement errors. Sector-specific dummy variables can also be incorporated to account for firm-specific variations in management or technological opportunity conditions.

Of further concern is that it is unlikely that R&D investment or expenditure becomes productive immediately. It is very likely that there are lags of varying numbers of periods for R&D investments to materialize into TFP growth. Various studies in the literature apply alternative lag distributions, with most finding that the effect of R&D on growth begins on average in the second to third year after the initial R&D input investment year and continues for several years after, with increasing influence (Geroski 1989; Leonard 1971; Mansfield et al. 1971; Pakes and Schankerman 1984; Ravenscraft and Scherer 1982; Seldon 1987).

The definition of the sample from which to infer estimates could be susceptible to selection bias if only R&D-performing firms are included in the sample. Several studies look at both R&D- and non-R&D-performing firms and find that the rate of return is not fundamentally different for the firms with and without R&D (Crépon and Mairesse 1993; Mairesse and Cunéo 1985; Mairesse and Sassenou 1989). However, Klette (1994) reports that non-R&D-performing firms have a lower productivity performance. Hall and Mairesse (1995) apply several measures to remove extreme outliers from the sample to clear abnormally high or low observations from their sample of US and French manufacturing firms. Hall et al. (2009) point out that in certain studies, the estimates can be very sensitive to the removal of outliers.

Finally, simultaneity bias is possible in the estimate of the elasticity or rate of return to R&D from a production function depending on the choice of output and inputs. Some studies use reduced form specification estimates, as in Griliches and Mairesse (1984) and Hall and Mairesse (1995), to deal with this bias. Others use instrumental variables or generalized method of moments (GMM) techniques (Bond et al. 2003; Griffith et al. 2006; Hall and Mairesse 1995; Klette 1994). Some studies use beginning-of-period instead of end-of-period R&D capital stock to account for potential simultaneity bias. Hall et al. (2009) indicate that both Griliches and Mairesse (1984) and Mairesse and Hall (1994) find higher R&D elasticities with end-of-period than with beginning-of-period R&D stocks (especially in the within-firm dimension), because of the feedback from sales to current levels of investment.

3 Data and variables

We use the SARS and National Treasury Firm-Level Panel (herein referred to as SARS-NT panel), which is an unbalanced panel dataset of administrative tax data from 2008 to 2016 at the time of the analysis. The SARS-NT dataset allows for the first economy-wide investigation into the dynamics of innovation in South Africa and the factors that affect firm-level decisions, and will allow us to test the contribution of R&D expenditure to productivity growth as well as its intensity and persistence over time in a more rigorous way than has been possible up to now. The analysis provides a useful contribution to the literature from a developing country perspective, as most previous studies focus on advanced or OECD countries.

The panel was created by merging four sources of administrative tax data received in 2015, which are: (1) company income tax from registered firms who submit tax forms; (2) employee data from employee income tax certificates submitted by employers; (3) value-added tax data from registered firms; and (4) customs records from traders (Pieterse et al. 2016). These data constitute a significant and unique source for the study of firm-level behaviour in post-apartheid South Africa, as it is at the level of firms and individuals. The integrated dataset thus can be used to provide a comprehensive, disaggregated picture of the economy over time. Detailed firm-level analysis has not been adequately explored from a South African policy research perspective due in part to data unavailability in addition to data quality concerns. For our purposes we make use of the company income tax records which contain firm characteristics, including financial information from their income statements and balance sheets and tax information. In addition, we draw from the employee records from individual IRP5 and IT3a forms which contain employee-related information such as incomes, taxes, and payments made by the firm (Pieterse et al. 2016). For the purposes of this paper, we make particular use of recorded R&D expenditure, found in the income statements of firms over the period 2009–2014.

The definition of the R&D expenditure variable is comparable to the guidelines in the OECD (2015) *Frascati Manual*, which is also the definition used in much of the literature. In short, firms are required to report any expenses on scientific or technological R&D for (1) the discovery of non-obvious information of a scientific and technological nature; and (2) the creation of any inventions, any design, or computer program of knowledge (South African Revenue Service 2013).

There are several caveats to be noted when using these data. (1) When restricting the number of firms that record both positive turnover and employment (have pay-as-you-earn (PAYE) records), which differ each year, there are roughly 200,000–250,000 firms each year (out of a total of 600,000–650,000 firms registered each year). These numbers exclude body corporates, and about two-thirds of 'firms' registered for tax purposes—which have no turnover or other income source. (2) The definition of a 'firm' is merely that of an entity registered for tax purposes—a company/group might have many 'firms' registered, depending on how they structure their business. Some of these registrations with no turnover are due to poorly filled out data, or because they are used for other tax purposes (e.g., complex group structures, shell companies where firms defray expenditure, registered entities specifically set up to hold assets and not be associated with the profit and loss account of the other companies in the group, or be liable to be attached for legal purposes). (3) Employment numbers refer to 'formally' employed individuals, where companies fill out employee details, but are not far off official Statistics South Africa Quarterly Employment Survey estimates. (4) The panel is short, with many missing observations in the time series, which renders it difficult or even impossible to create a cumulative time series for certain variables in the dataset. We restrict the period of analysis from 2009 to 2014 due to insufficient data being available in 2008, 2015, and 2016 at the time of analysis.

The variables we use are defined similarly to Hall and Mairesse (1995) and Mairesse and Hall (1996), but adjusted where necessary according to limitations in the SARS-NT panel dataset. We use: gross sales; end-year book value of fixed capital (which includes property, plant, and equipment); employment from the individual IRP5 returns certificates; R&D expenditure; materials (defined as the cost of goods sold); and value added (calculated as gross sales less the cost of goods sold). We use these variables to calculate R&D intensity, measured as the ratio of R&D expenditure to gross sales in percentage terms. We generate the logs of these variables for our productivity analysis. In addition, we compute these ratios using a one-year lag on sales and value added, as per Hall and Mairesse (1995).

None of the variables are deflated. This is not a significant oversight as inflation was relatively low over the period 2009–2014 (about 5 per cent per annum) and the time dummy variables capture this variability in part. It may be worthwhile to deflate output by an output deflator, fixed capital by an overall investment deflator, and R&D expenditure by a manufacturing sector-level value-added deflator, as done by Hall and Mairesse (1995).

4 Methodology

We use a production function approach to estimate the returns to R&D, a theoretical framework which is by far the predominant approach to estimating the return to R&D econometrically in the literature. This framework essentially relates the residual growth factor in production that is not accounted for by the usual factor inputs (i.e. labour, capital, intermediate inputs) to R&D that produces technical change (Hall et al. 2009). We follow this standard theoretical framework primarily for the purpose of comparing our results to the literature surveyed by Hall et al. (2009), which is summarized briefly in the previous section. Many of the data and model specification issues that we encounter using a production function approach are not dissimilar to those encountered in the papers that use this standard model set-up surveyed by Hall et al. (2009). We are therefore able to compare our results to the literature more closely than if we had used an alternative approach. For the same reason of comparability, we follow Hall and Mairesse (1995) and Mairesse and Hall (1996) closely. As in Hall and Mairesse (1995), we assume that the production function for manufacturing firms can be approximated by a Cobb–Douglas production function in the three inputs of fixed capital stock *C*, labour *L*, and knowledge capital *K*:

$$Y_{it} = A_{it} L_{it}^{\alpha} C_{it}^{\beta} K_{it}^{\gamma} e^{\varepsilon_{it}} \tag{1}$$

where Y is value added or gross sales, ε is a multiplicative disturbance, i denotes firms, and t is years. Technical change is captured by A_{it}, which varies over time as well as across firms. We take logarithms when estimating the Cobb–Douglas production function to obtain the following linear regression equation, which can be easily estimated:

$$y_{it} = \eta_i + \lambda_t + \alpha l_{it} + \beta c_{it} + \gamma k_{it} + \varepsilon_{it} \tag{2}$$

Lower-case letters denote the logarithms of variables. In this framework, we implicitly assume that the log of technical progress (A) can be written as the sum of a sector- or firm-specific effect η_i and a time effect λ_t (Hall et al. 2009). In practice, we replace λ_t with year dummies.

There are two methods to estimate the return to R&D, which is the marginal product of R&D capital (ρ). In the first method, and the one for which we present results in this paper, we use simple algebra manipulation of the identities below:[8]

$$\gamma \equiv \rho \frac{K_{it}}{Y_{it}}, \text{ hence } \rho \equiv \gamma / \frac{K_{it}}{Y_{it}}$$

Therefore we can estimate the return to R&D by estimating $\hat{\gamma}$ (Equation (2)), the R&D capital intensity ratio $\frac{K}{Y}$ (mean, median), and then use these two estimates to derive an estimate of the return to R&D, which is:

$$\hat{\rho} = \hat{\gamma} / \left(\frac{K}{Y}\right) \tag{3}$$

We use this relationship as our main empirical strategy—a method that is standard in the literature. An issue, however, with this method is that it is difficult to obtain a sufficient series of estimates of R&D capital stock K_{it} because a relatively long time series is required to cumulate R&D investment (R_{it}) and an assumed depreciation rate (δ) by the following equation:

[8] γ is the elasticity of output with respect to R&D capital.

$$K_{it} = R_{it} - \delta K_{it-t} \quad (4)$$

We have a short panel with frequent gaps in the time series so are unable to construct cumulated R&D capital K_{it}. As a solution to this problem, we follow Hall et al. (2009) in assuming a steady-state growth rate g_{it} to approximate for K_{it}:

$$K_{it} \approx \frac{R_{it}}{\delta + g_{it}} \quad (5)$$

For example, if $\delta = 15$ per cent (typical) and $g_{it} = 5$ per cent, then $K_{it} = 5\ R_{it}$.

