Estimating effects of information and communication technology (ICT) on the productivity of manufacturing industries in South Africa

Mapula Hildah Lefophane* and Mmatlou Kalaba
Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, Pretoria, South Africa
*Corresponding author email: Hildajie@gmail.com

Abstract

This paper serves to examine whether the growth in labour productivity (LP) in South Africa's manufacturing sector, following policy reforms after 1994, can be attributed to ICT use. To achieve this, we examine the link between ICT intensity and LP growth of 23 manufacturing industries for the period 1970–2016 and sub-periods 1970–1995 and 1996–2016. The industries are disaggregated into two groups, which are 'more ICT-intensive' and 'less ICT-intensive', using the ICT intensity index. Four dummy variable regression models are applied to test for the relationship between ICT intensity of industries and LP growth. The findings suggest that LP of the more ICT-intensive industries accelerated more than that of their counterparts. The results underscore the need for policy measures to increase ICT use with the aim of improving LP performance of industries.

Keywords: ICT intensity index; manufacturing; productivity; ICT;

Introduction

South Africa (SA) is faced with several economic challenges such as sluggish economic growth and the high unemployment rate. Yet, investment in ICT has been, and continues to be, credited for its potential to stimulate growth and drive development. To be specific, the United Nations' (UN) Sustainable Development Goal 9 on Industry, Innovation and Infrastructure views technological progress as one of the solutions to unemployment and considers the promotion of industries such as manufacturing as key for achieving sustainable development.[1] In the view of the UN, increasing the access to ICT and supporting innovation and technology development are some of the strategies to enhance productivity and development in developing countries (UNDP 2016). In the same vein, the World Bank holds an optimistic view that ICTs have great promise to create jobs, enhance productivity and boost the economic growth of the developing countries (World Bank 2012, 2017).

Despite the above optimistic viewpoints, the productivity gains from ICT use have been widely detected for the developed countries in contrast to developing countries (Dewan and Kraemer 2000; Lee, Gholami, and Tong 2005; Papaioannou and Dimelis 2007; Bloom, Sadun, and Van Reenen 2012; Pradhan et al. 2014; Niebel 2018). The findings for the developing countries are attributable to numerous factors, which are the late adoption of ICT, low levels of ICT investment, limited complementary factors such as human capacity and skills, and lack of high-quality data and the quality of the analytical approaches used (Lee, Gholami, and Tong 2005; Wu and Liang 2017; Niebel 2018). In the case of SA's manufacturing sector, there are no empirical findings on the productivity gains that might accrue from ICT use.

Empirical evidence by Rankin (2016) indicates that LP in SA's manufacturing sector grew substantially in the first twenty years of democracy. On this basis, this paper strives to unearth whether the growth in LP in the manufacturing sector is attributable to ICT use. Examining this is imperative, given that various ICT policy frameworks were implemented after democracy in 1994 to reverse historical inequalities in access to technologies and to ensure that ICTs are actively used to achieve development (DTPS 2015). The key ICT policy frameworks developed post-1994 are highlighted in Table 1A in the Appendix.[2]

In view of these policies, this paper contributes to the literature by providing empirical evidence on whether these policies contributed to the LP growth in the manufacturing sector.

In the empirical analysis, ICT contributes to productivity and economic growth in three ways. First, it increases multi-factor productivity (MFP), or labour and capital productivity in the ICT-producing sector. Second, it contributes to capital deepening through productivity gains generated from the use of ICT as capital input in the non-ICT sectors. Third, greater use of ICT throughout the economy contributes to economy-wide total factor productivity (TFP) (van Ark 2002; Piatkowski 2004; Farooquie et al. 2012; Mefteh and Benhassen 2015). Thus, ICT contributes directly to the growth of ICT-producing industries and indirectly to the productivity growth of the non-ICT industries (Abri and Mahmoudzadeh 2015).

With respect to the levels of analyses, aggregate studies have commonly applied standard growth accounting to explain the impact of ICT on productivity (Jorgenson and Stiroh 1995; Niebel, O'Mahony, and Saam 2016; Relich 2017). Of note, most of these studies found a negative or zero impact of ICT on productivity. However, empirical studies by Stiroh (2002a) and Corrado, Haskel, and Jona-Lasinio (2017) have proved that productivity growth varies according to the extent to which industries use ICT (i.e. ICT intensity).

Previous researchers have outlined reasons why aggregate studies that have employed the growth accounting model found a negative or zero impact of ICT. First, employing the growth accounting model cannot provide a deeper explanation of which part of productivity growth can be associated with the network effects of technology (i.e. productivity effects arising from the use of ICT in the non-ICT sectors) (Stiroh 2002a; van Ark 2014). Second, the neoclassical assumptions of constant returns to scale and competitive markets underlying the growth accounting model do not hold, and as such, the model provides poor estimates of the true relationship between ICT and productivity (Stiroh 2002b; Engelbrecht and Xayavong 2006). Third, the growth accounting model does not account for variations in ICT intensity among industries. Based on Stiroh (2002a), it can be said that studies that focus on the aggregate level miss out on the part of the productivity as the degree of ICT use, and hence productivity growth differs immensely across industries.

To avoid problems associated with aggregate studies, we follow methods described by Stiroh (2002a), van Ark, Inklaar, and McGuckin (2002), Engelbrecht and Xayavong (2006) and Abri and Mahmoudzadeh (2015) for examining variations in productivity growth across industries. We rank industries with respect to their ICT intensity (i.e. more ICT-intensive and less ICT-intensive) using the ICT intensity index. Disaggregation of industries into intensity clusters is essential as, in many cases, it is not ICT productivity growth per se, but rather the relative productivity performance of the more ICT-intensive against the less ICT-intensive industries that embodies the beneficial productivity effects of ICT (Engelbrecht and Xayavong 2006).

Table 1: Review of previous studies on the impact of ICT on productivity.

