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# Structure of R&D capital expenditure and national total factor productivity

**Juniours Marire** 

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## DEVELOPMENT ECONOMICS | RESEARCH ARTICLE Structure of R&D capital expenditure and national total factor productivity Juniours Marire<sup>1</sup>\*

Abstract: This paper examines the relationship between the structure of R&D fixed capital spending, measured as the ratio of the private sector to public sector R&D capital expenditure, and national total factor productivity. It employs South African data for the period 1965 to 2019. This study employs the nonlinear distributed lag modelling framework to cater for non-linearities in the relationship. The findings, first, suggest that the ratio of private sector to public sector R&D capital spending has a positive effect on total factor productivity. Second, the structure of R&D capital spending has large asymmetric effects on national total factor productivity, with negative changes dominating positive changes. Negative changes in the structure of R&D capital spending negatively influence total factor productivity, but positive changes have positive effects. Both in the short run and the long run, cumulative multipliers indicate that negative changes in the structure of R&D capital spending dominate positive changes by a very large margin. The findings imply that the private sector must become more dominant than the public sector in R&D capital spending in the national system of innovation.



Juniours Marire

## ABOUT THE AUTHOR

Juniours Marire is a lecturer at Rhodes University in South Africa. My current portfolio of research focuses on the link between productivity and R&D expenditures, and fiscal policy and productivity, as well as the effect of finance-led growth model on productivity growth. The current paper contributes to this portfolio by examining the role of capital expenditure in the R&D domain, an area of investment that has not received much attention recently.

### PUBLIC INTEREST STATEMENT

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Investing in research and development plays an important role in driving economic development. South Africa has been battling a declining share of private investment in research and development capital for nearly two decades. The purpose of this study is to examine the effect of the structure of research and development expenditure on fixed capital. The structure of research and development capital spending is measured as the ratio of private to public research and development capital spending. The paper finds that as the structure of research and development capital spending becomes more dominated by private spending relative to public spending, productivity grows faster. The study also found that when the structure becomes more public sector dominated, the decrease in productivity is much larger than the increase in the same if the private sector dominates spending. The implication for policy is that private sector spending on R&D must be encouraged.





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Keywords: <R&D capital expenditure; non-linear autoregressive distributed lag model; total factor productivity; white paper on science and technology; techno-military regime; capital budget

#### 1. Introduction

The role of public capital in promoting productivity growth has been a subject of debate for several decades and has been resurrected recently following declining productivity levels in many countries. For example, extending the World Bank's Long Term Growth Model, Kim and Loayza (2019) examined global changes in total factor productivity, while Yu and Yuping (2022) examined the role of public capital on productivity in the Chinese agriculture sector, and Rong (2020) examined whether the effect of public capital on productivity was any different under socialist-communist contexts. In the context of the European region, the same issue took up Beugelsdijk et al. (2018), as was Martino (2021) who focused on Italian regions.

It was Kaldor (1957, p. 596), in his model of economic growth, who postulated that "the growth in productivity will depend on the rate of growth in the capital stock." Kaldor (1961, p. 207) went on similarly to postulate that productivity was a function of the "speed with which capital is accumulated." Public capital could be decomposed into economic infrastructure (roads, energy, water, and research and development capital) and social infrastructure (schools, hospitals, and other social amenities infrastructure). Kaldor (1961) emphasised that the rate of capital accumulations has a lagged effect on the rate of productivity growth.

With reference to the African continent's poor growth record, Thirlwall (2015), and Wells and Thirlwall (2003), applying Kaldorian growth laws, demonstrated the existence of a substantial process of deindustrialisation, the causes of which included poor public capital accumulation, among others, resulting in high transaction costs of doing business. According to Koczyrkewycz et al. (2021), total factor productivity sits at the heart of the growth and development processes, and the capital stock explains its behaviour. They go as far as claiming that government expenditure might have either positive or negative effects.

Raising the levels of productivity at the micro and macro levels in an economy remains a crucial policy goal for many developing countries. D. Romer (2012) propounded that the share of capital and of labour allocated to R&D, as well as the existing stock of productive knowledge, were determinants of the growth rate of technology (also called total factor productivity growth). He showed that shocks to the shares of capital and labour allocated to R&D have a long-running effect on economic growth and productivity. This paper is concerned with the structure of the share of fixed capital allocated to R&D, which is decomposable into the private sector component and the public sector component. The ratio of the private sector to public sector R&D capital spending is of immediate concern in the present paper because it summarises the structure of R&D capital. structure of fixed capital allocated to R&D, it is meant the relative contribution of the private sector and government to capital expenditure allocation to the R&D processes. The discussion in D. Romer (2012) considers the stock of capital but does not take into account the structure of fixed capital committed to R&D. The structure of R&D fixed capital expenditure helps us understand whether private sector R&D capital spending drives the productivity growth process more than public sector R&D capital spending. This knowledge is helpful is the design of R&D investment incentive structures.

Nations have designed institutions, policies, and strategies to improve the productivity of their economies. The efforts targeted at improving national productivity include setting up national systems of innovation and investing in health, education, fixed capital within the innovation ecosystem and providing incentives for productivity-enhancing innovations. The first world and

the newly industrialising nations of Latin America and East Asia followed such development strategies, with fiscal policy playing a crucial role in some cases (Gore, 2000; M. H. Khan et al., 2000; M. Khan & Blankenburg, 2009; Rodrik, 2006). The catch-up process became much shorter than usual because of sustained levels of total factor productivity and in some cases, like China, sustained repression of wages (Amsden, 2001; Burger, 2014).

Not all countries that have embarked on this path of economic transformation have succeeded in unleashing the latent productivity potential they possess. Some countries have been locked into a low productivity growth mode despite substantial fiscal and other public policy incentives (Scerri et al., 2013). Such is the case of South Africa. For example, Aghion et al. (2008) empirically established that concentration of market power, as reflected in high product mark-ups, undermined national productivity in South Africa. According to Mbeki (2009) and North et al. (2012), the lack of economic competition buttressed by the lack of political competition seems to play an important constraining role in productivity growth in South Africa. More recently, Burger et al. (2016) and Burger and Calitz (2020) have shown that the government has been misallocating fiscal resources to consumption expenditure relative to fixed capital expenditure. They claim that the misallocation continues to undermine the long-run productivity of the economy. Yet more significantly, some scholars have argued that the problem underpinning the low productivity performance of the South African economy is underinvestment by the private sector. For example, literature suggests that the private sector is hoarding excess cash, which could have been invested into productivity-enhancing innovations (Diaw, 2020; Dudley & Zhang, 2016; Karwowski, 2015). However, Keeton (2018) disputes the excess corporate cash holdings claim as a myth.

Other scholars who have examined the productivity performance of South Africa have identified other potential drivers of micro and macro productivity of the economy. Ngepah (2012) demonstrated that focusing on building healthy long lives would positively influence productivity in South Africa. From a different angle, Jajri (2007) argued that increasing trade openness stimulates national productivity, but Torfinn and Jørn (2005) found that trade tariff policies in South Africa undermined this channel of productivity growth in South Africa. Wakeford (2004) held the view that productivity in South Africa had outgrown the wage share in GDP, suggesting two forces at work, namely job-replacing technology and capital intensification of production processes. Very interestingly, Ting (2020) has shown that the size of the wage share in GDP moves inversely to productivity.

Makuyana and Odhiambo (2016) investigated fixed capital accumulation in South Africa and found that the large-scale public investment activities of the apartheid government crowded in large levels of private capital. In a similar manner, Ncanywa and Makhenyane (2016) examined the effect of gross fixed capital formation on economic growth in South Africa and established a bidirectional causal relationship between them. As the nature of the fixed capital spending matters, the current study focuses on the role of the structure of R&D capital expenditure in the productivity growth process. This issues is quite important given that since the adoption of the White Paper on Science and Technology of 1996, government is searching for ways to make the national system of innovation vibrant. Literature has mostly examined the contribution of public capital in the form of transport infrastructure, education and health, as well as water and sanitation infrastructure to productivity (Baltagi & Pinnoi, 1995; Holtz-Eakin, 1994; Kim & Loayza, 2019; Makuyana & Odhiambo, 2016; Ncanywa & Makhenyane, 2016). For this reason, looking at the effect of the structure of R&D fixed capital spending on TFP is essential and deserves empirical investigation because it brings us closer to examining the effect of the mix of R&D capital that is allocated to R&D directly.

Complementary to the contestations about the productivity performance of South Africa, the purpose of this paper is to examine the influence of TFP on the evolution of the structure of research and development (R&D) capital expenditure. The ratio of private to public sector R&D capital expenditure captures the structure or mix of R&D capital expenditure and examining its

effect on national productivity is the main concern of the paper. The structure of R&D fixed capital and its effect on productivity has not been considered in the literature. The focus on the structure of R&D capital expenditure allows for a discussion of the effect of the relative growth rates of the two streams of R&D capital expenditure, private and public. There is a sense in which some scholars believe that the government is not investing enough in fixed capital relative to the private sector (Burger & Calitz, 2020; Burger et al., 2016), and another sense in which others believe the converse is true (Diaw, 2020; Karwowski, 2015; Makuyana & Odhiambo, 2016). The relative growth rates in these two streams of R&D capital expenditure help answer the question of why South Africa's productivity performance has been dismal and to infer whether the productivity growth process is private sector-driven or public sector-driven. The distinction speaks to the debate about whether economic transformation is a spontaneous market-led or purposeful state-led process. Further, the general belief is that the private sector deploys its R&D capital outlays more efficiently than public sector outlays. Thus, the behaviour of the ratio of the private sector to the public sector R&D capital expenditure in relation to TFP also captures the efficiency aspect. South Africa has been aspiring to be a developmental state following the footsteps of East Asian tigers (Burger, 2014; Edigheji, 2010). Therefore, understanding the relative growth rates of the two streams of spending on R&D fixed capital, and how they influence total factor productivity, is essential to understanding ways of unlocking total factor productivity growth.