The benefit of using this approximation is that we can justify using R&D expenditure (flow variable) instead of R&D capital stock in our estimations, which is the variable we have available in the dataset we use.

Our approach in estimating $\hat{\rho}$ is to use all practical methods available, taking into account data constraints and benchmark these results against previous studies using firm-level data from other countries. This framework is evidently susceptible to simultaneity bias, where the left-hand side (value added or gross sales) is determined jointly with variables on the right-hand side, R&D in particular. Moreover, the error term may include any errors in the specification which may arise because firms have different production functions or because we have not disaggregated the inputs adequately enough, as well as pure measurement error in any of the explanatory variables (Hall and Mairesse 1995). We adopt a number of measures to address these problems, such as using the first lag instead of the current value of the stock of fixed capital and the level of R&D expenditure, estimating $\hat{\gamma}$ using pooled ordinary least squares (OLS), fixed effects, first differences and long differences. The latter estimation methods attempt to address the potential for omitted variable bias by estimating after transforming Equation (2) to eliminate the firm-specific heterogeneity term η_i. However, the problem with first differences and fixed effects using annual data is that it removes the firm-specific heterogeneity term, but aggravates any measurement error problem, which is an area of concern in our estimations. This provides the motivation for using the long differences estimator, as it deals specifically with the familiar 'measurement error in panel data' problem discussed by Griliches and Hausman (1986). The long differences estimator is essentially firm average growth over the full available period, and because growth rates are averages, the measurement error bias is reduced.[9] We also, when doing these estimations, restrict our analysis to the manufacturing sector, as it is argued by Hall and Mairesse (1995) that both labour productivity and TFP are better measured and more meaningful in the manufacturing sector than other sectors (Mairesse and Hall 1996). Several other firm-level studies in the literature also restrict their analysis to manufacturing-sector firms only.

The second method estimates the marginal product of R&D capital (ρ) directly by estimating Equation (6) using first differences:

$$\Delta y_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \rho\ \left(\frac{R_{it} - \delta K_{it-1}}{Y_{it}}\right) + \Delta\varepsilon_{it} \quad (6)$$

[9] In our dataset, we encounter a problem in which we have many gaps in the time series dimension of the panel. In cases like this, it is useful to use a long-differences estimator. The advantage of this technique is that we can calculate average growth over a period even though there are gaps in the data.

A problem highlighted by Hall et al. (2009) in the literature is that this approach generally understates the estimates for ρ and generates unstable estimates. Similarly, unstable estimates are also our experience using this approach and so we do not report on this any further.

Table 1 is drawn from a summary compiled by Hall et al. (2009) of findings from the literature, which are for the most part based on studies of firms in OECD countries. The magnitude of the R&D elasticity coefficient range from 0.01 to 0.25, but are for the most part centred on 0.08. In general, the cross-sectional estimates are higher than the within estimates, which are often not even statistically significant (Hall et al. 2009). The rates of return in the last column are based largely on multiplying the estimated elasticity by the average output:R&D capital ratio. Estimates range from 20 to 80 per cent depending on the country and type of estimation method used.

Table 1: R&D elasticities of output and rates of return to R&D

Study	Sample	Period	Type of estimation	R&D elasticity	R&D rate of return
Cross-sectional and pooled results					
Hall and Mairesse (1995)	France: 197 firms	1980–1987	VA prod. function	0.25 (0.01)	78%*
Mairesse and Hall (1996)	France: 1,232 firms US: 103 firms	1981–1989 1981–1989	VA prod. function with ind. dummies Prod function with ind. dummies	0.176 (0.004) (corr.) 0.173 (0.013)	75%* 28%*
Bartelsman et al. (1996)	Netherlands: ~200 mfg firms	1985, 1989, 1993	Prod. function VA prod. function	0.006 to 0.014 (uncorr.) 0.018 to 0.033 (corr.) 0.008 to 0.043 (uncorr.) 0.046 to 0.099 (corr.)	
Haroff (1998)	Germany: 443 mfg firms	1979–1989	Prod. function	0.14 (0.01) (uncorr.) 0.11 (0.01) (corr.)	71%*
Wang and Tsai (2003)	Taiwan: 136 firms	1994–2000	VA prod. function with random effects	0.20 (0.03) (corr.)	8% to 35%*
Rogers (2009)	UK: 719 firms	1989–2000	VA prod. function with R&D flow as input	0.12 to 0.16 (mfg; corr.) 0.12 to 0.23 (non-mfg; corr.)	40% to 58%
Ortega-Argilès et al. (2009)	EU: 532 firms	2000–2005	Prod. function with sector dummies	0.1	35%
Temporal or within results					
Hall and Mairesse (1995)	France: 197 firms	1980–1987	Growth rates Within firm	0.02 to 0.17 0.069 (0.035)	23% 8%*
Mairesse and Hall (1996)	France: 1,232 firms US: 103 firms	1981–1989 1981–1989	VA prod. function within firm VA prod. function; growth rate Prod function with growth rate	0.068 (0.014) 0.080(0.021) 0.092 (0.026)	33%* 150%*
Bartelsman et al. (1996)	Netherlands: ~200 mfg firms	1985, 1989, 1993	Long differences	0.051	
Haroff (1998)	Germany: 443 mfg firms	1979–1989	Prod. function within firm Long diff growth rates	0.09 (0.02) (corr.) 0.07 (0.02) (uncorr.) 0.01 (0.03) 0.02 (uncorr.)	66%* 86%
Capron and Cincera (1998)	Multi-country: 625 firms	1987–1994	Growth rates Growth rates, GMM	0.32 (0.04) 0.13 (0.05)	
Los and Verspagen (2000)	US: 485 mfg firms	1974–1993	VA prod. function	0.014	

Notes: * computed using means or medians of the variables; standard errors in parentheses; production function dependent variable is gross sales unless otherwise noted.

GMM, generalized method of moments; mfg, manufacturing; prod function, production function; VA, value added. Corr, studies in which capital and labour are corrected for double-counting of R&D inputs; uncorr, not corrected. Unless otherwise noted, estimates use uncorrected data.

Source: authors, based on Hall et al. (2009: tables 2a and 2b).

5 Descriptive analysis

Initially, we restrict our sample to firms that report positive values of gross sales and fixed capital in a financial year. This leaves 189,000–241,000 in the sample over the period 2009–2014 (Table 2). Only a small number of these firms report positive values of R&D expenditure, herein referred to as R&D-active firms, in their income statements in a specific financial year (2011: 1,885 firms; 2012: 1,670 firms).[10] This is not entirely surprising as the majority of firms in most countries either do not perform R&D or do not specifically identify a portion of expenditure as being 'R&D', and hence we can expect that it could be understated, particularly among smaller firms. It is also important to emphasize that the SARS-NT panel dataset is (in theory, anyway) essentially a census that captures all firms, and therefore the share of firms that report R&D expenditure is expected to be a relatively small share of the total population of formal firms.

Table 2: Summary statistics of R&D-active firms in the SARS-NT panel dataset

	2009	2010	2011	2012	2013	2014
No. of firms (each year)	189,883	205,331	204,954	211,419	240,663	203,175
No. of firms reporting non-zero R&D expenditure	**1,425**	**1,833**	**1,885**	**1,670**	**944**	**746**
Mean sales (R million)	98.2	315.8	458.7	583.8	1,010.5	799.2
Median sales (R million)	5.0	9.6	12.1	23.3	69.4	77.3
Total sales (R million)	139,941.2	578,921.4	864,755.7	974,935.3	953,901.8	596,197.2
Mean fixed capital (R million)	39.0	155.2	245.8	215.6	443.2	214.1
Median fixed capital (R million)	0.4	0.6	0.7	1.1	3.9	4.7
Total fixed capital (R million)	55,550.7	284,467.2	493,393.6	360,100.8	418,350.7	159,746.8

Source: authors, based on SARS-NT Panel.

Of the R&D-active firms (firms reporting R&D expenditure in the income statement of the IT14 and ITR14 forms), the bulk of R&D expenditure reported is by older and large firms, both in terms of gross sales and number of employees. Second, only a small share of R&D-active firms (4.9 per cent) report R&D expenditure in each financial year over the period 2009–2014, while nearly one-third report in a single financial year period only, which suggests that the persistence of regular R&D spend (or reporting of specific R&D expenditure) is weak. R&D-active firms are more likely to be in the manufacturing, mining, utilities and business services subsectors, which is similar to the findings in the DST's annual National Survey of Research and Experimental Development (R&D) administered by the HSRC.