	Sampling frame	Approach	Main finding (s)
Firm-level studies			
Loveman (1994)	United States	Production function	The output elasticity of IT is negative.
Stare, Jaklič, and Kotnik (2006)	Service firms, Slovenia	Production function approach	There is a positive effect of ICT use on productivity.
Arvanitis and Loukis (2009)	Switzerland and Greece firms 2005	Production function	There is a positive effect of ICT on labour productivity.
Kılıçaslan et al. (2015)	Turkish manufacturing at the firm level	Growth accounting, fixed-effects and dynamic panel data analysis.	Growth accounting findings showed no significant impact of ICT capital. Dynamic panel and fixed-effects finding showed a positive effect of ICT capital on firms' productivity.
Aggregate-level studies			
Oliner and Sichel (1994)	US 1970–1992	Growth accounting framework	The contribution of computer hardware to the growth of gross output is small (0.16 percentage point annual).
Jorgenson and Stiroh (1999)	US household and business sectors, 1948–1996.	Growth accounting framework	Computers have capital deepening effect, but zero effect on TFP.
Khan and Santos (2002)	Canada 1988–2000	Growth accounting framework	There was no acceleration in the impact of ICT use output growth in the late 1990s. There was no acceleration in the impact of ICT use (capital deepening) on labour productivity growth.
Mačiulytė-Šniukienėa and Gaile-Sarkane (2014)	27 EU states	Correlation analyses	The relationship between ICT development and labour productivity was not found in some of the high and medium productivity countries.
Edquist and Henrekson (2017)	50 industries in Sweden 1993–2013.	Augmented Cobb-Douglas Production function and Growth Accounting Framework	There is no significant short-run relationship between ICT and TFP (positive relationship found with a lag of seven to eight years).
Relich (2017)	28 EU countries (EU 15 countries and 13 CEE countries) 2007–2015	A neoclassical framework of growth accounting and a translog production function	The impact of ICT (ERP, e-commerce and CRM software) on labour productivity is higher in CEE countries (transition economies) than in the EU countries (developed economies).

	Sampling frame	Approach	Main finding (s)
Industry-level studies			
Lee, Gholami, and Tong (2005)	Manufacturing sector (22 industries), 1993–1999	Panel data. Cobb-Douglas and Translog Stochastic Production Frontier Models (OLS and Maximum Likelihood Estimation methods)	The positive and significant impact of ICT investments on the productivity of manufacturing industries.
Engelbrecht and Xayavong (2006)	New Zealand, 29 industries, 1988–2003	Difference-in-difference models	Labour productivity growth is higher for those industries that are more ICT intensive.
Bloom, Sadun, and Van Reenen (2012)	Europe and the US multinational firms	Standard production function framework, fixed effects.	US productivity growth accelerated after 1995, relative to Europe's, particularly in high-ICT intensive sectors.
Niebel, O'Mahony, and Saam (2016)	Ten European Union (EU) countries.	Production function and growth accounting frameworks.	The contribution of ICT intangible assets to labour productivity is highest in the finance and manufacturing sectors.
Abri and Mahmoudzadeh (2015)	23 Iranian manufacturing industries, 2002–2006	Extended Cobb-Douglas, DEA and panel regression model.	Productivity is higher in ICT-intensive industries. There is no significant difference in labour productivity growth between IT-producing and IT-using industries.
Moshiri (2016)	10 Canadian Provinces and 16 industries, 1981–2008	Fixed effects	Manufacturing and service industries benefited from ICT investment much more than primary sector industries.
Corrado, Haskel, and Jona-Lasinio (2017)	10 EU member states	Cross-country Production function framework	Returns to a country's investments in intangible capital are stronger in the ICT-intensive industries.

The rest of the paper is structured as follows. Section two discusses the literature on the impact of ICT on productivity in the context of both the developed and developing countries. Section three presents the definition and measurement of productivity and classification of industries using the ICT intensity index. The empirical models, variables and parameters of estimates are also described in Section three. Section four presents both the descriptive and empirical results. Section five concludes the paper and highlights key implications.

Literature review

Impact of ICT on productivity: developed countries

Despite the productivity gains associated with ICT, empirical evidence suggests that the positive link between ICT and productivity is not clear-cut (T. Kijek and Kijek 2018). The limited or lack of evidence on the positive effects of ICT on productivity is referred to as a 'productivity paradox'. The term was coined by Solow (1987) to explain why researchers found limited evidence on the contribution of ICT to productivity in the US in the 1970s and 1980s. Consequently, various explanations have been put forward to explain productivity paradox at the firm, aggregate and industrial levels. Table 1 provides a summary of previous studies on the impact of ICT on productivity.

In general, earlier studies with a focus on the firm level found either a negative or no significant relationship between ICT and productivity (Loveman 1994; Berndt and Morrison 1995). To the contrary, later studies found evidence of a positive relationship (Stare, Jaklič, and Kotnik 2006; Arvanitis and Loukis 2009). According to T. Kijek and Kijek (2018), the reason for divergent results is that earlier studies focused mainly on a direct relationship between ICT and productivity, neglecting the indirect effects of ICT.

As with the firm-level studies, earlier studies focusing on the aggregate level found no significant impact (Oliner and Sichel 1994; Jorgenson and Stiroh 1995, 1999), while industry-level studies found significant impact (Steindel 1992; Lichtenberg 1993; Brynjolfsson and Hitt 1995). According to Stiroh (2002a), the reason for this is that productivity impact could not be observable due to aggregation of both the more ICT-intensive and less ICT-intensive industries at the aggregate level. This assertion is validated by empirical studies that found a positive significant effect of ICT when industries were disaggregated (McGuckin and Stiroh 2001; Engelbrecht and Xayavong 2006; Abri and Mahmoudzadeh 2015; Niebel, O'Mahony, and Saam 2016). Thus, the disaggregation of industries according to ICT intensity allows us to identify the differential impacts of ICT across industries with varying intensities of ICT use (Chen, Niebel, and Saam 2016).

Therefore, regardless of the level of analysis, the disaggregation of industries according to their ICT intensity is crucial in identifying the source of productivity growth. This is affirmed by previous studies that detected positive and significant results for those industries that are either producing or using ICT most intensively (Abri and Mahmoudzadeh 2015; Moshiri 2016; Corrado, Haskel, and Jona-Lasinio 2017). While there is a general acknowledgement that productivity gains from ICT are detectable when industries are disaggregated, Stiroh (2002a) alerted that ICT per se is not the key driver of the great disparities in productivity growth across industries. From this perspective, productivity gains from ICT use can only be fully realized through complementary factors, such as favourable regulatory environment, the adaptation of workers' skills to the demands of the new economy, and the ability of industries to effectively use ICT (Edquist 2005; Yousefi 2011; World Bank 2016).

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Impact of ICT on productivity: developing countries

While preceding studies unearthed the positive contribution of ICT to productivity growth when industries were disaggregated, most of those studies are centred on the developed world. To date, there is no clear-cut evidence on the contribution of ICT to the productivity performance of developing countries (Niebel 2018). Subsequently, both optimistic and pessimistic viewpoints have emerged regarding the effects that ICT will have on the developing countries.

The pessimistic voices argue that new technologies are not sufficient to reduce most problems facing developing countries, like poverty (Stevenson 1991), and high rates of unemployment and inequality. For instance, The Economist (2002) cautioned that ICT investment may not produce similar returns for developing countries. Their assertion is in accordance with their empirical study, based on 60 countries, which found that ICT starts to yield gross domestic product (GDP) per capita growth for developing countries only after a certain threshold of ICT development has been attained. On this basis, developing countries are advised to concentrate on delivering necessities, such as clean water, electricity, health care, and building of schools, instead of building costly ICT infrastructure, given their limited financial resources (Ngwenyama et al. 2006).