This paper takes advantage of a long time series on private and public R&D fixed capital spending, which has not been used in all existing studies that the author is aware of. The study period runs from 1965 to 2019. Using a non-linear autoregressive distributed lag model, the study found, firstly, that private sector dominance in R&D capital spending over government R&D capital spending increases the productivity of the economy in the long run. Secondly, both in the short run and the long run, cumulative multipliers of negative changes in the ratio of private sector R&D capital spending to government R&D capital spending dominate positive changes by a very large margin. The findings suggest that greater involvement of the private sector relative to government in the accumulation of R&D fixed capital plays a crucial role in raising the level of total factor productivity. This finding touches on a concern that was raised in the National Research and Development Strategy (2000–2009), which showed that private investment in R&D was declining over time.

The contribution of the study to the literature is fourfold. First, the paper uses unique time-series data—private and public R&D fixed capital accumulation—that have never been used in empirical investigations to answer a crucial question that is seizing scholars globally. Controlling for the structure of R&D fixed capital has demonstrated that private capital in R&D plays a greater role in increasing the total factor productivity. This complements literature that focuses on the effect of private capital on TFP. Second, the debate in South Africa is that government is underinvesting in fixed capital and the paper's finding on the contribution of private sector relative to the government sector provides new and complementary insights into the public policy question. Third, the paper uses a non-linear modelling framework that captures asymmetries in the effect of the structure of R&D capital spending on productivity. Fourth, the paper contributes to the search for answers to the question of why South Africa's total factor productivity has remained subdued and what could be done to unlock it. The answer the paper gives is that the government needs to promote greater private sector investment in R&D fixed capital accumulation. Existing literature on corporate savings suggests that South African firms are building up excess savings and not investing in them.

The rest of the paper is organised as follows: Section 2 reviews the literature. Section 3 reviews the trends in key variables. Section 4 presents the methods and data. Section 5 presents results and Section 6 discussions and conclusions.

#### 2. Literature review

In the well-known neoclassical growth model of Solow (1956), total factor productivity (TFP) was conceptualised as a residual of a well-behaved production function of a Cobb-Douglas type. By conceptualising TFP as a residual, the Solow growth model could not explain its determinants as it was treated as an exogenous variable. Kaldor (1957, 1961) provided a counter model in the Post-Keynesian tradition, which postulated that total factor productivity was endogenous, and determined by the rate of capital accumulation and society's ability to absorb the new capital (e.g. new machines that embody new ideas). Since the offering of the Kaldorian model and the subsequent offering of the endogenous growth model (P. M. Romer, 1990), it has become more apparent that technological change has a production function, the inputs of which include the existing stock of knowledge, physical capital, and human capital.

The literature demonstrates the importance of human capital in promoting technological change (Alston et al., 2009; Edigheji, 2010; P. M. Romer, 1990). Coe et al. (2009) have shown that, even after accounting for the effect of the human capital stock on total factor productivity (TFP), domestic and foreign R&D capital stocks considerably influence TFP. However, Engelbrecht (1997) found the effect of domestic R&D capital to be smaller than what had been empirically established earlier (e.g. by Coe and Helpman (1995)). R&D capital expenditure is crucial for transforming economies from low productivity trajectories to high productivity trajectories. Both the public and private sectors contribute significantly towards R&D capital expenditure. However, Alston et al. (2009) argued that the private sector tends to focus on short-term gains from R&D, which implies that its R&D capital expenditure might be lower than it ought to be. Short-termism and animal spirits in the private sector tend to make R&D capital expenditure unstable and procyclical (Akerlof & Shiller, 2010; Barlevy, 2007; Cozzi, 2005; Francois & Lloyd Ellis, 2003). As Barlevy (2007) argued, the short-term focus ends up manifesting as market failure when the level of private R&D capital spending falls short of the socially optimal.

Alston et al. (2009) pointed out the importance of public sector investment in R&D and emphasised that the public sector took a long-term view of R&D relative to the private sector. The longterm and short-term orientations of the two sectors made them complementary. They argued for a "healthy balance between the two and strong and growing support for both" (Alston et al., 2009, xi). Tsai and Wang (2004) went as far as demonstrating that the effect on total factor productivity (TFP) of the private sector expenditure on R&D is thrice the effect on the TFP of the public sector expenditure on R&D, while Voutsinas and Tsamadias (2014) found, for the Greek economy, evidence to the contrary. Similarly, Fuglie (2018) found TFPs in developing nations to have been driven more by private R&D spending and international R&D spillovers than by domestic public sector R&D spending. The results of a meta-analysis by Fuglie (2018) revealed that the elasticity of TFP to changes in public R&D capital expenditure was relatively low in sub-Saharan Africa (0.13) relative to the developed world (0.27). Levy and Terleckyj (1983) had earlier found evidence consistent with that of Fuglie (2018) and Tsai and Wang (2004).

The findings by Fuglie (2018) and Tsai and Wang (2004) point towards the desirability of a higher private sector to public sector R&D capital expenditure ratio. Coccia (2010), as did Bloch and Graversen (2012), Coccia (2011), Falk (2006), Rehman et al. (2020), and Wang et al. (2013), found that public and private R&D expenditures are complementary. They also demonstrated that the latter must be considerably higher than the former for national productivity to be unleashed in a transformative way. Notwithstanding, Rehman et al. (2020) found that animal spirits in the aftermath of an economic crisis eroded the complementarity between private and public R&D spending. David et al. (2000), however, maintained that the claim of complementarity is a result of methodological flaws in empirical measurement of R&D. At best, the relationship between private and public R&D capital expenditure is mixed—there might be crowding in or crowding out effects.

While R&D activity consumes knowledge and human capital, it can be equally emphasised that setting up R&D infrastructures such as laboratories that are fully equipped with modern equipment and setting up innovation hubs and science parks is indispensable to national productivity. Edquist and Henrekson (2017) found evidence that expenditure on R&D capital had significant lagged positive effects on total factor productivity growth. Englander et al. (1988) had earlier found a similar result but had also indicated that R&D capital expenditure, sometimes, passed through a phase of small to no effect on TFP. Rodrik and Subramanian (2009) argued that sub-Saharan African economies are capital-scarce, but their human capital accumulation is improving.

Literature suggests that economic growth, driven by TFP growth, responds to R&D expenditures, but the enduring challenge is that private R&D expenditures are highly procyclical (Barlevy, 2007). Short-termism in the priorities and decisions of private agents results in the procyclicality of R&D expenditures. The tendency is for R&D expenditures to remain sub-optimal persistently following political and economic shocks unless the government makes some Keynesian-type countercyclical intervention using the capital budget. Government intervention can take the form of subsidies for R&D expenditures or direct R&D expenditure through government agencies and state-owned enterprises. Literature finds that countercyclical R&D expenditures by government crowd-in private R&D expenditures, with the inevitable effect of increasing TFP (Coccia, 2010). Voutsinas and Tsamadias (2014) found, using vector error correction modelling, that public R&D capital expenditure than it was to private R&D capital expenditure. Szarowská (2017) concurred that government R&D spending, rather than private R&D spending, had a positive effect on growth.

In much earlier studies, Hu (2001) and Levy and Terleckyi (1983) found that private sector R&D fixed capital had a statistically significant and larger effect on output per capita than public sector R&D fixed capital, which was statistically insignificant. Baltagi and Pinnoi (1995) also established, as did Holtz-Eakin (1994) that public capital had no significant effect on private sector productivity, while Nourzad and Vrieze (1995) found that public investment had positive effects in a crosscountry study. However, by disaggregating public capital, Baltagi and Pinnoi (1995), Kim and Loayza (2019) and Rong (2020) found that greater public spending on water and sanitation infrastructure had positive effects consistently in all model specifications they constructed. By controlling for several fixed and time effects and making several variations in model specification, Khanam (1996) established in the case of Canada, contrary to Baltagi and Pinnoi (1995) and Holtz-Eakin (1994), that government spending on public infrastructure positively impacted productivity. Bronzini and Piselli (2009) found that there was uni-directional causality from public capital (infrastructure) to productivity for Italian regions, and Destefanis and Sena (2005) for the same regions found that core infrastructure investments in energy, transport, water and telecommunications had the greatest effects on total factor productivity. Ilzetzki et al. (2013) established that fiscal multipliers for government spending on fixed capital were positive for developing countries, and the composition of the spending mattered as much.

Everaert and Heylen (2001) tested the effect of public capital on total factor productivity for the Belgian economy using single equation cointegration techniques. The positive causal effect of public capital on total factor productivity was strong and significant. Beugelsdijk et al. (2018), emphasising that differences in total factor productivity explain diverging growth paths for European economies, examined determinants of TFP and found, quite surprisingly, that the capital stock had no effect, but that the number of patents per worker, among other factors, had a positive effect on TFP. On the contrary, Martino (2021) established that public fixed capital investment had significant positive effect. Butkiewicz and Yanikkaya (2011) also established the same result, finding that even ineffective governments benefited from public capital spending. Extending the World Bank's Long Term Growth Model, Kim and Loayza (2019) examined global changes in total factor productivity and found that public fixed capital investment in water, road,

energy and sanitation infrastructures had sustained positive effects on productivity. The effect of public capital was no less effective in agriculture than it was in other sectors of the economy; Yu and Yuping (2022) empirically established this evidence in the case of the Chinese agricultural sector. The effect was quite large where the elasticity of total factor productivity to changes in public investment was estimated to be six. Rong (2020), for the Chinese economy as a whole, found results complementary to Yu and Yuping (2022).