From these firms we extract a base sample of firms from which we drop any observations that have missing values of sales, fixed capital, labour, R&D expenditure, or materials in any particular year over the period 2009–2014. In addition, we only retain observations where R&D expenditure is non-zero and non-missing. Finally, we place a restriction on the size of firms included in the base sample to control for the change in tax forms from the IT14 to the ITR14 in October 2012. The ITR14 form specifies that only medium to large firms report R&D expenditure in the income statement section of the tax return, compared to the prior IT14 which allowed firms of all sizes to report such expenditure in the income statement. Therefore, only medium to large firms with total income greater than R14 million or total assets exceeding R10 million are retained in the sample.

[10] From 2010 to 2012, this share ranged between 0.79 and 0.92 per cent of total firms that record positive values of gross sales and fixed capital stock.

This results in quite a number of micro and small firms (all those that record R&D expenditure) being dropped from the sample, particularly from 2009 to 2012 before the change to the ITR14 form. This, however, does not change our results in any significant way. Both R&D intensity and R&D elasticity estimates change little. We also restrict the period of analysis from 2009 to 2014, and drop any observations in 2008 and 2015 respectively because of a limited number of observations reported in these financial years.

After placing these restrictions on the sample, an unbalanced sample of 1,776 firms remain in the base sample from 2009 to 2014 across several sectors of the economy. These firms record positive values of R&D expenditure in at least one financial year from 2009 to 2014. This sample of firms consists of 3,907 observations, as several of these firms report R&D expenditure in multiple years over the period 2009–2014. Table 3a shows the distribution of these firms across key sectors of the economy. We follow the same sector definitions as Hall and Mairesse (1995), using the International Standard Industrial Classification (ISIC) Revision 4 sector codes.[11] Of the 1,776 firms, 829 are in manufacturing (47 per cent), followed by 750 in services (42 per cent) and 76 in agriculture (4.3 per cent). The 829 firms in manufacturing is lower than the 1,073 US and 1,232 French manufacturing firms in the unbalanced samples from 1981 to 1989 used in the analysis undertaken by Hall and Mairesse (1995). South Africa has a relatively high share of R&D-active manufacturing firms in food, wood and miscellaneous,[12] primary metals, fabricated metals, and autos compared to the sample of US and French manufacturing firms from 1981 to 1989 (Mairesse and Hall 1996).

[11] ISIC-4 sector codes are available at https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27&Lg=1

[12] Includes tobacco, wood, furniture, glass, and miscellaneous products.

Table 3a: Unbalanced sample characteristics: South African firms 2009–2014

Industry	Number of firms	Number of observations	Mean sales (R million)	Median sales (R million)	Total sales (R million)	Mean employment	Median employment	Total employment[a]
Paper and printing	27	67	1,645.3	66.0	29,361.1	652.8	124.0	12,849
Chemicals	81	218	357.1	115.8	20,230.0	161.2	89.5	7,761
Rubber	48	82	163.2	84.5	4,506.4	158.6	71.5	4,231
Wood and misc.[b]	195	488	470.1	92.0	57,250.8	443.4	105.0	57,092
Primary metals	39	111	551.9	199.3	17,477.3	373.9	197.0	11,081
Fabricated metals	78	177	195.9	79.9	5,816.5	299.1	84.0	10,726
Machinery	81	187	247.1	76.0	9,313.2	145.3	71.0	6,166
Electrical machinery	19	59	838.5	100.6	10,090.5	597.6	112.0	7,663
Autos	59	127	1,110.7	151.1	52,812.0	368.0	132.0	14,615
Aircraft and boats	13	32	299.7	272.2	2,110.8	294.2	161.5	1,764
Textiles and leather	33	85	123.5	79.2	2,563.1	334.7	186.0	6,932
Pharmaceuticals	21	50	267.4	136.9	3,420.8	180.7	142.0	1,963
Food	104	270	1,422.9	145.5	94,631.8	819.3	167.0	57,406
Computers and instruments	19	40	487.4	71.1	1,430.8	405.4	80.5	1,379
Oil	12	29	9,766.0	366.9	106,694.7	4,790.0	105.0	36,171
Total manufacturing firms	**829**	**2,022**	**733.9**	**102.8**	**417,709.8**	**462.5**	**110.0**	**237,799**
Additional non-manufacturing sectors								
Agriculture	76	177	257.9	65.2	11,697.8	407.1	118.0	17,553
Mining	54	134	3,633.7	388.3	64,630.2	2,218.6	242.0	64,936
Electricity, gas, and water	30	66	5,271.9	70.4	118,999.4	2,512.7	108.5	73,589
Construction	37	66	561.4	83.4	2,731.6	771.4	125.0	4,369
Services	750	1,442	631.5	75.8	193,433.4	769.2	88.0	233,808
Total	**1,776**	**3,907**	**847.7**	**90.9**	**809,202.2**	**673.2**	**105.0**	**632,054**

Note: [a] Total employment is in 2012. [b] Includes tobacco, wood, furniture, glass and miscellaneous products.

Source: authors, based on SARS-NT panel.

Table 3b: Unbalanced sample characteristics: South African firms 2009–2014

Industry	Mean fixed capital (R million)	Median fixed capital (R million)	Total fixed capital (R million)[a]	Mean R&D expenditure (R million)	Median R&D expenditure (R million)	Total R&D expenditure (R million)	Mean R&D to sales ratio[b]	Median R&D to sales ratio
Paper and printing	950.3	9.8	15,300.2	2.68	0.08	39.4	0.16	0.11
Chemicals	65.6	4.9	3,282.8	1.04	0.12	45.8	0.29	0.09
Rubber	34.6	12.9	1,139.9	0.32	0.09	8.9	0.19	0.11
Wood and misc.[c]	106.5	7.3	14,777.2	2.32	0.14	381.2	0.48	0.12
Primary metals	107.6	12.6	2,284.7	1.03	0.16	38.2	0.19	0.07
Fabricated metals	35.2	7.9	2,214.6	0.65	0.10	8.4	0.33	0.12
Machinery	17.8	1.6	736.6	2.18	0.12	60.4	0.88	0.14
Electrical machinery	90.9	3.8	1,320.6	2.24	0.22	19.0	0.27	0.08
Autos	116.0	14.3	4,833.1	4.10	0.31	301.4	0.37	0.17
Aircraft and boats	32.1	9.9	98.1	12.63	0.42	164.7	4.22	0.14
Textiles and leather	12.2	6.0	242.3	0.41	0.14	6.3	0.33	0.12
Pharmaceuticals	29.8	10.2	416.5	4.61	0.66	47.9	1.57	0.46
Food	245.5	15.0	18,005.1	3.20	0.18	256.1	0.22	0.11
Computers and instruments	33.3	5.7	141.7	4.47	0.62	52.4	0.82	0.58
Oil	3,952.7	14.1	36,936.4	44.40	0.11	261.3	0.45	0.05
Total manufacturing firms	**178.1**	**7.5**	**101,729.7**	**2.9**	**0.16**	**1,691.3**	**0.39**	**0.12**
Additional non-manufacturing sectors								
Agriculture	33.0	6.4	1,651.7	2.80	0.15	119.1	1.08	0.19
Mining	1,898.5	107.0	26,715.3	11.51	0.65	113.7	0.31	0.09
Electricity, gas, and water	6,092.6	1.5	130,847.6	14.21	1.15	285.8	0.26	0.63
Construction	327.3	4.3	3,748.0	0.64	0.15	3.8	0.10	0.11
Services	384.8	2.5	67,882.0	1.81	0.16	503.2	0.22	0.16
Total	**409.3**	**5.2**	**332,504.7**	**2.94**	**0.17**	**2,716.9**	**0.32**	**0.14**

Note: [a] Total fixed capital is in 2012. [b] Mean R&D to sales ratio shown is the sales-weighted average over the period 2009–2014 [c] Includes tobacco, wood, furniture, glass, and miscellaneous products.

Source: authors, based on SARS-NT panel.

Table 3a and 3b also set out summary statistics (mean, median, and total) for our key variables (sales, employment, fixed capital, and R&D expenditure). The median firm in the base sample of manufacturing firms has around 110 employees, fixed capital stock worth R7.5 million (US$0.58 million[13]), R&D expenditure of R160,000 (US$12,383), and generates sales worth R102.8 million (US$7.96 million) on average each year over the period 2009–2014. The mean manufacturing firm, on the other hand, has 462 employees, R178.1 million (US$13.78 million) in fixed capital stock, R&D expenditure of R2.9 million (US$0.22 million), and generates sales of R733.9 million per year (US$56.80 million).

R&D-active firms are, on average, larger employers than R&D-inactive firms, which is standard in the literature. Manufacturing firms (excluding the oils and aircraft and boats subsectors) that recorded R&D expenditure over the period 2009–2014 had a mean employment value of 319.5 compared to 59.1 for R&D-inactive firms in the sector. Even when restricting the sample to only medium to large firms in the manufacturing sector, both mean and median employment is considerably higher for those firms reporting R&D expenditure (Table 4).