On the other side, international organizations such as the World Bank hold optimistic views that ICTs have great promise to reduce poverty, enhance productivity and boost the economic growth of developing countries (World Bank 2012). The Bank maintains the same view for SA, stating that ICTs can be the solution to the economic challenges facing the country. To be exact, the Bank posits that ICTs can help create jobs, and reduce poverty and inequalities in SA through the expansion of economic opportunities and provision of better and cheaper goods and services (Greve 2017; World Bank 2017).

Despite the above optimistic view, empirical studies have, in general, found a positive significant effect of ICT for developed countries, but an insignificant effect for developing countries (Dewan and Kraemer 2000; Papaioannou and Dimelis 2007). Previous studies outlined circumstances under which ICT can enhance productivity in the developing countries. For instance, Papaioannou and Dimelis (2007) found the highest ICT growth effect for the developed countries. However, using the same data but with the inclusion of foreign direct investment (FDI) as another explanatory variable, Dimelis and Papaioannou (2010) found that the impact of ICT is stronger for developing relative to developed countries (Niebel 2018). These findings underscore the need for the inclusion of other factors that explain productivity when modelling productivity effects of ICT.

Furthermore, findings from Commander, Harrison, and Menezes-Filho (2011) suggest that investment in ICT can yield similar productivity growth for developing countries as it has for developed countries. This is based on their empirical analysis of the relationship between ICT capital and productivity of 1000 manufacturing firms from Brazil and India for the period from 2001 to 2004. Their results revealed that the estimated elasticities were higher than those found in the literature on developed countries (i.e. OECD countries). Further analysis into possible complementary factors revealed that higher elasticities were concentrated in firms that have undertaken complementary organizational investment, at least with respect to Brazil. Akin to findings by Dimelis and Papaioannou (2010), these results underscore the need for the inclusion of other factors that explain productivity when modelling productivity effects of ICT.

The conflicting results for developing countries are also attributable to the lack of high-quality data and the quality of the analytical approaches used. For example, using aggregate data and mis-specified models, studies found that more than 40% of China's post-reform growth in GDP is due to TFP growth (Bosworth and Collins 2008; Perkins and Rawski 2008; Zhu 2012). However, using Jorgenson's growth accounting approach (incorporated with Domar aggregation) and an economy-wide industry database, Wu (2016) found that TFP growth accounted for only 13.5% of GDP growth between 1980 and 2010. These findings are attributable to the use of the Domar aggregation approach that allows for the decomposition of productivity growth into the contribution of ICT-specific groups to productivity and to the effect of factor reallocation across groups (Wu and Liang 2017).

The review of literature for both the developed and developing countries revealed that the productivity effects of ICT are confined mostly to the developed world. More specifically, studies focusing on the developed countries found positive effects of ICT for industries that are using ICT most intensively. In the South African context, there are no empirical findings on the productivity gains that might accrue from ICT use by industries. Therefore, this paper strives to examine which group of industries (between the more ICT-intensive and less ICT-intensive) contributes the most to productivity growth. The focus is on manufacturing industries (i.e. industry-level) due to both the economic and technical reasons.

Economically, the labour market in SA is characterized by persistent and high rates of unemployment. For this reason, the National Development Plan (NDP) was developed to achieve economic growth of 5% each year and to increase employment to 24 million (from 13 million in 2010) by 2030 (National Planning Commission 2011). The manufacturing sector has consequently been identified as one of the strategic sectors to achieve this aim.[3] However, the sector continues to perform poorly with respect to its contribution to both GDP growth and employment (Bhorat and Rooney 2017). While ICT has proven to improve productivity and resuscitate growth, there are no empirical findings on the productivity gains that might accrue through ICT use by manufacturing industries.

Technically, focusing on the manufacturing industries explains the network effects of ICT (i.e. productivity effects arising from the use of ICT in the non-ICT sectors) (Stiroh 2002a; van Ark 2014). Following Szewczyk (2009), it is assumed that developments in ICT at the national level will spill over to the industries, depending on their levels of ICT investment (expenditure), such that industries investing highly in ICT benefit the most. In other words, an industry's share of ICT investment is used to measure its ability to utilize advancement in ICT at the national level. In light of this, it is further assumed that a higher ICT-led LP growth would arise in those industries that are using ICT most intensively.

However, the above assumptions do not negate the point that various factors could impact upon the results of this paper. First, while various ICT policies have been developed to increase access to ICT, their biggest drawback is that they lack a clear direction and coherence on how ICT can be used to drive SA's overall growth and development (Gillwald, Moyo, and Stork 2012). To be exact, the existing ICT policies have not explicitly focused on ensuring access to and use of ICT goods and services by non-ICT sectors such as manufacturing. Although there is no evidence to support the view that these policies have failed to drive growth, this paper aims to examine the extent to which the ICT policies implemented post-1994 contributed to the LP growth of manufacturing industries. The results of the paper provide an insight into the role of ICT in enhancing the performance of the non-

ICT industries and the extent to which ICT policies contributed to the productivity growth of the manufacturing industries.

Research methods

Definition and measurement of productivity

An industry's productivity is defined as the efficient use of resources, such as land, labour, capital, energy, materials, information and so forth, in the production of various goods and services. Therefore, higher productivity can be attained through the production of greater output in terms of quantity with the same amount of resources. Therefore, mathematically, productivity is measured as the ratio of output to all inputs used in the production process, as follows:

$$P = \frac{Y}{X} \qquad (1)$$

where P = Productivity; Y = Output; X = Inputs.

Three types of productivity can be used: (1) productivity with respect to labour (i.e. LP), (2) productivity with respect to capital (i.e. capital productivity), and (3) productivity with respect to all inputs (i.e. TFP). The precise measure of productivity is TFP since it accounts for all inputs affecting productivity. However, it is practically difficult to measure TFP due to the problem of determining weights that would reflect scarcity prices of all inputs. In view of this, statisticians have replaced the term 'TFP' with 'MFP' (i.e. output per weighted average of labour and capital inputs), given that other variables are usually excluded in calculating TFP (Sriyani Dias 1991). In this paper, LP is used as a proxy for productivity due to both economic and technical reasons. Economically, LP is preferred, given SA's sluggish growth and the high unemployment rate as follows:

- LP growth could drive the country's GDP growth in that a highly productive economy means more quantities of outputs are produced with the same amount of resources, or the same level of output is produced with fewer resources.
- Increases in LP are associated with increases in real wages (Krueger 1993; Freeman 2002; Rankin 2016). Therefore, workers benefit if increased productivity leads to higher wages.
- Increased LP generates higher profits and creates investment opportunities for industries.
- In the longer term, increased productivity increases employment. In turn, increased employment translates to higher tax revenues for the government (ILO 2016).