According to the review, a high private sector to public sector R&D capital expenditure ratio, it seems, is desirable. The idea is that private R&D capital expenditure has more significant effects on total factor productivity than public R&D capital expenditure. The reason for this is that private R&D capital is managed and employed efficiently, which spills over to higher levels of total factor productivity. The review also shows that the public sector and private sector R&D capital expenditures are complementary. The review also demonstrates that private R&D capital is highly unstable and procyclical, and public R&D capital expenditure is crucial for total factor productivity growth. The hypothesis tested in this paper is that an R&D fixed capital expenditure structure that is more privately dominated than it is publicly dominated positively impacts total factor productivity. The next section reviews, for the South African economy, the evolution of the private sector to public sector to public sector R&D capital expenditure in relation to total factor productivity.

### 3. Evolution of total factor productivity in comparative context

Figure 1 casts South Africa's TFP productivity within a peer context. In general and first, Mauritius and Egypt have consistently outperformed South Africa in TFP terms. Second, the TFPs for all countries exhibit similar cyclical patterns with much higher TFPs in the pre-1990 period than the post-1990 period. Third, TFP has been increasing for South Africa since the 1960s and the advent of democracy marked a turning point in the trajectory, notwithstanding the slight recovery in the period 2000–2009. The recovery seems to have been influenced by the adoption of the White Paper on Science and Technology of 1996/7 and the setting up of various institutional arrangements and mechanisms to operationalise the national system of innovation. To operationalise the



# Figure 1. Average real total factor productivity 1954–2019.

Source: Calculated from the Federal Reserve Bank of St. Louis data

White paper, government adopted the National Research and Development Strateay 2000-2009 to deal with several problems that were constraining innovation, including the declining contribution of the private sector to R&D spending. The plan introduced measures such as tax credit for R&D spending and redistribution of R&D spending to provinces that lagged behind. Yet, the design and adoption of such institutions as the White paper and the National Research and Development Strategy has not helped South Africa regain the levels of TFP that were achieved in the 1960-1989 period. A comparison of the 1970-79 and 1980-89 periods shows that the sanctions imposed from 1985 to 1993 against apartheid did not have a major effect on TFP. It remained stable. One possible explanation is that import substitution industrialisation strategies adopted during this time resulted in a surge in public sector capital accumulation, with several major state-owned enterprises being created. Indeed, this period saw the development of a military-industry complex, which drove technological expansion (Scerri et al., 2013) and rising productivity as Figure 1 shows. According to Scerri et al. (2013), the adoption of a neoliberal policy framework-the Growth, Employment, and Redistribution policy (1996-2004), and the Accelerated and Shared Growth South Africa (2005-2008)—which emphasised fiscal consolidation resulted in underinvestment in capital and financing of innovation since the belief was that markets could correct price distortions of the apartheid era better. This undermined total factor productivity. As Scerri et al. (2013) points out, Science, Technology, and Innovation was afforded a peripheral status during the period 1998-2008. There was no integration of science, technology and innovation planning with human capital, industry, and trade planning. Although the White Paper provided for the use of extensive fiscal incentives to stimulate R&D activity, the neoliberal stance of the first decade of democratic transformation effectively blocked the use of these incentives. Thus, despite good policies on paper, they had no significant expansionary effect on TFP.

Figure 2 shows that TFP and the ratio of private to government R&D capital expenditure had a positive correlation in the pre-1990 period, while the two had a negative correlation in the post -1990 period. In the pre-1990 period, the ratio of private to government R&D spending was declining, while in the post-1990 period it was rising. This observation suggests that larger presents of the state in capital accumulation brought the apartheid state closer to a developmental state (Fine, 2010) than the market-based approach suggested by the rising ratio of private to government R&D capital spending in the post-1990 period. In general, the ratio of the private sector to



capital spending and total factor productivity in South Africa. Source: Plotted from South

African Reserve Bank, and Federal Reserve Bank of St. Louis data

Figure 2. Structure of R&D



public sector R&D capital spending exceeds a threshold of two on a decade upon decade of analysis, and Alston et al. (2009) and Tsai and Wang (2004) suggest that the impact on TFP and economic growth is transformative when the ratio surpasses two (2).

During apartheid (1949–1993), the pattern of capital accumulation was influenced by the state (Gentle, 2009) and threats to the apartheid government by the 1980s through to early 1990s saw an increase in the state-led pattern of capital accumulation, especially in the area of defence. The racial Keynesian system of state-led capital accumulation explains the slump in the ratio of the private sector to public sector R&D capital expenditure because government intervention in R&D capital expenditure increased at a faster rate than private R&D capital spending (Ndulu et al., 2008; Scerri et al., 2013). The fact that TFP slowly responded to the surge in state-controlled capital accumulation points to economic waste as Fedderke and Schirmer (2006) observed in the case of the manufacturing sector.

Crawford et al. (1999) indicated that during apartheid and the sanctions imposed on the Afrikaner government, the state adopted a capital and technology-intensive arms production strategy. Public sector R&D capital expenditure, as a result, rose sharply relative to private sector R&D capital expenditure, thus explaining the falling ratio in Figure 1 between 1965 and early 1990s. Crawford et al. (1999), indeed, suggest the coexistence of a techno-military regime with a distinct state-driven R&D capital expenditure program. State agencies such as Armscor and the National Institute of Defence Research became major conduits for channelling R&D expenditures into the techno-military regime. Defence R&D expenditure was estimated at 15% of the total R&D spending in the early 1980s and more than doubled to 32% by the mid–1980s (Crawford & Klotz, 1999) and trebled to nearly 48% by the end of the 1980s (Truesdell, 2009). In some cases, these shifts in R&D expenditure resulted in wasteful accumulation of R&D infrastructure (Fedderke & Schirmer, 2006; Truesdell, 2009).

The investments in military research and development, as well as production, created a wave of private industrial activity linked to the military industry, for example, the electronics industry that was still nascent in the early 1960s (Crawford et al., 1999; Truesdell, 2009). This created a military-industry complex that induced some dynamism into the economy as evidenced by rising TFP (Figure 2), albeit representing skewed priorities of the state. Military modernisation driven by technological capabilities and large R&D expenditures laid seeds for industrialisation. According to Maharajh et al. (2011), the apartheid government managed to develop a complex information and communications technology infrastructure that transformed some of its industrial sectors into globally competitive giants. To Truesdell (2009), in the post-apartheid era, government, unfortunately, is failing to use the military as a nucleus for driving further industrialisation and technological advancement. In other jurisdictions, military R&D spending crowds out private R&D spending (Guellec & Van Pottelsberghe De La Potterie, 2003), while in the USA defence R&D expenditure sits at the heart of the system of innovation (Alston et al., 2009).

South Africa is struggling to unlock growth, and scholars such as Burger et al. (2016) and Burger and Calitz (2020) have argued that the government needs to pursue fiscal consolidation to free up resources for investing in gross fixed capital to enhance national productivity. The years 1994–2008, for example, they argued, were characterised by an aggressive move towards fiscal sustainability, but with an undesirable decline in the government fixed capital-to-GDP ratio. R&D capital expenditure followed a similar trend in the years of aggressive fiscal consolidation.

Based on 10-year averages, the correlation between the ratio of private sector to public sector R&D capital expenditure and TFP (Figure 2) is positive for the greater part except in 1990–1999 and 2010–2019 periods. The divergence between the ratio of the private sector to public sector R&D capital expenditure and TFP seems to suggest untapped R&D potential and wasted spill over effects (Fedderke & Schirmer, 2006; Marire, 2021). However, the more credible explanation is that the divergence in the ratio of the private sector to public sector R&D capital spending and

TFP reflects the TFP-enhancing effect of rising public sector expenditure on R&D capital in relative terms. This observation is essentially the view that heterodox thinkers from the Keynesian and developmental state paradigms argue for (Edigheji, 2010; Kelton, 2020). The relationship between the trends of the variables seems to suggest the possibility of non-linear behaviour. This paper investigates this possibility.

R&D expenditure can undergo structural change. Sometimes economic crises induce structural change in R&D spending patterns. Barlevy (2007) established that R&D spending by the private sector was highly procyclical, rising significantly during booms and falling during recessions. Business cycles alter the behaviour of private players from a long-term commitment to R&D spending to a short-term focus on low-hanging fruits harvested through commercialisation of existing knowledge. Marire (2021) established that South African business R&D expenditure underwent structural change since the global financial crisis and hinted on the possibility of non-linear behaviour in the underlying data generating process. Business R&D expenditure allocated to applied research increased sharply without reversal, while expenditure allocated to experimental research declined sharply with a slight reversal of the trend.

D. Walwyn and Boraine (2006) and D. Walwyn and Cloete (2016) also expressed similar intellectual worry over declining business R&D spending. Rafferty (2003) found that business cycles have a significant influence over the composition of business R&D spending, but, unlike the case of South Africa, they found US firms to invest more in basic research than applied and experimental researches during recessions. Marire (2021) inferred that the changing structure of business R&D spending in favour of applied research relative to experimental and basic research was driven by animal spirits and undermined the productivity of the South African national system of innovation (NSI). Diaw (2020), Dudley and Zhang (2016), Harford et al. (2008), and Huang-Meier et al. (2016) argued that declining business R&D spending could be attributed to a build-up in corporate cash holdings.

The data employed by Marire (2021) was a short time series of only 15 years obtained from the Human Sciences Research Council, which made testing of any potential regime change of business R&D spending impossible. The present paper takes the hunch in Marire (2021) that a regime switch in the relationship between businesses R&D spending and innovation output might have occurred. Rather than focus on the effect of business R&D spending on the productivity of the NSI, the present effort examines the effect of the changing ratio of the private sector to public sector R&D capital expenditure on national total factor productivity. The existing literature employs linear econometric methods to model the effect of R&D capital expenditure on the total factor productivity (for example, Edquist & Henrekson, 2017; Voutsinas & Tsamadias, 2014). Given the prevalence of strong animal spirits in the evolution of business R&D capital expenditure, non-linearities are most likely to plague such analysis. The present effort overcomes that limitation in existing literature by employing non-linear time-series models (Schleer van Gellecom, 2013; Turkman et al., 2016).