Table 4: Features of active and inactive R&D firms in South Africa

		All firms				Medium to large firms only[c]			
		Median L[b]	Mean L	Median R&D/S[d]	Mean R&D/S	Median L	Mean L	Median R&D/S	Mean R&D/S
R&D-active firms	All sectors	38	392.7	0.22	0.34	105	673.2	0.14	0.32
	Manufacturing	**58**	**319.5**	**0.16**	**0.40**	**110**	**462.5**	**0.12**	**0.39**
	Manufacturing[a]	57	277.3	0.16	0.35	109	401.2	0.12	0.34
R&D-inactive firms	All sectors	11	78.1			58	264.6		
	Manufacturing	**16**	**59.1**			**60**	**154.3**		
	Manufacturing*	16	60			61	156.1		

Notes: [a] Manufacturing sector excluding oils and aircraft and boats subsectors. [b] Refers to number of employers. [c] Refers to firms with gross output greater than R14 million or total assets greater than R10 million.[d] S = sales.

Source: authors, based on SARS-NT panel.

Over the full period, the number of observations across manufacturing firms is 2002, considerably fewer than the 6,521 and 6,282 observations in the sample of US and French firms used by Mairesse and Hall (1996). This is despite the number of manufacturing firms in the South African sample being fairly comparable to the US and French samples (South Africa: 829 firms; US: 1,073 firms; France: 1,232 firms). This suggests a low persistence of R&D expenditure among R&D-active firms in South Africa compared to the US and French samples. To quantify and account for this, we construct three-, four-, and five-year balanced panels over the following periods: 2012–2014; 2011–2014; and 2010–2014. Of the 829 manufacturing firms in the unbalanced panel sample from 2009 to 2014, only 155 consistently report R&D expenditure in each year over the three-year period from 2012 to 2014. This number decreases further in the four-year and five-year balanced panels to 121 and 86 firms over the period 2011–2014 and 2010–2014 respectively (Table 5).

[13] Using the current exchange rate of R12.92 per US dollar on 27 July 2017.

Table 5: Number of firms by panel sample

Industry	Unbalanced sample	Three-year balanced (2012–2014)	Four-year balanced (2011–2014)	Five-year balanced (2010–2014)
Paper and printing	27	8	6	2
Chemicals	81	13	10	9
Rubber	48	2	2	1
Wood and misc.[a]	195	46	35	23
Primary metals	39	13	13	12
Fabricated metals	78	11	5	2
Machinery	81	12	10	6
Electrical machinery	19	7	6	5
Autos	59	5	4	2
Aircraft and boats	13	4	3	3
Textiles and leather	33	6	5	5
Pharmaceuticals	21	1	1	1
Food	104	21	17	11
Computers and instruments	19	4	2	2
Oil	12	2	2	2
Total manufacturing firms	**829**	**155**	**121**	**86**
Additional non-manufacturing sectors				
Agriculture	76	12	10	6
Mining	54	9	8	3
Electricity, gas, and water	30	4	3	2
Construction	37	3	2	2
Services	750	79	59	37
Total	**1,776**	**262**	**203**	**136**

Note: For each balanced panel sample, the distribution of firms reflected is in 2012. The distribution changes marginally across years for the balanced panels, most likely due to firms changing their reported sector in subsequent tax submissions. [a] Includes tobacco, wood, furniture, glass, and miscellaneous products.

Source: authors, based on SARS-NT panel.

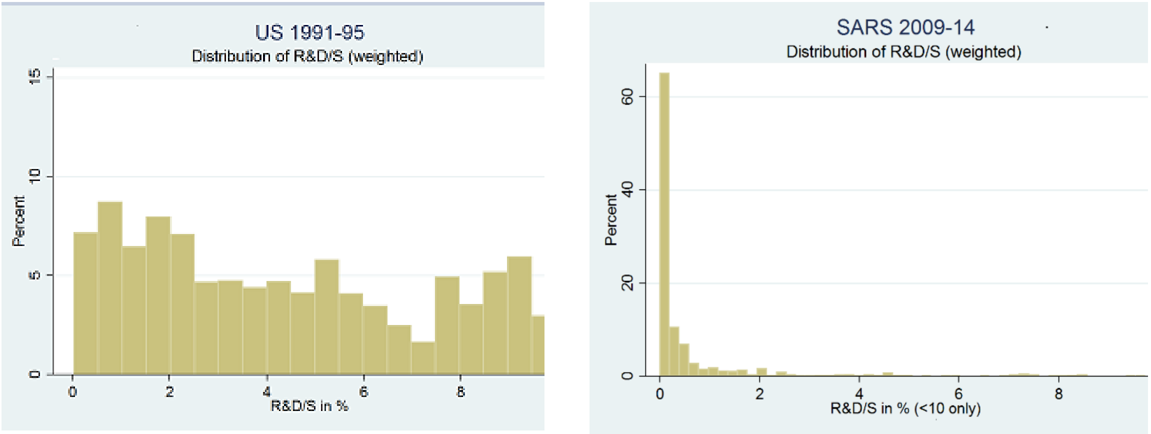
6 Intensity of R&D expenditure in South Africa

The majority of R&D-active firms in South Africa actually allocate a relatively small share of resources to R&D expenditure compared to OECD countries. For example, in Figure 3, approximately 80 per cent of South African firms over the period 2009–2014 have an R&D intensity ratio[14] of less than 0.5 per cent, compared to only 10 per cent of firms in a sample of R&D-active US firms in 1991–1994.[15]

[14] Sales weighted ratio of R&D expenditure divided by gross sales in per cent.

[15] This refers to the share of all R&D-active firms in the sample of South African (2009–2014) and US (1991–1994) firms respectively which have an R&D intensity ratio of less than 10 per cent. Therefore we are not considering firms

Figure 3: R&D intensity in the United States (1991–1994) and South Africa (2009–2014)



Note: R&D intensity ratios weighed by sales.

Source: authors, based on Compustat and SARS-NT panel.

After restricting our sample to medium to large firms in the manufacturing sector only, it is evident that R&D-active manufacturing firms have on average a very low sales-weighted mean R&D intensity ratio of approximately 0.39 per cent (Table 3b).[16] This ratio is even lower (0.34 per cent) when excluding the oil and aircraft and boats subsectors. This feature is not because there are many small firms in absolute size terms reporting low R&D intensity, as we restrict our sample to medium to large manufacturing firms only. We expect R&D intensity to increase with firm size, and if our dataset had a very large number of tiny firms, this could make the median (or even mean) R&D intensity of firms very low. Even when including micro and small firms, the ratio remains relatively unchanged at 0.4 per cent. This low R&D intensity compares unfavourably to a sample of US and French firms over the period 1981–1989, which had a mean ratio of 2.9 and 2.3 per cent respectively (Mairesse and Hall 1996). R&D intensity in South Africa is approximately 6–8 times lower than was found for manufacturing firms across several OECD countries, including manufacturing firms in the US and France. It is unsurprising that the number of firms undertaking and reporting R&D expenditure is low, but the low intensity of R&D among R&D-active South African manufacturing firms is concerning.

At a manufacturing subsector level, the sales-weighted mean R&D to sales ratio is highest in the aircraft and boats (4.22 per cent), pharmaceuticals (1.57 per cent), machinery (0.88 per cent), and computers and instruments (0.82 per cent) manufacturing subsectors. It appears that on average, this intensity ratio is higher in the manufacturing sector compared to other sectors in the economy, with the exception of the agriculture sector, which has a relatively high ratio of 1.08 per cent. When comparing these ratios to those of US and French manufacturing firms from 1981 to 1989 in Mairesse and Hall (1996), all South African manufacturing subsectors report a lower intensity ratio with the exception of aircraft and boats, where South Africa reports a higher ratio than the US (albeit comparing different time periods).

There are several plausible explanations for these findings. First, it could be that there is under-reporting of R&D expenditure, which places a downward bias on the intensity of R&D activity among South African manufacturing firms. This could be due to difficulties in either defining R&D activity or isolating expenditure that aligns strictly within the definition of R&D provided.

that have relatively high R&D intensity ratios of 10 per cent or greater, of which there are very few in the South African sample.

[16] This ratio is even lower at 0.32 per cent when all sectors of the economy are taken into account.

Firms therefore either refrain from reporting their R&D expenditure or under-report it. On the other hand, it is also possible that some firms do not adhere to the definition of R&D and over-report R&D expenditure, in which case the intensity of R&D expenditure may be biased upwards.

Second, the low intensity of R&D expenditure may be related to the fact that 'R&D' may take on a different nature in developing countries, where it is less easily defined compared to R&D activity in developed countries. Countries that are not at the technological frontier engage more in activities that 'absorb' technologies established elsewhere, and this activity may not be counted explicitly as 'R&D' expenditure by the firm. Earlier research using the SARS-NT dataset suggests that in South Africa there is a positive correlation between importing intermediate goods directly and exporting (Edwards et al. 2016; Matthee et al. 2016). This link is strengthened by increasing the variety of imports and by importing from developed rather than emerging markets. Where intermediates are imported from appears to also affect the productivity of firms—with imports from developed countries having a large positive effect—due to technology and knowledge transfer. This suggests that the channel of increasing productivity may be through technology transfer embodied in the imports, and that many of these firms may be part of global value chains, instead of R&D activity originating in South Africa. This suggests that policies that restrict imports, or raise the costs of intermediates, may hinder exports and productivity growth. It also suggests that integrating into global value chains may raise productivity, or having higher productivity may preclude the ability of firms to join value chains (depending on how the chain originates in South Africa). Importing from a variety of sources also appears to be critical for raising productivity and export growth. This suggests that one should be careful when trying to restrict imports from particular regions (or when risking trade policy retaliation through aggressive policy moves), and should not focus only on very narrow preferential or regional trade agreements.