Technically, LP is preferred for the following reasons (Stiroh 2002a):

- In a neoclassical world, the primary effect of IT-use is on LP growth through traditional capital deepening effects (Baily and Gordon 1988; Stiroh 1998; Jorgenson and Stiroh 1999). Within this vein, ICT is viewed as an intermediate input that industries invest in to raise the LP.
- Investment in ICT affects productivity through 'embodied technological change' (in the ICT-producing sector) and capital deepening (in the ICT-using sector). However, differentiating between the two forces is difficult and subject to potentially severe

measurement problems. Thus, by focusing on LP, one can examine the impact of ICT on productivity without making the problematic distinction between embodied technological change and traditional capital deepening.

- Over and above, in this paper, the data required to estimate LP growth, as well as other measures of labour input, are more readily available than data required to correctly measure TFP.

Theoretically and empirically, LP can be measured by using either gross output or value added. For the purpose of this paper, we define LP as gross output per hours worked, instead of value-added. Our choice is based on empirical studies by Basu and Fernald (1995, 1997a, 1997b), as quoted by Stiroh (2002a), which showed that value-added data result in biased estimates and incorrect inferences regarding production parameters.

Classification of industries by ICT intensity

Various indexes have been developed to rank industries according to their ICT intensity. The most common indexes entail the grouping of industries based on their share of ICT capital services (Stiroh 2002a), industries' direct requirement for ICT (Engelbrecht and Xayavong 2006), and industries' investment in ICT (Abri and Mahmoudzadeh 2015). For all indexes, the industries with values of less than the median value of the index are classified as 'less ICT-intensive', while those with values above the median are 'more ICT-intensive'. In practice, no index is superior to the others (Chen, Niebel, and Saam 2016). However, indexes by Stiroh (2002a) and Abri and Mahmoudzadeh (2015) require data on ICT capital stock. We lack statistics on the ICT capital stock variable; hence, these indexes are not adopted for the current analysis.

Specifically, we adapt the method of Engelbrecht and Xayavong (2006) for ranking industries into 'more ICT-intensive' and 'less ICT-intensive' categories, based on their direct requirements for ICT inputs by using Input-Output (I-O) tables. I-O tables were used due to their ability to account for the nature of ICTs produced by the ICT sector and used by various industries. Thus, using I-O data is critical for the segregation of industries into 'ICT-producing' and 'ICT-using' groups. Within this vein, it is assumed that innovation firstly occurs in the ICT-producing sector and later spreads to other sectors (i.e. ICT-using sectors) (Abri and Mahmoudzadeh 2015). Therefore, productivity effects are firstly realized by a few industries, particularly producers of those new technologies in the ICT sector. Afterwards, effects become more noticeable in other industries when innovations mushroom across the economy (van Ark 2014).

In measuring the ICT intensity of industries, we calculated the direct requirements of ICT inputs for each industry (measured in million rands (ZAR)), using I-O data for 23 manufacturing industries for the period 1996. The ICT intensity of a sector is, generally, defined as the share of its purchase of goods and services from the ICT sector in its total intermediate inputs (Vu 2013). In this paper, following Engelbrecht and Xayavong (2006), the ICT intensity index for industry *j*'s (I_j) is defined as industry *j*'s requirements for ICT intermediate inputs to total requirements by all the manufacturing industries for ICT inputs, expressed as follows:

$$I_j = \frac{\sum_{j=1}^{n} \text{ict}*j}{Tj} \qquad (2)$$

where I_j = ICT intensity index for industry j's; $\sum_{j=1}^{n} \text{ict}*j$ = Industry j's requirements for ICT intermediate inputs; and T_j is the total requirements for ICT inputs by all the manufacturing industries. We adapted the ICT intensity index by Engelbrecht and Xayavong (2006) in that our index considers only the ICT intermediate inputs, while that of Engelbrecht and Xayavong includes the total inputs (i.e. both the ICT and non-ICT inputs).

Empirical models

Differences-in-Differences (DD) approach is applied to estimate the effect of ICT on LP of 23 manufacturing industries. This approach is typically used to estimate the effect of a policy by comparing the changes in outcomes over time between the treatment and control groups (Wooldridge 2013). Considering this, DD is applied to estimate the effects of ICT policies by comparing the changes in LP growth over time between the more ICT-intensive and less ICT-intensive industries.[4] It is acknowledged that the DD approach has several limitations that might impact on the findings of this paper. First, ICT's impact on the economy follows a Schumpeterian trend that begins with a negative or zero impact on productivity, followed by acceleration (Moshiri 2016). The reason for this trend is that the ICT investments might be counter-productive at the start due to the training of labour, redesign of job practices, and realignment of work structures and scope; hence returns are notable over a longer period (Becchetti, Bedoya, and Paganetto 2003; Lee, Gholami, and Tong 2005). Yet, the DD cannot estimate how long it would take for ICT to yield a positive significant impact. Thus, the DD cannot predict the future potential effects of ICT beyond the sample period.

Despite the aforementioned drawbacks, the approach has been widely used to compare productivity growth of industries with varying levels of ICT use (McGuckin and Stiroh 2001; Stiroh 2002a; Engelbrecht and Xayavong 2006; Corrado et al. 2013; Chen, Niebel, and Saam 2016; Corrado, Haskel, and Jona-Lasinio 2017). An alternative to the DD is the standard growth accounting model. However, DD is preferred for the current analysis due to its ability to account for variations in ICT use across industries and to control for time-invariant unobserved heterogeneity, which cannot be achieved using cross-sectional data.