Therefore, the present effort seeks to contribute to the current discourse by providing an examination of the non-linear behaviour of national total factor productivity in relation to the ratio of the private sector to public sector R&D capital expenditure. The paper takes advantage of a long time series on R&D capital expenditure collected by the South African Reserve Bank and the national total factor productivity constructed by the Federal Reserve Bank of St. Louis for the period 1965–2019. Such a long period makes non-linear analysis possible and informative.

#### 4. Materials and methods

#### 4.1. Variable description

Table 1 describes the variables used in the paper. The variables chosen for this paper were guided by the empirical literature. TFP can be measured in many ways including the use of Malmquist

Table 1. Definition of variables and measurement				
Variable	Description and measurement	Source		
Total factor productivity (TFP)	Measure of technological progress measured through the Malmquist Total Factor Productivity decomposition procedure.	Federal Reserve Bank of St. Louis		
Ratio of private to government R&D capital spending (lnpvt_gvt)	Private sector R&D capital spending to public sector R&D capital spending, expressed in logarithmic form.	South African Reserve Bank		
Capital intensity (lnintensity)	Gross fixed capital formation to economically active population, expressed in logarithmic form.	World Development Indicators		
Labour share in GDP (labshare)	Proportion of labour income to GDP	World Development Indicators		
Openness	Sum of exports and imports over GDP, percentage	World Development Indicators		
Financial development (findvpt)	Broad money (M <sub>3</sub> ) to GDP, percentage	South African Reserve Bank		

Total Factor Productivity index approach, growth accounting methods, and growth rate of gross value added per worker. The TFP measure used in the study was estimated through a Malmquist productivity index decomposition approach. Ting (2020) and Wakeford (2004) support the inclusion of the labour share in GDP in productivity analysis. Jajri (2007) and Torfinn and Jørn (2005) suggest controlling for openness in modelling TFP. Isaksson (2007), Kim and Loayza (2019), Martino (2021) and Rong (2020) provide an excellent survey of factors that influence TFP, not least fixed capital, capital intensity, spending on education, spending on health, financial development, and openness among others. Limited by data availability, this paper focuses on a selection of these variables. The data is commonly available for all variables for the years 1965–2019, although some variables have data from 1954 and from 1960. The effective sample period for the study comprised 55 years, 1965–2019.

#### 4.2 Estimation strategy: Non-linear autoregressive distributed lag (NARDL) models

To overcome the overly restrictive assumption that decreases and increases in the explanatory variable have identical effects on the dependent variable, a NARDL model is estimated. A better assumption is that positive and negative changes in the explanatory variables have asymmetric effects on the dependent variable. Kaldor (1961) and Edquist and Henrekson (2017) emphasise that R&D spending has lagged effects on productivity, thus justifying the use of an autoregressive distributed lag model. Thus, the assumption of asymmetric effects of changes in the ratio of private sector to government R&D capital spending on TFP leads to the specification of non-linear ARDL (NARDL) model, as follows:

$$\begin{split} \mathsf{TFP}_{t} &= \beta_{1} + \sum_{i=1}^{p} \rho_{1i} \mathsf{TFP}_{t-i} + \sum_{h=0}^{q} \beta_{2h}^{+} \mathsf{Inpvt\_gvt}_{t-h}^{+} + \sum_{h=0}^{q} \beta_{2h}^{-} \mathsf{Inpvt\_gvt}_{t-h}^{-} \\ &+ \sum_{k=1}^{r} \beta_{3k} \mathsf{Inintensity}_{t-k} + \sum_{m=1}^{s} \beta_{4m} \mathsf{Iabshare}_{t-m} + \sum_{n=1}^{v} \beta_{5n} \mathsf{Openness}_{t-n} \\ &+ \sum_{u=1}^{w} \beta_{6u} \mathsf{findvpt}_{t-u} + \mu_{t} \end{split}$$
(1)

In equation (1), the log of the ratio of private to government R&D capital spending (lnpvt\_gvt) is decomposed into positive and negative changes so that a test of asymmetric effects can be carried out. In general, therefore, the optimal lags for each decomposed variable do not necessarily have to be the same for positive and negative changes, even though in the representation in (1) they might appear to be. The test for asymmetric effects is carried out on the hypotheses that

$$-\frac{\beta_{2h}^{+}}{\rho_{11}} = -\frac{\beta_{2h}^{-}}{\rho_{11}}; \forall j = 0, \dots, q$$
(2)

The test in (2) is an F-test based on the linear restrictions imposed on coefficients in (1).

Further, an F-bounds test can be carried out to examine the existence of a long-run relationship between TFP and the set of explanatory variables, a finding which paves the way for an error correction representation. The error correction mechanism can be expressed as (3), following Schleer van Gellecom (2013)

$$\begin{split} \Delta \mathsf{TFP}_{t} &= \alpha_{0} + \sum_{i=1}^{p} \alpha_{1i} \Delta \mathsf{TFP}_{t-i} + \sum_{h=0}^{q} \alpha_{2h}^{+} \Delta \mathsf{Inpvt\_gvt}_{t-h}^{+} + \sum_{h=0}^{q} \alpha_{2h}^{-} \Delta \mathsf{Inpvt\_gvt}_{t-h}^{-} \\ &+ \sum_{k=1}^{r} \alpha_{3k} \Delta \mathsf{Inintensity}_{t-k} + \sum_{m=1}^{s} \alpha_{4m} \Delta \mathsf{Iabshare}_{t-m} + \sum_{n=1}^{v} \alpha_{5n} \Delta \mathsf{openness}_{t-n} \\ &+ \sum_{u=1}^{w} \alpha_{6u} \Delta \mathsf{findvpt}_{t-u} + \theta \ \mathsf{ECT}_{t-1} + \varepsilon_{t} \end{split}$$
(3)

The coefficient of the error correction term (ECT),  $\theta \in (-1, 0)$  for convergence to occur. If statistically significant, it also indicates that the explanatory variables granger-cause TFP. Furthermore, short-run dynamics can also have asymmetric effects on total factor productivity, which can be tested in much the same way as in Equation 2. In the estimations, three dummy variables are included, namely, democracy (=1 for 1994 to 2019), sanctions (=1 for 1985–1993), and White paper on science and technology (=1 for 1996 to 2019). A multivariate break point test was carried out and it only suggested the year 1999. However, the author has a strong conviction that the purposefully chosen dummy variables serve the purpose better.

Several diagnostic tests are carried out to ensure the results are reliable, not least normality test, serial correlation test, heteroscedasticity test, and stability test. Examination of actual and predicted values alongside the residuals of the models provides another lever for assessing the reliability of the model.

#### 5. Results

#### 5.1 Descriptive statistics

Table 2 shows that the average productivity level in South Africa suggests that the economy is experiencing technical progress, which could be fostered by technical efficiency, and technical change, as well as allocative efficiency. The average level of the ratio of private to government R&D capital spending exceeds the rule of thumb of 2, which fits well with a transformative growth trajectory. Literature suggests that a labour share in GDP exceeding 0.5 is detrimental to total factor productivity growth (Ting, 2020). A mean labour share of 0.58 suggests South Africa falls in the category of wage-led growth regimes. The average value of financial development suggests South Africa had deep financial markets, while its level of openness is on the lower side. With the exception of labour share, all other variables are normally distributed.

The zero order correlations do not suggest severe collinearity issues (Table 3). The signs of the correlation coefficients between TFP and the other variables do not necessarily conform to theoretical expectations. The labour share in GDP has a relatively weak positive correlation with TFP, significant at the 1% level. One would expect the coefficient to have a negative effect, although it is possible to provide an explanation that justifies the positive sign. In a wage-led economy, a virtuous Keynesian growth model increases TFP through the effect of the aggregate demand channel on profitability of private investment (Skidelsky & Craig, 2016). The ratio of private to government R&D expenditure ratio has a weak negative association with TFP, significant at the 5% level. In essence, this means that as the ratio becomes larger (greater private R&D capital investment), TFP decreases. This defies theoretical expectations, but scholars such as Aghion et al. (2008) have found that the concentration of power in goods and financial markets of South Africa undermines productivity growth. In general, trade openness supports productivity growth through

Table 2. Summary statistics	10-					
	TFP	Private to government R&D capital spending	Capital intensity	Labour share in GDP	Openness	Financial development
Mean	1.124	2.796	10680.74	0.577	47.045	57.052
Median	1.110	2.877	10888.79	0.593	49.363	56.610
Maximum	1.300	3.385	15568.12	0.603	59.389	73.295
Minimum	0.970	2.016	6654.883	0.513	32.966	41.5166
Std. Dev.	0.085	0.329	2535.246	0.032	7.627	7.599
Skewness	0.184	-0.722	0.157	-0.822	-0.391	0.144
Kurtosis	2.029	2.672	1.699	2.143	1.915	2.324
Jarque-Bera	2.472 (0.291)	5.030 (0.081)	4.104 (0.128)	7.873 (0.020)	4.100 (0.129)	1.237 (0.539)
Observations	55	55	55	55	55	55

the import channel. The relationship with TFP is expected to be ambiguous because it is dependent on the type of imports. A country that imports capital-intensive goods is most likely to experience productivity enhancement.

#### 5.2. Unit root tests

Table 4 shows that all variables are integrated of order one. A single equation test of cointegration (not reported here) also confirms the existence of cointegration. Since none of the variables has an order of integration exceeding two, both an ARDL model and a non-dynamic model can also be estimated.