Lastly, it may be that our findings are for the most part accurate, and that the intensity of R&D expenditure is genuinely low in South Africa. To test our findings with other data, we analysed R&D expenditure data from listed companies on the Johannesburg Stock Exchange (JSE) from 2012 to 2016 as an alternative benchmark. This sample consists of 379 unique companies, of which 59 report R&D expenditure at some point over the period. These companies are large and in many cases have diversified operations across several sectors and large parts of the value chain. Table 6 shows that the mean and median values of sales and R&D expenditure for R&D firms in the JSE sample are considerably larger compared to the base sample of firms we use from the SARS-NT panel (referred to in Tables 2 and 3). The JSE sample definition is perhaps more comparable to the sample of firms in Mairesse and Hall (1996) than the SARS-NT sample we use, as the US sample consists of listed firms, so there are few, if any, small firms.

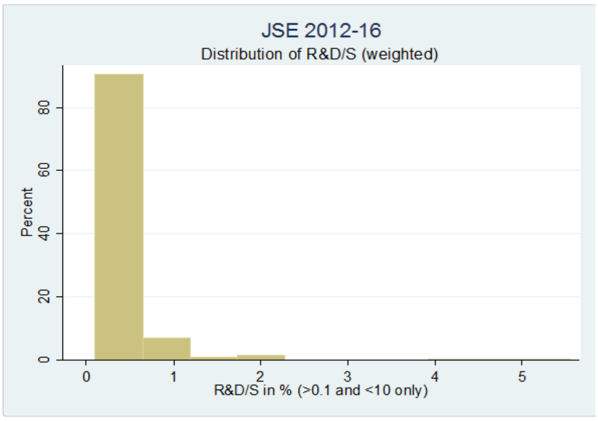
Table 6: Comparison of characteristics of R&D firms in SARS-NT sample (2009–2014) and JSE sample (2012–2016)

	Number of firms	Number of observations	Median sales (R million)	Mean sales (R million)	Median R&D (R million)	Mean R&D (R million)
All firms						
SARS-NT sample	1,776	3,907	90.9	847.7	0.17	2.94
JSE sample	59	217	8,511	17,981	15.6	48.9
Manufacturing firms						
SARS-NT sample	829	2,022	102.8	733.9	0.16	2.9
JSE sample	32	120	7,021.4	11,839.2	21.35	43.7

Source: authors, based on McGregor Database 2017, and SARS-NT data.

Although these data are not exactly comparable to the SARS-NT dataset, the trends that emerge are very similar—low R&D intensity and a relatively low share of listed firms investing in R&D each year. Only around 11–12 per cent of firms listed on the JSE invested in R&D annually over the period 2012–2016. The average sales-weighted mean R&D intensity ratio across 59 firms is 0.31 per cent over the period 2012–2016. After restricting the sample to only manufacturing-sector firms, the sales-weighted mean R&D intensity ratio increases to 0.51 per cent. The trouble is that many of these large listed JSE firms are vertically integrated, and it is therefore difficult to confine them only to manufacturing. These results validate the SARS-NT sample basic features but with named companies, capturing the leading R&D firms. It is particularly striking that the distribution of R&D intensity is identical to the distribution in the SARS-NT sample, which validates our findings considerably.

Figure 4: Distribution of R&D intensity of JSE-listed firms (2012–2016) and top 10 companies: R&D intensity average (2012–2016)



Company	R&D intensity (%)
Silverbridge Holdings	9.856448
Psg Konsult Limited	4.497555
Taste Hldgs Ltd	2.615601
Adcock Ingram Hldgs Ltd	1.620435
Purple Group Ltd	1.233805
Anchor Group Limited	1.1123
Reunert Ltd	0.934902
Avi Ltd	0.587605
Compagnie Fin Richemont	0.575759
Anglo American Plat Ltd	0.556895

Note: R&D intensity ratios weighed by sales.

Source: authors, based on McGregor Database 2017.

Is South Africa 'different' in terms of the intensity or scale of R&D activity and the return to R&D activity? Our descriptive analysis reveals our first substantive result and a very robust finding—R&D activity or intensity is very low in South African R&D-active firms when compared with firms in OECD countries and other studies. We want to measure the rate of return that these R&D-active firms receive for their financial outlay towards R&D, and how this compares to what has been found in other countries. As outlined in Section 4, the next step in our approach to measuring the rate of return is to estimate the elasticity of output with respect to R&D expenditure.

7 Regression analysis

7.1 Elasticity of output with respect to R&D expenditure

In this section we discuss our production function results using several econometric specifications, as discussed in Section 4. First, we construct a *large* sample from the base sample used in the descriptive analysis in the previous section. The *large* sample includes all manufacturing-sector firms except those in the oil and aircraft and boats subsectors (804 firms and 1,961 observations) for the regression analysis. The agriculture, mining, electricity, gas, and water, construction, and services sectors are not included in the *large* sample as both labour productivity and TFP are considered to be better measures in the manufacturing sector than in these other sectors (Hall and Mairesse 1995). We exclude the oil and aircraft and boats subsectors for our results to be comparable with Hall and Mairesse (1995), even though oil is a relatively large subsector in the South African manufacturing context.

Table 7 presents a complete set of estimates of R&D elasticities for the *large* sample across several specifications using beginning-of-year and end-of-year fixed capital dating. Overall the results are sensible—the elasticity of output with respect to R&D ranges from 0.02 to 0.14 in the cross dimension, which includes pooled OLS with year dummy variables and within industry where manufacturing subsector dummy variables are added. The standard errors are smallest (0.005–0.006) when gross sales is used as the dependent variable and materials are included as a regressor, although the magnitude of the elasticity on R&D is consistently at the lower bound of around 0.02 to 0.03. When materials are not included as an explanatory variable, the size of the coefficient on R&D ranges between 0.12 and 0.14; however, the standard errors are marginally larger at around 0.01. The magnitude of the coefficients on R&D is also marginally lower when sector dummy variables are included in the specification.

The within firm estimators (fixed effects and first differences) are lower compared to the cross-sectional estimators, ranging between 0.01 and 0.06 depending on the output variable used and fixed capital dating. The standard errors are also marginally higher, ranging from 0.01 to 0.02. One reason for this is that measurement errors can have a more serious impact on growth rates than on the levels of variables (Griliches and Hausman 1986). Hall et al. (2009) also suggest that the omission of cyclical variables in the production function, such as challenges of providing adequate specifications of the lags and dynamic evolution of variables, can explain the differences. The elasticity coefficients on fixed capital stock and labour vary in magnitude depending on specification; however, they are positive in every instance, with standard errors ranging between 0.01 and 0.06.

Our results fall within the range of those found in several other studies summarized in Table 1. Mairesse and Hall (1996) get an R&D elasticity of 0.17 (0.013) and 0.18 (0.004) using pooled estimates on a sample of US and French firms respectively. Estimates of R&D elasticity using cross-sectional and pooled estimators range from 0.01 in the Netherlands (Bartelsmann et al. 1996) to 0.14 in Germany (Haroff 1998). When using temporal or within-firm estimators, estimates range from 0.07 in France (Hall and Mairesse 1995) to 0.09 in Germany (Haroff 1998).

We also compare these results to estimations using the JSE sample. The elasticity estimates are for the most part similar to what we get using the SARS-NT data, although less precisely estimated and not significant in certain instances. However, the sample size is very small in comparison (120–250). The similarity of the JSE results to the SARS-NT results is very helpful and a useful benchmark. Given that our R&D elasticities are standard in terms of the literature using the SARS-NT sample, it is not necessary to expand further on our results using the JSE data.