In summation, the DD approach is used to estimate the effect of ICT intensity on LP growth outcome by comparing the average change over time in the LP growth for the more ICT-intensive industries, compared with the average change over time for the less ICT-intensive industries. Data required for DD estimation includes LP of industries pre-and post-1996. Our data consist of LP for the 23 industries from 1970 to 2016. To control for systematic differences between the two groups, we divided LP data into two sub-periods: 1970–1995 and 1996–2016. Thus, the former sub-period accounts for the pre-policy era, while the latter sub-period represents the post-policy era. The rationale for delineating the sub-periods in this way is because various ICT policy frameworks were introduced during the second half of the 1990s (i.e. from 1996) following the advent of democracy in SA in 1994. Thus, this paper strives to evaluate whether those policies contributed to the LP growth in the manufacturing sector. To achieve this, we calculated the ICT intensity of industries using the I-O data for 23 manufacturing industries for the period 1996. We then grouped industries into more ICT-intensive and less ICT-intensive using the ICT-intensive index. After grouping of industries, we apply a similar methodology to Engelbrecht and Xayavong (2006) to calculate the mean growth rate (i.e. annual growth rate (%)) of LP for each industry and group of industries. To apply the DD estimation, we estimated four dummy variable regression models as described by Equations (3) to (6). Equation (3) is used to examine the growth rate of productivity of all industries pre-and post-1996. Equations (4) and (5) distinguish the growth rate of productivity pre-and post-1996 for the less ICT-intensive industries and more ICT-intensive industries, respectively. Equation (6) statistically tests for the effect of ICT on the productivity of the two groups of industries pre-and post-1996. The models are presented as follows (Engelbrecht and Xayavong 2006):[5]

$$dLnP_{i,t} = \alpha_0 + \alpha_1 D + \varepsilon_{i,t}, \tag{3}$$

$$dLnP_{i,t} = \beta_{L0} + \beta L_1 ICT_L + \varepsilon_{i,t}, \tag{4}$$

$$dLnP_{i,t} = \beta_{M0} + \beta_{M1} ICT_M + \varepsilon_{i,t}; \tag{5}$$

$$dLnP_{i,t} = \delta_0 + \delta_1 D + \delta_2 ICT + \delta_3 D.ICT + X's + \varepsilon_{i,t}, \tag{6}$$

where i, t $i = 1, 2 \ldots \ldots 23$ industries; $t = t = 1, \ldots, 46$, indexes the annual observations over the period 1970–2016.

$dlnP_{i,t}$ an annual growth rate of productivity (LP) of industry i.

D Dummy variable where $D = 1$ if $t \geq 1996$ and $D = 0$ otherwise.

ICT_L ICT intensity for the less ICT-intensive industries.

ICT_M ICT intensity for the more ICT-intensive industries.

ICT Dummy variable equals 1 if the industry is more ICT-intensive and 0 otherwise.

α_0 Mean growth rate of LP, pre-1996.

$\alpha_0 + \alpha_1$ Mean growth rate of LP, post-1996.

α_1 Change in the mean growth rate of LP post-1996.

βL_0 Mean growth rate of LP for less ICT-intensive industries, pre-1996.

$\beta L_0 + \beta L_1$ Mean growth rate of LP for less ICT-intensive industries, post-1996.

βL_1 Change in the mean growth rate of LP for less ICT-intensive industries, post-1996.

BM_0 Mean growth rate of LP for more ICT-intensive industries, pre-1996.

$BM_0 + \beta M_1$ Mean growth rate of LP for more ICT-intensive industries, post-1996.

βM_1 Change in the mean growth rate of LP for more ICT-intensive industries, post-1996

δ_0 Mean growth rate of LP for less ICT-intensive industries, pre-1996.

$\delta_0 + \delta_1$ Mean growth rate of LP for less ICT-intensive industries, post-1996.

δ_1 Acceleration of LP for less ICT-intensive industries, post-1996.

$\delta_0 + \delta_2$ Mean growth rate of LP for more ICT-intensive industries, pre-1996.

$\delta_0 + \delta_2 + \delta_1 + \delta_3$ Mean growth rate of LP for more ICT-intensive industries, post-1996.

$\delta_1 + \delta_3$ Acceleration of LP for more ICT-intensive industries, post-1996.

δ_3 Differential acceleration (i.e. difference-in-difference) of the LP growth rate for more ICT-intensive industries relative to others.

X's Explanatory variables, namely, the unit cost of labour, remuneration, employment and capital to labour ratio.

$\varepsilon_{i,t}$ Random error term.

This paper departs from Engelbrecht and Xayavong (2006) in that we account for other variables besides ICT that might influence LP growth. Excluding other variables leads to the econometric problem of omitted variable bias, resulting in biased and inconsistent coefficients of estimates (Wooldridge 2013). To avoid this problem, we introduced four explanatory variables (i.e. controls), namely, unit cost, capital-labour ratio, remuneration, and employment, which account for LP growth besides ICT. Table 2 presents the empirical studies on the effect of the controls on productivity. The units of measurement for the controls are presented in Table 3.

It should be noted that while various factors might affect LP, our choice of the four controls is based solely on data availability. Given the above background, this paper focuses on manufacturing industries to address one underlying question: Is the LP growth in the manufacturing sector post-1996 attributable to ICT use? The objectives of the paper are:

1. To analyze the growth rate of LP of manufacturing industries pre- and post-1996.
2. To distinguish the growth rate of LP between the more ICT-intensive and less ICT-intensive industries.
3. To statistically test for the effect of ICT on LP growth of the two types of industries pre- and post-1996.

Data source

The data used, in this paper, were sourced from the South African Standardised Industry Indicator Database, which is collected, managed and owned by Quantec (2018a). The database is organized on an industry basis and disaggregates the economy into three main sectors (i.e. primary, secondary and tertiary sectors) and 46 industries. Each industry is described by up to 400 variables. The South African Reserve Bank (SARB) data are used as the framework to which all the industry data were benchmarked. Thus, the Quantec industry database is consistent with the balance of payments account, public sector accounts, and the national accounts of SA. In particular, Quantec's database provides a unique, consistent, disaggregated and long-term view of SA's economic structure by industry at the 3-digit Standard Industrial Classification (SIC) level. The data are compiled through the combination of a comprehensive set of national account and industry indicators with a consistent input-output framework. Ultimately, the result is an up-to-date and systematic set of standardized industry time-series for SA (Quantec 2018b).

Table 2: A summary of the relationship between explanatory variables and LP.

Author (s)	Sample	Finding (s)
Unit cost of labour		
Statistics Netherlands (2006)	Eurozone countries	A positive correlation between labour productivity and unit labour costs for the Netherlands. A weak correlation between labour productivity and unit labour cost for Finland.
Remuneration		
Rankin (2016)	Manufacturing industries in South Africa, 1966–2014.	Manufacturing industries with lower labour productivity had the lowest average wage.
Krueger (1993)	US Micro data, 1984–1989.	Workers who utilize computers earn higher wage rate.
Freeman (2002)	Progressive Policy Institute (PPI)'s new-economy data on 21 new-economy indicators, 1984–2001, US	Computerization and internet use is correlated with greater hours worked (i.e. unit measure of productivity) and higher wages. A positive link between computer use and hourly earnings. A positive link between internet use and hourly earnings.
Nikulin (2015)	Poland and other 5 new EU members (Estonia, Hungary, Slovak, Czech Republic and Slovenia).	The changes in the ratio of wages in Poland to wages in other countries are more connected to the changes in the ratio of productivity.
Yildirim (2015)	Turkish manufacturing industry, 1988–2012.	Unidirectional causality from real wages to productivity.
Employment		
Junankar (2013)	Developed and developing countries, 1950–2015.	A negative and statistically significant association between productivity growth and employment growth.
M. Gallegati et al. (2014)	US quarterly data, 1948 and 2013.	Productivity creates unemployment in the short and medium terms, but employment in the long run.
Muscatelli and Tirelli (2001)	G7 economies, 1955–1990.	There is a significant negative impact of unemployment on labour productivity in 5 G7 countries (i.e. Canada Japan, Italy, Germany and France). No significant relation between employment and labour productivity in the USA, and the UK. There seems to be a negative correlation between unemployment and labour productivity growth.
Capital-labour ratio		