#### 5.3. Regression results

Table 5 presents estimation results. We consider an ordinary least squares (OLS) model, a linear autoregressive distributed lag (ARDL) model and a non-linear autoregressive distributed lag (NARDL) model. Since Table 4 shows that the variables are cointegrated, an error correction representation is possible. Further, F-bounds test for the ARDL and NARDL indicate that there is a long-run relationship, and the single equation cointegration test (Engle–Granger test) indicates the existence of a long-run relationship.

In terms of the key variable—the ratio of private to government R&D capital spending (the structure of R&D capital spending), the OLS model shows that a 1% increase in the ratio (increasing dominance of the private sector) reduces TFP by 0.11 percentage points (Table 5). In the NARDL regression output (Table 5 column 5), positive changes in the ratio of private to government R&D capital expenditure have statistically insignificant effects on TFP. Negative changes in the ratio are statistically significant. For the lagged terms, a 1% decrease in the ratio of private to government R&D capital spending, on average, leads to 0.12 percentage points and 0.31 percentage points decrease in the TFP for levels and the first lagged terms, respectively. In the case of the term in two lags, a one percent decrease in the ratio, on average, leads to the TFP increasing by 0.21 percentage points.

Table 5 also shows that the estimates are, in large part, estimated consistently across the models, and the estimates are quite close in terms of effect size and theoretical signs with the exception of  $TFP_{t-2}$ . For example, the coefficients of the log of capital intensity are 0.252 (OLS), 0.114 (ARDL), and 0.072 (NARDL). The average response of TFP to a 1% increase in capital intensity ranges between 0.07 and 0.25 percentage points, other things being equal. Similarly, the coefficients for the labour share in GDP are also close: -1.946 (OLS), -1.142 (ARDL), and -0.951 (NARDL). The sign and size of the coefficients suggest that the cost of labour in South Africa is a major determinant of the behaviour of TFP over time, and it undermines TFP growth. Trade openness has insignificant effects on TFP across all three models, although the first lag has a significant negative effect on TFP. The effect of financial development has almost equivalent magnitudes in all three models except that in the NARDL it is not significant. The TFP was much lower—by between 0.047 and 0.055 percentage—after democratic transition than it was during apartheid. The other significant dummy variable is the White Paper on Science and Technology, which indicates that TFP was higher after this institutional change than before it.

Looking at the error correction representation for the OLS, ARDL, and NARDL in Table 6 columns 2, 3 and 4, it is evident that a long-run relationship exists among the variables. Although the long-run equilibrium multipliers are different across the error correction models (ECMs), they satisfy the convergence condition and are quite close in the case of the OLS (-0.646) and the ARDL (-0.456). The multiplier for the NARDL is much smaller, estimated at -0.175. In general, therefore, the speed of adjustment back to the long-run equilibrium, following a shock to the long-run relationship, lies between 17.5% and 64.6%. In the short run, the negative changes in the ratio of private to government R&D capital spending have positive effects on TFP (Table 6 column 4). A 1% decrease in the ratio of private to government R&D capital spending, on average, reduces TFP by 0.12 percentage points, other things being equal. Further, for the first lagged term, a 1% decrease in the

I able 3. Correlation analys	SIS					
Correlation Probability	TFP	Labour share in GDP	Ratio of private to government R&D capex	Capital intensity	Openness	Financial development
TFP	1.000					
Labour share in GDP	0.374	1.000				
	0.005					
Ratio of private to government R&D capex	-0.313	-0.480	1.000			
	0.0198	0.0002	-			
Capital Intensity	0.153	-0.467	0.345	1.000		
	0.2662	0.0003	0.0099	-		
Openness	-0.473	-0.671	0.817	0.411	1.000	
	0.0003	0.0000	0.0000	0.0018	-	
Financial development	-0.023	-0.490	0.444	0.819	0.588	1.000
	0.8687	0.0001	0.0007	0.0000	0.0000	

Table 4. Unit root tests based on Augmented Dickey–Fuller procedure				
	Levels	First difference	Order of integration	
TFP	-1.356	-5.579***	One	
Lnpvt_gvt	-2.227	-7.741***	One	
Inintensity	-3.011 <sup>+</sup>	-4.678***	One	
Labshare	-1.269	-8.175***	One	
Openness	-0.913	-6.357***	One	
Findvpt	-1.176	-5.851***	One	

Notes 1:  $\dagger$  means test equation includes a trend term; trend is significant; \*\*\*means p < 0.01.

2: Lnpvt\_gvt is the log of the ratio of private R&D capital to government R&D capital spending; lnintensity is capital intensity; Labshare is labour share; Findvpt is financial development.

ratio of private to government R&D capital spending, on average, reduces TFP by 0.3 percentage points, other things being equal. As is expected in growth theory, in the short run, a 1% increase in capital intensity increases TFP by 0.21 percentage points. The contemporaneous effect of the labour share in GDP, on average, reduces TFP by between 0.98 percentage points (OLS) and 0.95 percentage points (NARDL), other things being equal. Lastly, the labour share in GDP, on average, consistently reduces total factor productivity in the short-run by 0.95 percentage points (firs lag), 1.29 percentage points (second lag), and 1.07 percentage points (third lag), other things being equal.

The first hypothesis that the paper tested is whether the structure of R&D capital expenditure is dominated more by the private sector than by the public sector and has a positive effect on productivity. All the estimates across the linear and non-linear models, though varying in size, lead the paper to fail to reject this hypothesis. The dominance of private sector R&D capital investment over public sector R&D capital investment promotes productivity growth. This broad conclusion agrees with several scholars (e.g. Coccia, 2010; Fuglie, 2018; Rehman et al., 2020; Tsai & Wang, 2004; Wang et al., 2013) who have found that an increasing level of private sector investment in R&D capital spending increases productivity. However, these studies did not approach the analysis in terms of the structure of R&D capital spending, which the present paper does.

Finally, Figure 3 summarises the cumulative dynamic multiplier effect of the ratio of private to government R&D capital spending on TFP. It is clear that in the short run, positive changes in the ratio of private to government R&D capital spending have very small effects, but the effects steadily and marginally grow in the long run, reaching a multiplier of 0.25. However, the negative changes in the ratio of private to government R&D capital spending, in the short run, up to about 2 years, dramatically reduce TFP (the cumulative multiplier reaches -0.4), and continue to reduce it in a less dramatic way in the long run, between 3 and 8 years (the multiplier rising from -0.4 to -0.8). Furthermore, the long-run multipliers for negative changes in the ratio of private to government R&D capital spending dominate multipliers for positive changes in the same ratio. The asymmetric plot clearly diverges from the zero line, suggesting that the ratio of private to government R&D capital spending has asymmetric effects on TFP. Overall, therefore, an R&D fixed capital structure that is dominated by private sector spending over public sector spending tends to work favourably for productivity growth in the economy. The cumulative multiplier analysis depicted in Figure 3 confirms the corollary hypothesis that changes in the ratio of private to public sector R&D fixed capital spending have asymmetric effects on productivity. The implication is that the government needs to work very hard to prevent further decreases in private R&D capital spending, a problem that has been unfolding for nearly two decades as the National Research and Development Strategy 2000-2009 indicated.

Table 5. Regression results for OLS, ARDL, and NARDL models				
Explanatory variable	TFP OLS	TFP ARDL (1,0,0,0,0,0)	TFP NARDL levels (2,0,3,0,3,1,0)	
TFPt -1		544***(.122) (0.122)	.339**(.143) (0.143)	
TFPt -2			.486***(.145) (0.145)	
Ln(pvt_gvt)	113**(.050) (0.050)	038(.046) (0.046)		
Ln(pvt_gvt)+			.032(.054) (0.054)	
Ln(pvt_gvt)-			.122*(.067) (0.067)	
Ln(pvt_gvt)t - 1-			.305***(.095) (0.095)	
Ln(pvt_gvt)t - 2-			210**(.089) (0.089)	
Ln(pvt_gvt)t - 3-			094(.081) (0.081)	
Ln(cap_intensity)	.252***(.032) (0.032)	.114***(.041) (0.041)	.072**(.032) (0.032)	
Labour share in GDPt	-1.946***(.198) (0.198)	-1.142***(.246) (0.246)	951***(.227) (0.227)	
Labour share in GDPt – 1			801***(.284) (0.284)	
Labour share in GDPt – 2			.215(.299) (0.299)	
Labour share in GDPt – 3			1.074***(.280) (0.280)	
Opennesst	.001(.001) (0.001)	.001(.001) (0.001)	002(.001) (0.001)	
Opennesst -1			003***(.001) (0.001)	
Financial development	004***(.001) (0.001)	003***(.001) (0.001)	.0003(.001) (0.001)	
Democracy = 1 for 1994- 2019	055**(.027) (0.027)	047**(.023) (0.023)	.033(.029) (0.029)	
Sanctions = 1 for 1985- 1993	026(.019) (0.019)	024(.016) (0.016)	.016(.018) (0.018)	
White paper on science = 1 for 1996–2019	.027(.020) (0.020)	.009(.018) (0.018)	.028*(.014) (0.014)	
Constant	1.093***(.218) (0.218)	.666(.207) (0.207)	.126(.241) (0.241)	
Observations	55	55	55	
Cointegration Engle- Granger test, tau, [p-value]	-6.671**[.011] [0.011]			
R2	.936	.956	.982	
Std. error of regression	.023	.020	.014	
F-calc [p-value]	84.384[.000] [0.000]	107.773[.000] [0.000]	109.373[.000] [0.000]	
F-bounds test, F-calc {lower F, upper F critical}		5.842{2.62; 3.79} {2.62; 3.79}	4.260{2.45; 3.61] {2.45; 3.61]	
JB normality test [p-value]	.524[.769] [0.769]	.516[.773] [0.773]	1.018[.601] [0.601]	

(Continued)

Table 5. (Continued)				
Explanatory variable	TFP OLS	TFP ARDL (1,0,0,0,0,0)	TFP NARDL levels (2,0,3,0,3,1,0)	
LM seial correlation test [p-value]	1.060[.589] [0.589]	.408[.816] [0.816]	4.602[.100] [0.100]	
BPG heteroscedasticity test [p-value]	23.017[.003] [0.003]	13.082[.159] [0.159]	16.960[.526] [0.526]	
Stability test: Cusum squares	Stable	Stable	Stable	

Notes 1: \*\*\* means *p* < 0.01; \*\* means *p* < 0.05 and \* means *p* < 0.10.