Table 7: Productivity regressions 2009–2014, South Africa

Capital dating	Beginning of year			End of year		
Dep. variables	Log VA	Log sales	Log sales	Log VA	Log sales	Log sales
Pooled OLS						
Log L	0.494***	0.455***	0.116***	0.438***	0.418***	0.095***
	(0.040)	(0.039)	(0.017)	(0.035)	(0.03)	(0.014)
Log C	0.177***	0.194***	0.030***	0.182***	0.198***	0.030***
	(0.026)	(0.025)	(0.010)	(0.023)	(0.02)	(0.008)
Log M			0.786***			0.803***
			(0.028)			(0.023)
Log R	0.132***	0.121***	0.025***	0.137***	0.121***	0.025***
	(0.014)	(0.014)	(0.005)	(0.014)	(0.01)	(0.005)
R^2 (s.e.)	0.640	0.656	0.944	0.603	0.627	0.944
Number of observations	1,518	1,536	1,528	1,858	1,883	1,872
Within industry						
Log L	0.531***	0.490***	0.125***	0.467***	0.445***	0.101***
	(0.040)	(0.038)	(0.018)	(0.035)	(0.03)	(0.015)
Log C	0.175***	0.182***	0.032***	0.181***	0.189***	0.031***
	(0.025)	(0.024)	(0.010)	(0.022)	(0.02)	(0.008)
Log M			0.784***			0.804***
			(0.030)			(0.023)
Log R	0.121***	0.114***	0.021***	0.128***	0.115***	0.021***
	(0.014)	(0.014)	(0.005)	(0.014)	(0.01)	(0.005)
R^2 (s.e.)	0.660	0.679	0.947	0.622	0.649	0.946
Number of observations	1,518	1,536	1,528	1,858	1,883	1,872
Within firm (fixed effects estimator)						
Log L	0.080	0.078*	0.049	0.097***	0.092***	0.038**
	(0.061)	(0.047)	(0.034)	(0.031)	(0.025)	(0.017)
Log C	0.054*	0.033**	0.019*	0.031	0.048**	0.017**
	(0.030)	(0.015)	(0.010)	(0.019)	(0.020)	(0.007)
Log M			0.429***			0.501***
			(0.123)			(0.106)
Log R	0.038**	0.020**	0.006	0.046***	0.0229***	0.011
	(0.015)	(0.008)	(0.008)	(0.013)	(0.01)	(0.008)
R^2 (s.e.)	0.581	0.526	0.937	0.521	0.293	0.938
Number of observations	1,518	1,536	1,528	1,858	1,883	1,872
First differences						
Log L	0.062	0.053	0.045	0.058**	0.0462***	0.026
	(0.058)	(0.041)	(0.036)	(0.026)	(0.0173)	(0.019)
Log C	0.024	0.022	0.008	0.007	0.0177	0.009
	(0.023)	(0.014)	(0.010)	(0.016)	(0.0115)	(0.007)
Log M			0.373***			0.414***
			(0.138)			(0.127)

Log R	0.032*	0.023**	0.005	0.043***	0.0268***	0.010
	(0.019)	(0.010)	(0.008)	(0.015)	(0.00832)	(0.007)
R^2 (s.e.)	0.023	0.029	0.330	0.03	0.059	0.578
Number of observations	766	782	774	1,033	1,056	1,398

Notes: Robust standard errors in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: authors, based on SARS-NT panel.

Robustness checks

To test the robustness of the estimation results of the *large* sample, we construct several additional subsamples by removing various outliers and placing additional restrictions on which manufacturing firms are included in the sample. We follow the approach taken by Hall and Mairesse (1995) and Mairesse and Hall (1996) and apply it to the *large* sample according to the following criteria:

1. We remove any observations where value added is zero or negative, as this creates problems for the logarithmic specification. This removes 53 observations, which is 3 per cent of the base sample of 1,776 observations.
2. We apply an interquartile range-based trimming on the unlogged values of value added per worker, sales per worker, fixed capital per worker, and R&D expenditure per worker. Any observations that are outside three times the interquartile range above or below the median are removed.
3. We remove any observations for which the growth rates of sales, employment, or fixed capital are less than minus 50 per cent or greater than 200 per cent. In addition, we remove observations where the growth rate in value added is less than minus 90 per cent or greater than 300 per cent.

The number of observations and firms in each of the five samples we use in the regression analysis are shown in Table 8, where the various restrictions applicable to each sample are summarized.

Table 8: Description of samples used in the regression analysis

Sample	Description of sample	Number of observations	Number of firms
Large	Manufacturing-sector firms but excluding oil and aircraft and boats subsectors	1,961	804
hm95clean	Large sample excluding observations where: • VA per worker ≤ 0 • IQR-based trimming of the values of VA per worker, sales per worker, fixed capital per worker and R&D per worker • Growth rates of sales, employment, and fixed capital less than –50% or greater than 200% • Growth rate of VA less than –90% or greater than 300%	1,245	465
mh96clean	Large sample excluding observations where: • VA per worker ≤ 0 • Growth rates of sales, employment, and fixed capital less than –50% or greater than 200% • Growth rate of VA less than –90% or greater than 300%	1,533	578
Large incl. aircraft and boats	Large sample including aircraft and boats subsector	1,993	817
Large incl. R&D/Sales ratio > 0.1%	Large sample including observations where the R&D to sales ratio is greater than 0.1%	1,075	410

Notes. VA, value added; IQR, interquartile range.

Source: authors, based on SARS-NT panel.

The sign, magnitude, and standard errors of the R&D coefficients remains consistent using pooled OLS and within-industry estimates on the *mh96clean*, *hm95clean*, and *large incl. aircraft and boats* samples (Table A1 in the Appendix). Across all specifications, including the aircraft and boats subsector in the sample (*large incl. aircraft and boats* sample) does not change the coefficients or standard errors on R&D significantly. For both the within- (fixed effects) and first-difference estimators, the sign of the coefficient on R&D does not change, but coefficient size is smaller and more precisely estimated using the *mh96clean* and *hm95clean* samples compared to the *large* sample.

The *large* sample contains a disproportionately high number of firms with R&D to sales ratios of less than 0.1 per cent. We run an additional robustness check, where we restrict the *large* sample to contain firms with an R&D to sales ratio of greater than 0.1 per cent only (i.e. using the *Large and R&D/Sales > 0.1* sample) to test if this has any substantial effect on the results found using the other samples. Across all specifications, the magnitude of the coefficient on R&D is much larger when only including firms with a mean R&D to sales ratio of greater than 0.1 per cent. These estimates are also less precisely estimated, with larger standard errors compared to the *large*, *mh96clean*, and *hm95clean* samples.

On aggregate, however, the elasticity of output with respect to R&D using different samples and value added as the measure of output remains relatively consistent and mostly statistically significant when compared to the estimates using the *large* sample. This indicates that the estimates using the *large* sample are robust to different econometric specifications and sample restrictions. Across all samples, the R&D elasticity magnitudes range from 0.03 to 0.14. These results compare very similarly to other studies in the literature that use similar econometric approaches (see Table 1). Mairesse and Hall (1996) estimate an R&D elasticity coefficient of 0.176 (0.004) using a production function with industry dummy variables and output proxied for by value added based on a sample of 1,232 French firms from 1981 to 1989. They find a similar result 0.173 (0.013) for US firms over the same period using a sample of 1,073 US firms, but with gross sales as output. Harhoff (1998) estimate an R&D elasticity of between 0.11 (0.14) and 0.14 (0.01) when both correcting for and not correcting for double-counting of R&D in other input variables based on a sample of 443 German manufacturing firms over the period 1979–1989. Griffith et al. (2006) find an R&D elasticity estimate of 0.03 (0.01) for 188 UK manufacturing firms from 1990 to 2000. Rogers (2009), however, obtains an estimate of 0.12–0.23 using a value-added production function with R&D flow as input based on a sample of 719 UK firms from 1989 to 2000. These finding hold very similarly when using gross sales as the measure of output, both including and excluding materials as an input factor (Tables A2 and A3 in the Appendix). There are only two instances in which the sign on the elasticity of R&D changes from positive to negative, using first differences with materials included as an input factor. These results also remain relatively consistent across different samples when using long differences to estimate the elasticity of R&D (Table 9).

Table 9: Productivity regressions using long differences 2009–2014

	Large	*mh96clean*	*hm95clean*	*Large incl. aircraft and boats*	*Large and R&D/S > 0.1*
Dependent variable: value added					
Log L	0.099***	0.230***	0.299***	0.099***	0.087**
	(0.032)	(0.056)	(0.068)	(0.032)	(0.039)
Log C	0.023	0.073**	0.132	0.023	0.012
	(0.022)	(0.035)	(0.040)	(0.022)	(0.032)
Log M					
Log R	0.084***	0.020*	0.024*	0.088***	0.134***
	(0.014)	(0.011)	(0.012)	(0.014)	(0.020)
R^2 (s.e.)	0.031	0.028	0.049	0.027	0.073
Number of observations	1,117	944	784	1,135	636
Dependent variable: sales					
Log L	0.036***	0.110***	0.149***	0.036***	0.043**
	(0.013)	(0.028)	(0.036)	(0.013)	(0.018)
Log C	0.026	0.056	0.087	0.026***	0.032**
	(0.009)	(0.017)	(0.021)	(0.009)	(0.015)
Log M	0.655***	0.487***	0.414***	0.659***	0.508***
	(0.020)	(0.022)	(0.025)	(0.020)	(0.030)
Log R	0.032***	0.005	0.003	0.033***	0.040***
	(0.006)	(0.005)	(0.006)	(0.005)	(0.009)
R^2 (s.e.)	0.524	0.468	0.432	0.523	0.524
Number of observations	1,119	943	783	1,138	638
Dependent variable: sales					
Log L	0.080***	0.136***	0.198***	0.081***	0.072
	(0.023)	(0.040)	(0.046)	(0.023)	(0.025)
Log C	0.060***	0.066***	0.103***	0.061***	0.058***
	(0.016)	(0.025)	(0.028)	(0.016)	(0.020)
Log M					
Log R	0.041***	-0.002	0.002	0.045***	0.081***
	(0.001)	(0.008)	(0.008)	(0.010)	(0.012)
R^2 (s.e.)	0.034	0.026	0.051	0.032	0.076
Number of observations	1,120	944	784	1,139	638

Notes: Robust standard errors in parenthesis

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: authors, based on SARS-NT panel.