Author (s)	Sample	Finding (s)
Mason and Osborne (2007)	New Zealand, United Kingdom and the US using 21 different market sectors	Most of the low-productivity sectors are comparatively low in capital intensity. Average labour productivity was associated capital-intensity in the UK relative to other countries.
Lannelongue, Gonzalez-Benito, and Quiroz (2017)	23 European Economic countries EA countries	Attaining greater environmental performance in capital-intensive firms diminishes labour productivity.
Datta, Guthrie, and Wright (2005)	US manufacturing sector	Firms with high capital intensity focus on exploiting their investments, leading to higher costs and efficiency and are, therefore, more prone to increase labour productivity.

Table 3: Units of measurement for the explanatory variables.

Explanatory variable	Unit of measurement
1. Unit cost of labour	Index of the total wages and salaries paid out by industry or sector divided by the net output (value-added) of that industry and multiplied by 100.
2. Remuneration	Total amount paid to employees in money or in kind and includes salaries and wages, bonuses and employers' contributions to pension and provident funds.
3. Employment	The total number of employees in a particular industry, including formal, informal as well as casual and permanent employment.
4. Capital to labour ratio	An index of the capital stock divided by an index of the number of employees, times 100.

Source: Quantec (2018b).

I-O data were sourced for calculating the ICT intensity Index. While the first I-O tables for the South African economy were first published in 1967 (Bouwer 2002), Statistics South Africa (StatsSA), the National Statistical Agency of SA, only began to publish the I-O tables on an annual basis from 2009 to 2014. Hence, the I-O data are missing for the years 1994, 1995, 1996, 1997, 2001, 2003, 2004, 2006 and 2008. Considering that I-O tables were not available from the StatsSA for the year 1996, the I-O tables used, in this paper, were sourced from Quantec. The classification of industries in the I-O tables is similar to the framework used by the StatsSA. The definition and classification of both the ICT and manufacturing industries used, in this paper, are based on the UN's International Standard Industrial Classification (ISIC) of Economic Activities (ISIC, Rev, 4), which is used by both StatsSA and Quantec (StatsSA 2015; Quantec 2018b). Furthermore, the industry classification follows a three-digit ISIC scheme reported by StatsSA in its monthly sales, production, price and employment releases. To date, Quantec has published I-O tables for the South African economy for the years 1993–2017. Their data are based on estimates and the last full release of the underlying dataset by StatsSA.

The data for LP and controls were sourced from the Trend Tables of the South African Standardised Industry Indicator Database compiled by Quantec (2018c) due to the lack of comprehensive and up-to-date information at StatsSA. The database focuses mainly on the input, output, capital employed, and labour utilization structure for each industry from 1970 to 2016. For the purpose of this, we extracted data on LP and controls for each of the 23 manufacturing industries. The methodology used to compile the I-O tables and all the variables can be obtained from Quantec website (Quantec 2018b). So far, the data have been extensively used for empirical research studies on the economic and financial analyses of the South African economy (Altman et al. 2005; Laubscher 2011; Burrows and Botha 2013; Mukandla 2016; Quantec Research 2016).

Descriptive and empirical results

Descriptive results

Classification of industries according to their ICT intensity

Using an ICT intensity index, defined as the industries' direct requirements for ICT intermediate inputs, we distinguish industries into two categories (i.e. more ICT-intensive and less ICT-intensive industries). Akin to previous studies, we use the median of the index as the point of reference for ranking industries into the two categories.[6] Within this vein, industries with an ICT intensity index of greater than the median value of 0.46% are ranked as more ICT-intensive, and vice versa for less ICT-intensive industries. Table 4 shows the ICT intensity of the industries.

Columns 3–6 of Table 4 present the rankings of the respective industries in column 1 as reported by previous studies. Columns 7 and 8 present the ranking of the industries and the ICT intensity index values, consecutively, as found by the current study.

The findings are that more than half of the industries (52%) are ranked as more ICT-intensive, while the remaining industries are less ICT-intensive. Of the agro-processing industries, four industries, namely, Food, Beverages, Wearing Apparel, and Wood, rank as more ICT-intensive, while the rest are less ICT-intensive. This implies that these four industries have the highest share of direct requirements for ICT intermediate inputs. Turning

Table 4: ICT intensity of manufacturing industries.

Industry	ICT intensity of the industry					
	Stiroh (2002a)	**van Ark, Inklaar, and McGuckin (2002)**	**Engelbrecht and Xayavong (2006)**	**Abri and Mahmoudzadeh (2015)**	**This study**	**ICT intensity index (%)**
Agro-processing Industries						
1. Food	More/Less[a]	Less	Less	Less	More[b]	2.51
2. Beverages	More/Less	Less	Less	Less	More	1.98
3. Tobacco	More/Less	Less	Less	Less	Less	0.21
4. Textile	More/Less	More/Less	Less	More	Less	0.16
5. Wearing Apparel	More/Less	More/Less	Less	More	More	1.69
6. Leather & leather products	More/Less	More/Less	Less	More	Less	0.02
7. Wood & wood products	Less[c]	Less	Less	Less	More	0.46
8. Paper & paper products	Less	Less	Less	Less	Less	0.14
9. Rubber products	Less	Less	Less	N/A	Less	0.14
10. Furniture	More/Less	More/Less	Less	Less	Less	0.41
ICT-Manufacturing Industries						
11. Printing, publishing & recorded media	More	More	More	More	More	8.44
12. Radio,TV instruments, watches & clocks	N/A	N/A	N/A	More	More	37.69
13. TV, radio, communication equipment	N/A	N/A	N/A	More	More	35.86
Rest of Manufacturing Industries						
14. Coke & Refined petroleum	Less	Less	Less	Less	Less	0.11
15. Basic chemicals	Less	Less	More	More	Less	0.34
16. Other chemicals & man-made fibres	N/A[d]	N/A	More	N/A	More	1.08
17. Other non-metallic products	N/A	N/A	N/A	Less	Less	0.27

Industry	ICT intensity of the industry					
	Stiroh (2002a)	**van Ark, Inklaar, and McGuckin (2002)**	**Engelbrecht and Xayavong (2006)**	**Abri and Mahmoudzadeh (2015)**	**This study**	**ICT intensity index (%)**
18. Glass & glass products	N/A	N/A	N/A	N/A	Less	0.04
19. Non-metallic mineral products	Less	Less	Less	Less	Less	0.23
20. Machinery & equipment	More	More	More	N/A	More	2.12
21. Electrical machinery & apparatus	N/A	N/A	N/A	More	More	3.40
22. Transport equipment	More/Less	Less	More	Less	More	1.92
23.Motor vehicles, parts & accessories	N/A	Less	N/A	Less	More	0.80

[a]'More/Less' implies that other parts of the industry are categorized as More ICT-intensive, while others are Less ICT-intensive.