2: Lnpvt\_gvt is the log of the ratio of private R&D capital to government R&D capital spending; Inintensity is capital intensity; Labshare is labour share; Findvpt is financial development.

Table 6. Error correctio	n model results		
Explanatory variable	ΔTFP OLS-ECM	ΔTFP ARDL ECM	ΔTFP NARDL ECM
∆TFPt −1			486***(.108) (0.108)
ΔLn(pvt_gvt)t	028(.043) (0.043)		
ΔLn(pvt_gvt)t-			.122**(.058) (0.058)
ΔLn(pvt_gvt)t – 1-			.304***(.057) (0.057)
ΔLn(pvt_gvt)t – 2-			.094(.067) (0.067)
ΔLn(cap_intensity)t	.207***(.057) (0.057)		
ΔLabour share in GDPt	977***(.305) (0.305)		952***(.187) (0.187)
$\Delta$ Labour share in GDPt – 1			-1.290***(.199) (0.199)
$\Delta$ Labour share in GDPt – 2			-1.074***(.218) (0.218)
ΔOpennesst	.002(.002) (0.002)		.002**(.001) (0.001)
∆Financial developmentt	002(.001) (0.001)		
ECTt -1	646***(.155) (0.155)	456***(.073) (0.073)	175***(.030) (0.030)
Democracy = 1 for 1994- 2019	018(.016) (0.016)	047***(.016) (0.016)	.033*(.017) (0.017)
Sanctions = 1 for 1985- 1993	013(.011) (0.011)	024***(.007) (0.007)	.016(.011) (0.011)
White paper on science = 1 for 1996-2019	.011(.015) (0.015)	.009(.014) (0.014)	.028**(.010) (0.010)
Constant	.006(.005) (0.005)	.666***(.106) (0.106)	.126***(.018) (0.018)
Observations	54	55	55
Cointegration Engle- Granger test, tau, [p-value]			

(Continued)

Explanatory variable	ΔTFP OLS-ECM	ΔTFP ARDL ECM	ΔTFP NARDL ECM
R2	.510	.513	.803
Std. error of regression	.020	.019	.013
F-calc [p-value]	5.084(.000)	13.145[.000]	14.229[.000]
	(0.000)	[0.000]	[0.000]
F-bounds test, F-calc		5.842{2.62; 3.79}	4.260{2.45; 3.61]
{lower F, upper F critical}		{2.62; 3.79}	{2.45; 3.61]
JB normality test	.177[.915]	.516[.773]	1.018[.601]
[p-value]	[0.915]	[0.773]	[0.601]
LM serial correlation test	1.289[.525]	.408[.816]	4.602[.100]
[p-value]	[0.525]	[0.816]	[0.100]
BPG heteroscedasticity	5.904[.750]	13.082[.159]	16.960[.526]
test [p-value]	[0.750]	[0.159]	[0.526]
Stability test: Cusum squares	Stable	Stable	Stable

Note 1: \*\*\*means *p* < 0.01; \*\*means *p* < 0.05 and \*means *p* < 0.10.

2: Lnpvt\_gvt is the log of the ratio of private R&D capital to government R&D capital spending; lnintensity is capital intensity; Labshare is labour share; Findvpt is financial development.



# Figure 3. Non-linear ARDL model multiplier analysis.

#### 5.4. Diagnostic tests

First, the predicted values almost perfectly match the actual values of the total factor productivity (Figure 4). The residual graph suggests that the residuals fluctuate around the zero line, suggesting a constant mean. They also suggest a constant variance over time. The model is reliable.

In addition to Figure 4, no models violate the normality assumption, the no serial correlation assumption, and the homoscedasticity assumption as well as parameter stability requirement (Table 5). Therefore, the estimated results are reliable.

#### Figure 4. Examination of predicted versus actual TFP and the structural residuals for the non-linear ARDL model.





### 6. Conclusions

The purposes of the paper were to examine if [1] the relationship between the structure of R&D capital spending and TFP and [2] to investigate if the relationship is non-linear. The main hypothesis tested in this paper is that an R&D fixed capital structure dominated by the private sector relative to the public sector enhances the total factor productivity. Based on the results of the error correction model results of the non-linear autorearessive distributed lag model and long-run multiplier analysis, the paper has substantiated the hypothesis. To put the findings into context, with a long-run multiplier for positive changes in the ratio of private to public R&D capital spending of 0.25, it means that if the positive change in the ratio doubles, total factor productivity is expected to increase by 0.5 percentage points. However, in the long run, the multiplier for negative changes is -0.8 and if the negative change in the ratio doubles, TFP falls by nearly 1.6 percentage points. Thus, a reduction in the private sector in R&D capital regardless of how small it might be has large negative effects on total factor productivity. It follows, therefore, that encouraging greater private sector investment in R&D capital is crucial for unlocking productivity. The result suggests that technological process in the South African context needs to be market-led rather than state-led. We are aware of the literature that has no estimated multiplier effects on R&D fixed capital spending. Differences in methodology, variable measurements and data make comparison to other studies difficult, but the consensus is that a rising level of private spending on R&D increases TFP.

The implication of this paper is that a volatile ratio of private sector to public sector R&D capital spending is detrimental to TFP, especially when the changes are negative. The implication can be explained by the animal spirits argument. If the ratio of the private sector to public sector R&D capital spending is smaller, there is a tendency for the ratio to become highly procyclical. The resulting procyclicality filters through to declining TFP. The literature tends to find rising levels of R&D spending regardless of the state of the business cycle to be desirable (Alene, 2010; Filippetti & Archibugi, 2011; Perez, 2011). Mainstream literature tends to favour a larger ratio of the private sector to public sector R&D capital spending (Alston et al., 2009; Tsai & Wang, 2004; Voutsinas & Tsamadias, 2014). However, heterodox literature argues for a greater role of the state in the evolution of the system of innovation, its financing, and the setting up of major R&D infrastructure that end up crowding in private R&D capital spending (Edigheji, 2010; Mazzucato & Penna, 2015; Mazzucato, 2015). The result is rising levels of TFP. However, the findings of this paper confirm the mainstream view that private sector investment in R&D capital must dominate the public sector contribution.

The lesson for South African policymakers is that the worrying trend of falling private sector R&D spending needs to be reversed if productivity is to be unlocked, a worry expressed by D. Walwyn (2008), D. Walwyn and Cloete (2016) and D. R. Walwyn and Naidoo (2020) and the National Research Development Strategy 2000–2009 as well. It follows that significant efforts would have to be invested in winning the trust of the private sector so that it can allocate the excess cash holdings it sits on towards R&D expenditure. The institution of the National System of Innovation through the White Paper on Science and Technology 1996 needs to ratchet up efforts at building the R&D capital stock. These efforts have not been coming through quite strongly as other scholars have observed (Burger & Calitz, 2020; Burger et al., 2016; D. Walwyn & Boraine, 2006; D. Walwyn, 2008). The tendency has been for private R&D capital spending to decline with declining public R&D capital spending.

The limitations of the paper are that, firstly, variables such as the human capital stock could not be controlled for data availability reasons. Secondly, examining the behaviour of the ratio at the sectoral level would allow the study to examine the heterogeneous investment behaviour across sectors. However, the data were not available at a disaggregated level. Future research can explore possibilities of regime change in the ratio of private to public sector R&D capital expenditure. There is definitely an important question to be answered in this regard, since the government for nearly two decades has struggled to unlock high levels of private R&D spending. Further, broadening the study to a group of countries can deepen the insights into the role of the structure of R&D capital expenditure in driving productivity growth.