7.2 Return to R&D in South Africa

Our empirical strategy for estimating the returns to R&D in South Africa is essentially comparative. We obtain estimates of R&D intensity that we can compare to those obtained in previous studies (as previously noted, largely relating to firms in OECD countries). We also use estimation methods that are comparable to those used in these earlier studies. The measurement and estimation issues that have beset previous researchers are present for us as well, but this also allows us to compare our results more directly to these studies. In summary, we find that: (1) R&D intensity, as measured by the R&D to sales ratio, in South African manufacturing firms is considerably lower than that observed in previous studies; (2) the elasticity of output with respect to R&D is within the range observed in previous studies; and (3) as a simple matter of arithmetic—since the return to R&D is the elasticity times the inverse of the R&D intensity—(1) and (2) imply that the estimated return to R&D in South Africa is high compared to that found for other countries. The worked example below to calculate the estimated return to R&D using the theoretical framework discussed in Section 4 demonstrates these findings.

Estimating the R&D intensity ratio $\left(\frac{\boldsymbol{K}}{\boldsymbol{Y}}\right)$

Using the approximation used in the literature surveyed by Hall et al. (2009):

$$K_{it} \approx 5\, R_{it}$$

$$\frac{K}{Y} \approx 5 * \frac{R}{Sales} \approx 5 * 0.34 \approx 1.7 \text{ per cent}$$

$$\frac{K}{Y} \approx 5 * \frac{R}{Value\ added} \approx 5 \times 1.2 \approx 6 \text{ per cent}$$

Estimating the marginal product of R&D capital $(\hat{\boldsymbol{\rho}})$

$$\hat{\rho} = \hat{\gamma} / \left(\frac{K}{Y}\right)$$

and $\hat{\gamma}$ (estimate of the elasticity of output with respect to R&D) is estimated to range between 0.02 and 0.14 using either sales or value added as the measure of output across a range of estimation techniques. Therefore, assuming $\hat{\gamma}$ = 0.02 and $\frac{K}{Y} = 0.017$ (using sales as output), then

$$\hat{\rho} = \hat{\gamma} / \left(\frac{K}{Y}\right)$$ = 1.18 (implying a rate of return of **118 per cent**)

Assuming $\hat{\gamma}$ = 0.05 and $\frac{K}{Y} = 0.017$ (using sales as output), then

$$\hat{\rho} = \hat{\gamma} / \left(\frac{K}{Y}\right)$$ = 2.94 (implying a rate of return of **294 per cent**)

Assuming $\hat{\gamma}$ = 0.02 and $\frac{K}{Y} = 0.06$ (using value added as output), then

$$\hat{\rho} = \hat{\gamma} / \left(\frac{K}{Y}\right)$$ = 0.33 (implying a rate of return of **33.3 per cent**)

Assuming $\hat{\gamma}$ = 0.14 and $\frac{K}{Y} = 0.06$ (using value added as output), then

$$\hat{\rho} = \hat{\gamma} / \left(\frac{K}{Y}\right)$$ = 2.33 (implying a rate of return of **233 per cent**)

Typical results from studies using this method (via $\hat{\gamma}$) generate an R&D elasticity ranging from 0.05 to 0.25 if value added is used to measure output, and from 0.02 to 0.15 if sales is used to measure output. These studies mostly find a rate of return of R&D of 20–80 per cent (predominantly for OECD countries). Therefore the implied rate of return to R&D in South Africa is high by international standards. Intuitively this makes sense, given the low prevalence, persistence, and intensity of R&D of those firms that do R&D in South Africa.

There are a number of interpretations for these results. First, it may be that our findings are genuine—the return to R&D is very high in South Africa compared to other countries. Second, it could be because of an upward bias that operates in South Africa but not (or not to anything like the same extent) in the countries/datasets in the other studies surveyed by Hall et al. (2009) and cited here. The leading culprit for this would be omitted variable bias, and specifically innovative activity that is not being recorded as R&D. We raised the point earlier that R&D activity, and innovative activity in general, in firms in a catching-up country that is not at the technological frontier may be different from that in firms that are at the frontier. For this reason, R&D expenditure that we have recorded from firms may not accurately reflect the true level of R&D activity and innovation taking place in firms more broadly. It is also possible that both of these explanations are true, since they are not mutually exclusive.

8 Concluding remarks

From a global perspective, there has been a persistent slowdown in productivity growth over recent decades in many advanced economies, and more recently this slowdown has extended to emerging economies (OECD 2016). This is concerning given that productivity gains are considered a central driver of long-term improvements in living standards. It is argued that to boost productivity growth, policy action to address the obstacles to knowledge and technology diffusion is required, while continuing to support technological progress and innovation at the frontier. Understanding the dynamics of innovation activity at the country and firm level is therefore of critical importance to contribute to the development of a supportive policy environment. Policy reforms and additional instruments, where appropriate, can foster greater levels of innovation practice, drive productivity growth, and thereby contribute to raising average living standards, a particularly urgent need in South Africa.

This research provides a deeper understanding into the dynamics of R&D expenditure at a firm level in South Africa over the period 2009–2014. The interpretation of the findings summarized and discussed above raises important public policy questions around the need to better nurture and support innovation practice, such as investment in R&D, and thereby drive longer-term productivity growth, which is critical for South Africa to transition from an upper middle-income country to a more developed economy.

One possible explanation for the implied high rate of return to R&D relates to how innovative activity in a catching-up country like South Africa might differ from that in an OECD country on the technological frontier. If the composition of spending on innovative activity in South Africa is such that less is spent on R&D and more is spent on licensing and similar activities that import (buy-in) established technology, it could explain in part the high return to R&D that we find. If R&D spending and this (unmeasured in our study) buy-in spending are correlated, then we have omitted variable bias and the elasticity is biased upwards (and more so than in OECD countries), basically because our R&D variable is also proxying for this unobserved innovative activity. This would then imply a lower rate of return than our results are suggesting from this analysis.

This study contributes to broadening our understanding of the persistence, intensity, and returns to R&D expenditure in South Africa at a firm level, which is linked directly to innovation. Based on these results, potential policy considerations may centre around methods to do the following. (1) Build on existing innovation system strengths across industry to develop a knowledge infrastructure base (e.g. revitalize the mining research, development, and innovation (RD&I) capability in the country, so that South Africa can once again be sought after as a focal point for mining RD&I offerings, particularly into the region). (2) Improve the governance and design of existing innovation policies, such as the R&D Tax Incentive and Industry Innovation Partnership (IIP) to make accessibility and administration as user-friendly as possible. (3) Increase private-sector participation and stakeholder buy-in for large R&D projects with the potential to create substantial new industries and niche markets (e.g. the CSIR has allocated R150 million in 2017/2018 to establish a focused research and technology development programme that will improve the competitiveness of the local mining equipment manufacturing firms and also assist them to develop technology solutions and products required for narrow reef, hard rock mining, increase mine safety and productivity, and reduce the costs that will ultimately extend the working lives of mines). (4) Improve access to local and export markets through a combination of industry spending (e.g. export credit financing that is not cross-cutting) and investment that enhances the quality of and access to logistics infrastructure to lower logistics costs for firms. (5) Expand on the availability of early stage funding and establish sectoral innovation funding instruments to address technology and innovation issues within sectors, based on joint public–private funding.

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Appendix

Table A1: Productivity regressions 2009–2014, dependent variable: log value added, beginning period fixed capital

	Large	*mh96clean*	*hm95clean*	*Large incl. aircraft and boats*	*Large and R&D/S > 0.1*
Pooled OLS					
Log L	0.493***	0.493***	0.607***	0.495***	0.375***
	(0.040)	(0.041)	(0.042)	(0.040)	(0.048)
Log C	0.177***	0.226***	0.148***	0.176***	0.114***
	(0.026)	(0.030)	(0.027)	(0.025)	(0.030)
Log M					
Log R	0.132***	0.113***	0.081***	0.131***	0.375***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.027)
R^2 (s.e.)	0.640	0.690	0.682	0.641	0.696
Number of observations	1,518	1,221	1,011	1,543	828
Within industry					
Log L	0.531***	0.532***	0.637***	0.532***	0.413***
	(0.040)	(0.042)	(0.043)	(0.040)	(0.051)
Log C	0.175***	0.220***	0.148***	0.174***	0.108***
	(0.025)	(0.029)	(0.026)	(0.025)	(0.029)
Log M					
Log R	0.121***	0.102***	0.070***	0.120***	0.361***
	(0.014)	(0.013)	(0.014)	(0.014)	(0.029)
R^2 (s.e.)	0.660	0.707	0.704	0.661	0.710
Number of observations	1,518	1,221	1,011	1,543	828
Within firm (fixed effects estimator)					
Log L	0.080	0.214***	0.318***	0.086	-0.020
	(0.061)	(0.078)	(0.080)	(0.062)	(0.054)
Log C	0.054*	0.101**	0.134***	0.054*	0.096
	(0.030)	(0.040)	(0.038)	(0.030)	(0.071)
Log M					
Log R	0.038**	0.019**	0.017	0.038***	0.107***
	(0.015)	(0.009)	(0.011)	(0.014)	(0.027)
R^2 (s.e.)	0.581	0.673	0.665	0.586	0.572
Number of observations	1,518	1,221	1,011	1,543	828
First differences					
Log L	0.062	0.247***	0.305***	0.064	0.020
	(0.058)	(0.068)	(0.069)	(0.058)	(0.075)
Log C	0.024	0.026	0.039*	0.025	0.025
	(0.023)	(0.020)	(0.022)	(0.023)	(0.035)
Log M					
Log R	0.032*	0.005	0.006	0.032*	0.082*
	(0.019)	(0.013)	(0.015)	(0.018)	(0.047)
R^2 (s.e.)	0.023	0.034	0.053	0.021	0.054
Number of observations	766	664	552	781	442