[b]'More' implies that the industry is More ICT-intensive.

[c]'Less' implies that the industry is Less ICT-intensive.

[d]'N/A' implies that the industry was not included in the study under review.

Source: Authors' classification based on previous studies.

to other industries, we observe that the ICT industries have the highest ICT intensity index. These industries account for 82% of the share of direct ICT intermediate inputs required by the 23 industries. These results are as expected since the ICT sector is the most intensive user of ICT goods and services (OECD 2016). Amongst the remaining manufacturing industries, four industries – Manufacture of Other chemicals, Machinery and Equipment, Electrical Machinery Equipment, and Transport Equipment and Motor Vehicles – rank as more ICT-intensive, while the remaining industries rank as less ICT-intensive.

LP growth rates

This section presents a brief report on the mean growth rate of LP of each of the 23 manufacturing industries for the period from 1970 to 2016 and sub-periods 1970–1995 and 1996–2016. The detailed results are presented in Table 5.

In general, most of the industries (i.e. 78.2%) have positive LP growth in all periods. Specifically, 86.9% of the industries (i.e. 20 out of 23) show an acceleration in LP, suggesting a broad productivity growth.[7] Of the agro-processing industries, the Beverages and Tobacco industries exhibit decelerating LP, while the rest display acceleration in LP.

The industries were further grouped into two groups: Category A and Category B. Category A encompasses all the manufacturing industries as presented in Table 4, while Category B comprises agro-processing industries. We calculated the mean of LP growth rates between the two groups of industries for the two categories for the periods under investigation. The results are presented in Table 6.

With respect to Category A, it is observed that both the more and less ICT-intensive industries experienced an acceleration in LP growth. However, the LP growth rate of the more ICT-intensive industries is slightly higher than that of the less ICT-intensive industries (i.e. 2.24% relative to 1.97%), as presented in Figure 1.

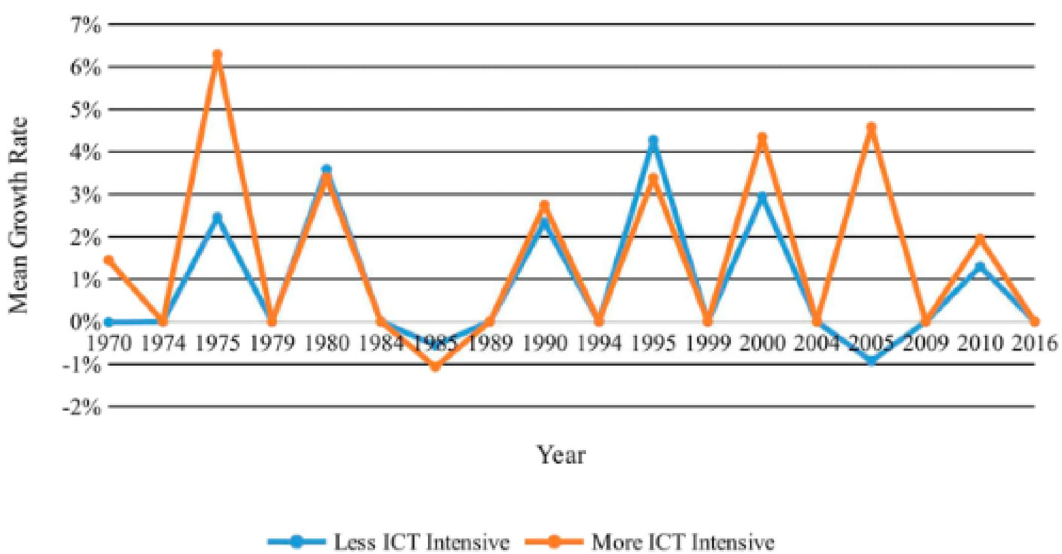

Figure 1: Mean growth rates of industries, Category A.

Source: Authors based on Quantec (2018a)

Table 5: LP growth rates of industries

Annual growth rate (%)

Industry	1970–2016	1970–1995	1996–2016	Acceleration [(1996–2016)–(1970–1995)]	Is there an acceleration in LP?
Agro-processing industries					
1. Food	2.56	1.62	4.01	2.39	Yes
2. Beverages	1.25	3.38	−1.51	−4.89	No
3. Tobacco	1.24	3.38	−1.51	−4.89	No
4. Textile	1.20	0.92	2.63	1.71	Yes
5. Wearing Apparel	1.28	0.42	5.31	4.89	Yes
6. Leather	1.27	1.14	1.09	−0.05	No
7. Wood	0.52	0.08	1.42	1.34	Yes
8. Paper	1.04	1.11	1.31	0.2	Yes
9. Rubber	1.04	1.11	1.31	0.2	Yes
10. Furniture	1.85	0.67	3.74	3.07	Yes
ICT manufacturing industries					
11. Printing	−0.49	−1.03	0.10	1.13	Yes
12. Radio, TV instruments	1.26	0.12	0.93	0.81	Yes
13. TV, radio, communication equipment	1.92	0.25	1.50	1.25	Yes
Rest of manufacturing industries					
14. Coke and Refined petroleum	1.37	1.44	1.22	−0.22	No
15. Basic chemicals	2.92	2.15	3.60	1.45	Yes
16. Other chemicals	2.09	3.13	0.60	−2.53	No
17. Other non-metallic products	1.58	−0.39	4.33	4.72	Yes
18. Glass and Glass Products	3.24	2.96	3.96	1	Yes
19. Non-metallic mineral products	1.32	−0.80	4.23	5.03	Yes
20. Machinery and Equipment	0.83	0.12	1.61	1.49	Yes
21. Electrical machinery and Equipment	1.95	1.85	2.97	1.12	Yes
22. Transport equipment	1.08	−0.90	3.66	4.56	Yes

Annual growth rate (%)					
Industry	**1970–2016**	**1970–1995**	**1996–2016**	**Acceleration [(1996–2016)–(1970–1995)]**	**Is there an acceleration in LP?**
23. Motor vehicle parts	2.28	1.09	4.22	3.13	Yes

Source: Authors' calculations based on Engelbrecht and Xayavong (2006).