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#### References

- Aghion, P., Braun, M., & Fedderke, J. (2008). Competition and productivity growth in South Africa. *The Economics of Transition*, 16(4), 741–768. https://doi. org/10.1111/j.1468-0351.2008.00336.x
- Akerlof, G. A., & Shiller, R. J. (2010). Animal spirits: How human psychology drives the economy, and why it matters for global capitalism. Princeton university press.
- Alene, A. D. (2010). Productivity growth and the effects of R&D in African agriculture. Agricultural Economics, 41 (3-4), 223–238. https://doi.org/10.1111/j.1574-0862. 2010.00450.x
- Alston, J. M., Andersen, M. A., James, J. S., & Pardey, P. G. (2009). Persistence pays: US agricultural productivity growth and the benefits from public R&D spending. Springer Science & Business Media. https://doi.org/10. 1007/978-1-4419-0658-8
- Amsden, A. H. (2001). The rise of the rest: Challenges to the west from late-industrializing economies. Oxford University Press. https://doi.org/10.1093/0195139690. 003.0001

- Baltagi, B. H., & Pinnoi, N. (1995). Public capital stock and state productivity growth: Further evidence from an error components model. *Empirical Economics*, 20(2), 351–359. https://doi.org/10.1007/BF01205444
- Barlevy, G. (2007). On the cyclicality of research and development. American Economic Review, 97(4), 1131–1164. https://doi.org/10.1257/aer.97.4.1131
- Beugelsdijk, S., Klasing, M. J., & Milionis, P. (2018). Regional economic development in Europe: The role of total factor productivity. *Regional Studies*, 52(4), 461–476. https://doi.org/10.1080/00343404.2017. 1334118
- Bloch, C., & Graversen, E. K. (2012). Additionality of public R&D funding for business R&D-A dynamic panel data analysis. World Review of Science, Technology and Sustainable Development, 9(2-4), 204–220. https:// doi.org/10.1504/WRSTSD.2012.047688
- Bronzini, R., & Piselli, P. (2009). Determinants of long-run regional productivity with geographical spillovers: The role of R&D, human capital and public infrastructure. *Regional Science and Urban Economics*, 39 (2), 187–199. https://doi.org/10.1016/j.regsciurbeco. 2008.07.002
- Burger, P. (2014). Facing the conundrum: How useful is the "Developmental state" concept in South Africa? South African Journal of Economics, 82(2), 159–180. https://doi.org/10.1111/saje.12030
- Burger, P., & Calitz, E. (2020). Covid-19, economic growth and South African fiscal policy. South African Journal of Economics, 89(1), 3–24. https://doi.org/10.1111/ saje.12270
- Burger, P., Siebrits, K., & Calitz, E. (2016). Fiscal consolidation and the public sector balance sheet in South Africa. South African Journal of Economics, 84(4), 501–519. https://doi.org/10.1111/saje.12126
- Butkiewicz, J. L., & Yanikkaya, H. (2011). Institutions and the impact of government spending on growth. *Journal of Applied Economics*, 14(2), 319–341. https:// doi.org/10.1016/S1514-03261160017-2
- Coccia, M. (2010). Public and private R&D investments as complementary inputs for productivity growth. International Journal of Technology, Policy and

Management, 10(1–2), 73–91. https://doi.org/10. 1504/IJTPM.2010.032855

Coccia, M. (2011). The interaction between public and private R&D expenditure and national productivity. *Prometheus*, 29(2), 121–130. https://doi.org/10.1080/ 08109028.2011.601079

- Coe, D. T., & Helpman, E. (1995). International R&D spillovers. European Economic Review, 39(5), 859–887. https://doi.org/10.1016/0014-29219400100-E
- Coe, D. T., Helpman, E., & Hoffmaister, A. W. (2009). International R&D spillovers and institutions. European Economic Review, 53(7), 723–741. https:// doi.org/10.1016/j.euroecorev.2009.02.005
- Cozzi, G. (2005). Animal spirits and the composition of innovation. European Economic Review, 49(3), 627–637. https://doi.org/10.1016/j.euroecorev.2003. 08.003
- Crawford, N., Klotz, A., Crawford, N. C., Crawford, N. C., & Klotz, A. (1999). How sanctions work: Lessons from South Africa. Springer. https://doi.org/10.1057/ 9781403915917
- David, P. A., Hall, B. H., & Toole, A. A. (2000). Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research Policy*, 29(4–5), 497–529. https://doi.org/10.1016/ S0048-73339900087-6
- Destefanis, S., & Sena, V. (2005). Public capital and total factor productivity: New evidence from the Italian regions, 1970–98. *Regional Studies*, 39(5), 603–617. https://doi.org/10.1080/00343400500151863
- Diaw, A. (2020). Corporate cash holdings in emerging markets. *Borsa Istanbul Review*, 21(2), 139–148. https://doi.org/10.1016/j.bir.2020.09.005
- Dudley, E., & Zhang, N. (2016). Trust and corporate cash holdings. Journal of Corporate Finance, 41, 363–387. https://doi.org/10.1016/j.jcorpfin.2016.10.010
- Edigheji, O. (Ed.) (2010) Constructing a democratic develop mental state in South Africa: Potentials and challenges (pp. 1–36). Human Sciences Research Council, Cape Town. 978-0-7969-2334-9.
- Edquist, H., & Henrekson, M. (2017). Do R&D and ICT affect total factor productivity growth differently? *Telecommunications Policy*, 41(2), 106–119. https:// doi.org/10.1016/j.telpol.2016.11.010
- Engelbrecht, H. (1997). International R&D spillovers, human capital and productivity in OECD economies: An empirical investigation. *European Economic Review*, 41(8), 1479–1488. https://doi.org/10.1016/ S0014-29219600046-3
- Englander, A. S., Evenson, R., & Hanazaki, M. (1988). R&D, innovation and the total factor productivity slowdown. *OECD Economic Studies*, 11, 8–42. https://www. oecd.org/economy/growth/35257726.pdf
- Everaert, G., & Heylen, F. (2001). Public capital and productivity growth: Evidence for Belgium, 1953–1996. *Economic Modelling*, 18(1), 97–116. https://doi.org/ 10.1016/S0264-99930000029-8
- Falk, M. (2006). What drives business research and development (R&D) intensity across organisation for economic co-operation and development (OECD) countries? *Applied Economics*, *38*(5), 533–547. https://doi.org/10.1080/00036840500391187
- Fedderke, J., & Schirmer, S. (2006). The R&D performance of the South African manufacturing sector, 1970–1993. *Economic Change and Restructuring*, 39(1), 125–151. https://doi.org/10.1007/s10644-007-9023-3
- Federal Reserve Bank of St. Louis. Total factor productivity data. https://fred.stlouisfed.org/series/ RTFPNAZAA632NRUG
- Filippetti, A., & Archibugi, D. (2011). Innovation in times of crisis: National systems of innovation, structure, and

demand. Research Policy, 40(2), 179–192. https://doi. org/10.1016/j.respol.2010.09.001

- Fine, B. (2010). Can South Africa be a developmental state. In O. Edigheji (Ed.), Constructing a democratic developmental state in South Africa: Potentials and Challenges (pp. 169–183). Human Sciences Research Council.
- Francois, P., & Lloyd Ellis, H. (2003). Animal spirits through creative destruction. American Economic Review, 93 (3), 530–550. https://doi.org/10.1257/ 000282803322156972
- Fuglie, K. (2018). R&D capital, R&D spillovers, and productivity growth in world agriculture. Applied Economic Perspectives and Policy, 40(3), 421-444. https://doi.org/10.1093/aepp/ppx045
- Gentle, L. (2009). Escom to Eskom: From racial keyenesian capitalism to neo-liberalism (1910-1994). In McDonald, A David (Ed.), *Electric Capitalism Recolonising Africa on the Power Grid* (pp. 50–72). HSRC Press, Cape Town. 978-0-7969-2246-5.
- Gore, C. (2000). The rise and fall of the Washington consensus as a paradigm for developing countries. *World Development*, 28(5), 789–804. https://doi.org/10. 1016/S0305-750X9900160-6
- Guellec, D., & Van Pottelsberghe De La Potterie, B. (2003). The impact of public R&D expenditure on business R&D. Economics of Innovation & New Technology, 12 (3), 225–243. https://doi.org/10.1080/ 10438590290004555
- Harford, J., Mansi, S. A., & Maxwell, W. F. (2008). Corporate governance and firm cash holdings in the US. Journal of Financial Economics, 87(3), 535–555. https://doi. org/10.1016/j.jfineco.2007.04.002
- Holtz-Eakin, D. (1994). Public-sector capital and the productivity puzzle. *The Review of Economics and Statistics*, 76 (1), 12–21. https://doi.org/10.2307/2109822
- Hu, A. G. (2001). Ownership, government R&D, private R&D, and productivity in Chinese industry. *Journal of Comparative Economics*, 29(1), 136–157. https://doi. org/10.1006/jcec.2000.1704
- Huang-Meier, W., Lambertides, N., & Steeley, J. M. (2016). Motives for corporate cash holdings: The CEO optimism effect. Review of Quantitative Finance & Accounting, 47(3), 699–732. https://doi.org/10.1007/ s11156-015-0517-1
- Ilzetzki, E., Mendoza, E. G., & Végh, C. A. (2013). How big (small?) are fiscal multipliers? *Journal of Monetary Economics*, 60(2), 239–254. https://doi.org/10.1016/j. jmoneco.2012.10.011
- Isaksson, A. (2007). Determinants of total factor productivity: A literature review. United Nations Industrial Development Organization (UNIDO).
- Jajri, I. (2007). Determinants of total factor productivity growth in Malaysia. *Journal of Economic Cooperation*, 28(3), 41–58.
- Kaldor, N. (1957). A model of economic growth. The Economic Journal, 67(268), 591–624. https://doi.org/ 10.2307/2227704
- Kaldor, N. (1961). Capital accumulation and economic growth. In The theory of capital (pp. 177–222). Springer. https://doi.org/10.1007/978-1-349-08452-4\_10
- Karwowski, E. (2015). The finance-mining nexus in South Africa: How mining companies use the south African equity market to speculate. *Journal of Southern African Studies*, 41(1), 9–28. https://doi.org/10.1080/ 03057070.2015.991601
- Keeton, G. (2018). "Post-Truth", "Alternative Facts" and "Fakenomics.". South African Journal of Economics, 86(1), 113–124. https://doi.org/10.1111/saje.12181
- Kelton, S. (2020). The deficit myth: Modern monetary theory and how to build a better economy. Hachette UK.