Between estimator (end period fixed capital)					
Log L	0.472***	0.503***	0.640***	0.473***	0.394***
	(0.031)	(0.034)	(0.037)	(0.031)	(0.036)
Log C	0.159***	0.174***	0.094***	0.158***	0.089***
	(0.018)	(0.020)	(0.022)	(0.018)	(0.021)
Log M					
Log R	0.134***	0.116***	0.075***	0.133***	0.387***
	(0.015)	(0.015)	(0.016)	(0.014)	(0.026)
R^2 (s.e.)	0.598	0.654	0.644	0.599	0.677
Number of observations	1,858	1,477	1,219	1,888	1,004

Notes: Robust standard errors in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: authors, based on SARS-NT panel.

Table A2: Productivity regressions 2009–2014, dependent variable: log sales, beginning period fixed capital

	Large	*mh96clean*	*hm95clean*	*Large incl. aircraft and boats*	*Large and R&D/S > 0.1*
Pooled OLS					
Log L	0.116***	0.118***	0.165***	0.117***	0.095***
	(0.017)	(0.019)	(0.026)	(0.017)	(0.018)
Log C	0.030***	0.029***	0.028***	0.030***	0.012
	(0.010)	(0.008)	(0.009)	(0.010)	(0.010)
Log M	0.786***	0.807***	0.747***	0.785***	0.767***
	(0.028)	(0.024)	(0.032)	(0.028)	(0.028)
Log R	0.025***	0.021***	0.021***	0.025***	0.092***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.015)
R^2 (s.e.)	0.944	0.960	0.952	0.945	0.947
Number of observations	1,528	1,224	1,008	1,553	837
Within industry					
Log L	0.125***	0.128***	0.175***	0.126***	0.107***
	(0.018)	(0.019)	(0.030)	(0.018)	(0.018)
Log C	0.032***	0.030***	0.031***	0.032***	0.010
	(0.010)	(0.008)	(0.009)	(0.010)	(0.010)
Log M	0.784***	0.805***	0.743***	0.783***	0.778***
	(0.030)	(0.024)	(0.032)	(0.027)	(0.025)
Log R	0.021***	0.017***	0.017***	0.032***	0.079***
	(0.005)	(0.004)	(0.005)	(0.010)	(0.014)
R^2 (s.e.)	0.947	0.962	0.954	0.947	0.951
Number of observations	1,528	1,224	1,008	1,553	837
Within firm (fixed effects estimator)					
Log L	0.049	0.083**	0.126**	0.051	-0.001
	(0.034)	(0.038)	(0.048)	(0.034)	(0.020)
Log C	0.019*	0.043***	0.059	0.018*	0.030**
	(0.010)	(0.016)	(0.020)	(0.009)	(0.011)
Log M	0.429***	0.531***	0.497***	0.432***	0.561***
	(0.123)	(0.091)	(0.102)	(0.121)	(0.116)
Log R	0.006	0.007**	0.006*	0.007	0.044
	(0.008)	(0.003)	(0.004)	(0.007)	(0.013)
R^2 (s.e.)	0.937	0.956	0.946	0.938	0.940
Number of observations	1,528	1,224	1,008	1,553	837
First differences					
Log L	0.045	0.121***	0.165***	0.047	0.013
	(0.036)	(0.040)	(0.047)	(0.037)	(0.035)
Log C	0.008	0.009	0.023*	0.009	0.016
	(0.010)	(0.010)	(0.013)	(0.010)	(0.017)
Log M	0.373***	0.348***	0.308***	0.381***	0.365***
	(0.138)	(0.117)	(0.116)	(0.137)	(0.006)
Log R	0.005	-0.005	-0.004	0.005	0.013
	(0.008)	(0.009)	(0.009)	(0.008)	(0.021)
R^2 (s.e.)	0.330	0.410	0.391	0.338	0.293
Number of observations	774	660	548	789	448

Between estimator (end-of-period fixed capital)					
Log L	0.114***	0.126***	0.175***	0.114***	0.097***
	(0.013)	(0.013)	(0.017)	(0.012)	(0.015)
Log C	0.031***	0.017**	0.017**	0.031***	0.012
	(0.007)	(0.008)	(0.009)	(0.007)	(0.008)
Log M	0.778***	0.803***	0.743***	0.777***	0.775***
	(0.012)	(0.012)	(0.014)	(0.012)	(0.017)
Log R	0.024***	0.021***	0.019***	0.024***	0.090***
	(0.006)	(0.006)	(0.006)	(0.005)	(0.012)
R^2 (s.e.)	0.943	0.956	0.949	0.944	0.949
Number of observations	1,872	1,485	1,215	1,903	1,015

Notes: Robust standard errors in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: authors, based on SARS-NT panel.

Table A3: Productivity regressions 2009–2014, dependent variable: log sales, beginning period fixed capital

	Large	*mh96clean*	*hm95clean*	*Large incl. aircraft and boats*	*Large and R&D/S > 0.1*
Pooled OLS					
Log L	0.455***	0.473***	0.582***	0.457***	0.339***
	(0.039)	(0.040)	(0.040)	(0.038)	(0.044)
Log C	0.194***	0.238***	0.177***	0.192***	0.125***
	(0.025)	(0.029)	(0.029)	(0.024)	(0.028)
Log M					
Log R	0.121***	0.107***	0.077***	0.120***	0.372***
	(0.014)	(0.015)	(0.014)	(0.014)	(0.028)
R^2 (s.e.)	0.656	0.705	0.737	0.657	0.738
Number of observations	1,536	1,230	1,011	1,561	842
Within industry					
Log L	0.490***	0.514***	0.607***	0.491***	0.371***
	(0.038)	(0.039)	(0.039)	(0.038)	(0.045)
Log C	0.182***	0.223***	0.174***	0.181***	0.108***
	(0.024)	(0.028)	(0.027)	(0.024)	(0.027)
Log M					
Log R	0.114***	0.098***	0.068***	0.113***	0.369***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.028)
R^2 (s.e.)	0.679	0.726	0.759	0.681	0.751
Number of observations	1,536	1,230	1,011	1,561	842
Within firm (fixed effects estimator)					
Log L	0.078*	0.204***	0.277***	0.084*	0.035
	(0.047)	(0.063)	(0.071)	(0.048)	(0.047)
Log C	0.033**	0.103***	0.125	0.033**	0.072***
	(0.015)	(0.023)	(0.030)	(0.014)	(0.020)
Log M					
Log R	0.020**	0.004	0.006	0.022***	0.087***

	(0.008)	(0.005)	(0.005)	(0.008)	(0.022)
R^2 (s.e.)	0.526	0.667	0.711	0.541	0.654
Number of observations	1,536	1,230	1,011	1,561	842
First differences					
Log L	0.053	0.199***	0.252***	0.056	0.040
	(0.041)	(0.050)	(0.052)	(0.041)	(0.050)
Log C	0.022	0.013	0.030*	0.024	0.033
	(0.014)	(0.014)	(0.017)	(0.015)	(0.024)
Log M					
Log R	0.023**	0.002	0.005	0.024**	0.053**
	(0.010)	(0.005)	(0.006)	(0.010)	(0.023)
R^2 (s.e.)	0.029	0.045	0.083	0.031	0.057
Number of observations	782	668	552	797	453
Between estimator (period fixed capital)					
Log L	0.451***	0.489***	0.615***	0.452***	0.360***
	(0.029)	(0.032)	(0.033)	(0.028)	(0.032)
Log C	0.181***	0.191***	0.132	0.179***	0.110***
	(0.017)	(0.020)	(0.020)	(0.017)	(0.019)
Log M					
Log R	0.119***	0.109***	0.076***	0.118***	0.380***
	(0.014)	(0.014)	(0.014)	(0.013)	(0.023)
R^2 (s.e.)	0.624	0.672	0.707	0.625	0.723
Number of observations	1,883	1,493	1,219	1,914	1,023

Notes: Robust standard errors in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: authors, based on SARS-NT panel.