- Khanam, B. R. (1996). Highway infrastructure capital and productivity growth: Evidence from the Canadian goods-producing sector. In Barry E. Prentice (Ed.), *Proceedings of the 31st Annual Canadian Transportation Research Forum*, Winnipeg, Manitoba. Canadian Transportation Research Forum. https://doi. org/10.22004/ag.econ.314713
- Khan, M. H, & Blankenburg, S. (2009). The Political Economy of Industrial Policy in Asia and Latin America. In Cimoli, M., Dosi, G., & Stiglitz, J. (Eds.), Industrial Policy and Development: The Political Economy of Capabilities Accumulation (pp. 336–377). Oxford University Press. 9780191715617. https://doi. org/10.1093/acprof.oso/9780199235261.003.0013
- Khan, M. H., & Sundaram, J. K., Khan, M. H., Jomo, K. S. (2000). Rents, rent-seeking and economic development: Theory and evidence in Asia. Cambridge University Press. https://doi.org/10.1017/ CB09781139085052
- Kim, Y. E., & Loayza, N. (2019). Productivity growth: Patterns and determinants across the world. World Bank Policy Research Working Paper, 8852, 1–69. https://ssrn.com/abstract=3386434
- Koczyrkewycz, M., Chaiechi, T., & Beg, R. (2021). Productivity growth recovery mechanisms: An ARDL approach lessons from the United States, Japan and South Korea. Bulletin of Applied Economics, 8, 163–184. https://doi.org/10.47260/bae/8211
- Levy, D. M., & Terleckyj, N. E. (1983). Effects of government R&D on private R&D investment and productivity: A macroeconomic analysis. *The Bell Journal of Economics*, 14(2), 551–561. https://doi.org/10.2307/ 3003656
- Maharajh, R., Motala, E., & Scerri, M. (2011). South Africa: Reforming higher education and transforming the national system of innovation. In B. Göransson & C. Brundenius (Eds.), Universities in transition: The Changing Role and Challenges for Academic Institutions (pp. 193–218). Springer New York. https:// doi.org/10.1007/978-1-4419-7509-6\_10
- Makuyana, G., & Odhiambo, N. M. (2016). A review of public and private investment in South Africa. *Journal* of Global Analysis, 6(2), 141–155. 2041-1944.
- Marire, J. (2021). Effect of changing business R&D expenditure mix on productivity of the South African national system of innovation. African Journal of Science. Technology, Innovation and Development (Online). https://doi.org/10.1080/20421338.2021. 1935424
- Martino, R. (2021). Public Investment, Convergence and Productivity Growth in European Regions. WorkingPaper No 19/2021. DISEI Università degli Studi di Firenze. https://www.disei.unifi.it/upload/sub/pubblicazioni/ repec/pdf/wp19\_2021.pdf
- Mazzucato, M. (2015). Building the entrepreneurial state: A new framework for envisioning and evaluating a mission-oriented public sector. *Levy Economics Institute of Bard College Working Paper*, (824), https:// doi.org/10.2139/ssrn.2544707
- Mazzucato, M., & Penna, C. (2015). Mission-oriented finance for innovation: New ideas for investment-led growth. Policy Network and Rowman & Littlefield International.
- Mbeki, M. (2009). Architects of poverty :Why African capitalism needs changing. Picador.
- Ncanywa, T., & Makhenyane, L. (2016). Can investment activities in the form of capital formation influence economic growth in South Africa? SAAPAM Chapter 5<sup>th</sup> Annual Conferences Proceedings. http://ulspace. ul.ac.za/handle/10386/1653.

- Ndulu, B. J., O'Connell, S. A., Bates, R. H., Collier, P., Soludo, C. C. (2008). The Political Economy of Economic Growth in Africa, 1960–2000. Cambridge University Press. https://doi.org/10.1017/ CB09780511492648
- Ngepah, N. (2012). Long Life and Productivity in South Africa: Long Burdensome or Long Healthy? *African Development Review*, 24(4), 371–387. https://doi.org/ 10.1111/1467-8268.12004
- North, D. C., Wallis, J. J., Webb, S. B., & Weingast, B. R., North, D. C., Wallis, J. J., Webb, S. B., Weingast, B. R. (2012). In the shadow of violence: Politics, economics, and the problems of development. Cambridge University Press. https://doi.org/10.1017/ CBO9781139013611
- Nourzad, F., & Vrieze, M. D. (1995). Public capital formation and productivity growth: Some international evidence. Journal of Productivity Analysis, 6(4), 283–295. https://doi.org/10.1007/BF01073521
- Perez, C. (2011). Finance and technical change: A long-term view. African Journal of Science, Technology, Innovation & Development, 3(1), 10–35. https://0-hdl.handle.net.wam.seals.ac.za/10520/ EJC10576
- Rafferty, M. (2003). Do business cycles alter the composition of research and development expenditures? *Contemporary Economic Policy*, 21(3), 394–405. https://doi.org/10.1093/cep/byg020
- Rehman, N. U., Hysa, E., & Mao, X. (2020). Does public R&D complement or crowd-out private R&D in pre and post economic crisis of 2008? *Journal of Applied Economics*, 23(1), 349–371. https://doi.org/10.1080/ 15140326.2020.1762341
- Rodrik, D. (2006). Goodbye Washington consensus, hello Washington confusion? A review of the world bank's economic growth in the 1990s: Learning from a decade of reform. *Journal of Economic Literature*, 44(4), 973–987. https://doi.org/10.1257/jel.44.4.973
- Rodrik, D., & Subramanian, A. (2009). Why did financial globalisation disappoint? *IMF Staff Papers*, 56(1), 112–138. https://doi.org/10.1057/imfsp.2008.29
- Romer, D. (2012). Advanced macroeconomics 4e. McGraw-Hill. Romer, P. M. (1990). Endogenous technological change.
- Journal of Political Economy, 98(5, Part 2), S71–S102. https://doi.org/10.1086/261725
- Rong, Z. (2020). Productivity, public capital, and socialism with Chinese characteristics-A critique of the doctrine of incompatibility between capital and public ownership. China Political Economy, 3(1), 121–139. https://doi.org/10.1108/CPE-05-2020-0011
- Scerri, M., Lastres, H. M., Cassiolato, J. E., & Couto Soares, M. C. (2013). Role of the state. IDRC.
- Schleer van Gellecom, F. (2013). Advances in non-linear economic modeling: Theory and applications. Springer Science & Business Media. https://doi.org/10.1007/ 978-3-642-42039-9
- Skidelsky, R., & Craig, N. (2016). Who runs the economy?: The role of power in economics. Springer. https://doi. org/10.1057/978-1-137-58017-7
- Solow, R. M. (1956). A contribution to the theory of economic growth. The Quarterly Journal of Economics, 70 (1), 65–94. https://doi.org/10.2307/1884513
- South African Reserve Bank. Research and development expenditure. https://www.resbank.co.za/en/home/ what-we-do/statistics/releases/online-statisticalquery.
- Szarowská, I. (2017). Does public R&D expenditure matter for economic growth? Journal of International Studies, 10(2). https://doi.org/10.14254/2071-8330. 2017/10-2/6

- Thirlwall, A. (2015). Essays on Keynesian and Kaldorian economics. Hampshire, Springer. https://doi.org/10. 1057/9781137409485
- Ting, C. C. (2020). Lucas paradox, declining labor share, tendency of rate of profit to fall of Karl Marx and growth theory of the firm. *International Journal of Economics and Finance*, 12(9), 53–72. https://doi.org/ 10.5539/ijef.v12n9p53
- Torfinn, H., & Jørn, R. (2005). The barrier model of productivity growth: South Africa. Discussion Paper No. 425, Statistics Norway, Research Department.
- Truesdell, A. (2009). Achieving political objectives: South African defense priorities from the apartheid to the postapartheid era. *African Studies Review*, 52(3), 107–125. https://doi.org/10.1353/ arw.0.0279
- Tsai, K., & Wang, J. (2004). The relative impact of government and private R&D on productivity growth: A quantitative analysis. International Journal of Technology, Policy and Management, 4(3), 210–217. https://doi.org/10.1504/IJTPM.2004.006074
- Turkman, K., Scotto, M. G., & Patrícia, Z. B. (2016). Nonlinear time series: Extreme Events and Integer Value Problems. Springer.
- Voutsinas, I., & Tsamadias, C. (2014). Does research and development capital affect total factor productivity? Evidence from Greece. Economics of Innovation & New Technology, 23(7), 631–651. https://doi.org/10. 1080/10438599.2013.871169
- Wakeford, J. (2004). The productivity-wage relationship in South Africa: An empirical investigation. Development Southern Africa, 21(1), 109–132. https:// doi.org/10.1080/0376835042000181444

- Walwyn, D. (2008). A target for South Africa's business expenditure on research and development based on industry structure. *South African Journal of Science*, 104(9–10), 340–344. https://0-hdl.handle.net.wam. seals.ac.za/10520/EJC96842
- Walwyn, D., & Boraine, H. (2006). The South African national system of innovation: Structures, policies and performance: Background report to the OECD country review of South Africa's national system on innovation National Advisory Council on Innovation (South Africa).
- Walwyn, D., & Cloete, L. (2016). Universities are becoming major players in the national system of innovation. South African Journal of Science, 112(7–8), 1–8. https://doi.org/10.17159/sajs.2016/20150358
- Walwyn, D. R., & Naidoo, S. (2020). Policy mixes and overcoming challenges to innovation in developing countries: Insights from a mixed methods study of south africa's manufacturing sector. African Journal of Science, Technology, Innovation & Development, 12(1), 33–46. https://doi.org/10.1080/20421338.2019.1610250
- Wang, S. L., Heisey, P. W., Huffman, W. E., & Fuglie, K. O. (2013). Public R&D, Private R&D, and U.S. agricultural productivity growth: Dynamic and long-run relationships. American Journal of Agricultural Economics, 95 (5), 1287–1293. https://doi.org/10.1093/ajae/aat032
- Wells, H., & Thirlwall, A. P. (2003). Testing kaldor's growth laws across the countries of africa. African Development Review, 15(2-3), 89–105. https://doi. org/10.1111/j.1467-8268.2003.00066.x
- Yu, Y., & Yuping, P. (2022). An empirical study on the influence of agricultural public infrastructure on total factor productivity of china's grain production. *Contemporary Social Sciences*, 2022(3), 2.