Table 6: LP growth rates, categories.

Annual growth rate (%)				
	1970–2016	**1970–1995**	**1996–2016**	**Acceleration [(1996–2016)–(1970–1995)]**
***Category A*[a]**				
Mean growth rate for more ICT intensive industries	1.61	0.76	3.00	2.24
Mean growth rate for less ICT intensive industries	2.46	1.68	3.65	1.97
***Category B*[b]**				
Mean growth rate for more ICT intensive industries	1.89	1.24	3.00	1.76
Mean growth rate for less ICT intensive industries	2.39	2.08	3.00	0.92
***Category C*[c]**				
Mean growth rate for more ICT intensive industries	1.89	1.28	2.9	1.62
Mean growth rate for less ICT intensive industries	2.46	1.68	3.65	1.97

[a]Category A = All industries as outlined in Table 4.

[b]Category B = Agro-processing industries.

[c]Category C = All industries in category A, excluding the ICT-manufacturing industries.

Source: Authors' calculations based on Engelbrecht and Xayavong (2006)

It is also noted that less ICT-intensive industries display a stagnant but positive trend in LP growth across the entire period, while their counterparts exhibit downwards and upwards trends. Equally, both the more and less ICT-intensive industries in Category B exhibit acceleration in LP growth. However, in general, the more ICT-intensive industries experienced a slightly higher acceleration in LP (1.76% relative to 0.92%), as displayed in Figure 2.

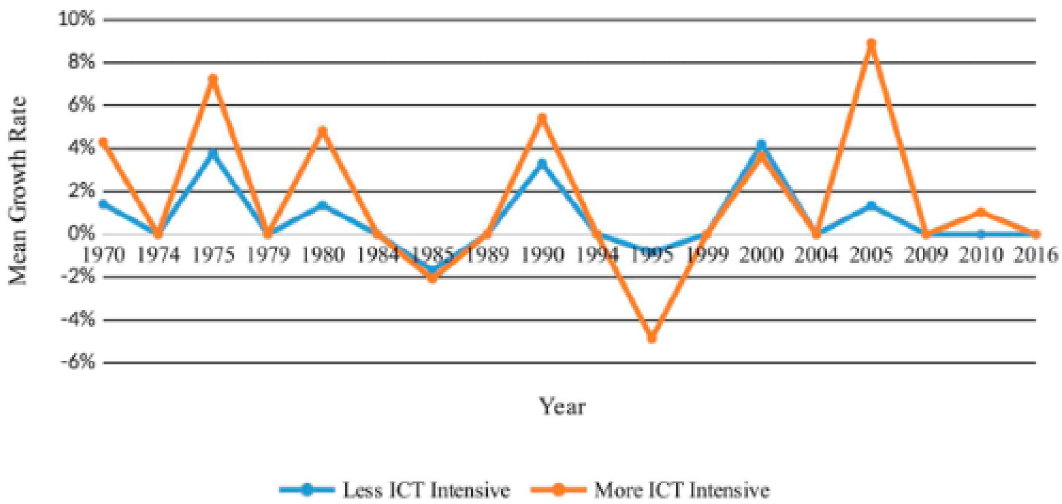

Figure 2: Mean growth rates of industries, Category B.

Source: Authors based on Quantec (2018a)

In general, the findings suggest that the more ICT-intensive industries are slightly outperforming their counterparts in terms of LP growth, irrespective of the Category. Our findings are in line with those observed in previous studies in other countries such as New Zealand (Engelbrecht and Xayavong 2006) and Iran (Abri and Mahmoudzadeh 2015). However, there is conflicting international evidence with regard to whether the ICT-producing industries contribute more or less to LP growth, as compared with other industries categorized as ICT-using. For instance, empirical evidence reported by van Ark, Inklaar, and McGuckin (2002) proved that in the US, the wholesale and retail industries exhibited stronger productivity growth in the second half of the 1990s, while the telecommunications sector displayed weaker growth.

Contrarily, Engelbrecht and Xayavong (2006), with the focus on New Zealand, found lower LP growth for the wholesale and retail industries but higher growth for the communication industries. On the other hand, in Iran, Abri and Mahmoudzadeh (2015) found that there was no significant difference in LP growth between IT-producing and IT-using industries. In view of this conflicting evidence, we deleted the three ICT-manufacturing industries from Category A and re-calculated the mean growth rates for all periods.[8] We then defined the industries excluding the ICT-manufacturing industries as Category C and included the results in Table 6.

The finding shows that, with the exclusion of ICT-producing industries, LP growth of the more ICT-intensive industries declined from 2.24% to 1.62%. Moreover, the less ICT-intensive industries are outperforming their counterparts in terms of acceleration in LP growth rates (i.e. 1.97 relative to 1.62%). This finding suggests that the LP growth rate of the more ICT-intensive industries is driven by the ICT-producing manufacturing industries. This conclusion is rational since ICT industries registered higher LP growth rates. More particularly, the Manufacture of Printing, Publishing and Recorded Media industry group registered the highest LP growth rate among all the 23 industries.

Empirical results

Through the descriptive analysis, we established that, in general, the mean growth rates for more ICT-intensive industries are greater than those of their counterparts are. Further to this, the LP growth rate of the more ICT-intensive industries is slightly driven by the ICT-manufacturing industries. The purpose of this section is, therefore, to formally test whether the differences in the mean growth rates between the two categories of industries are statistically significant. In other words, we formally test whether the differences in the LP growth rates of industries between the two groups can be associated with ICT use. To achieve this, we analyzed data using Equations (3–5) for Categories A, B and C. Table 7 highlights the results.

Before presenting the results, it must be noted that Category A includes all the 23 industries, while Category B covers the agro-processing industries. Category C is all industries except the ICT-manufacturing industries. All the ICT-manufacturing industries are more ICT-intensive. Therefore, there are no results for Equation (4), Category C, since Equation (4) is for the less ICT-intensive industries.

The results for all the 23 manufacturing industries reveal that the LP growth estimate for the pre-1996 era is insignificant, while that for the post-1996 era is significant (i.e. Equation (3), Category A). Further to this, the post-1996 estimate is larger than the pre-1996 estimate is. This implies that the LP growth of industries accelerated more post-1996, as compared with pre-1996. Of importance, the DD estimator (α_1) is significant, which validates the point that LP of manufacturing industries increased post-1996. These findings are in line with those of Rankin (2016) who found that the LP of SA's manufacturing sector grew substantially after 1994.

The results for the less ICT-intensive industries show that the LP growth estimate for the pre-1996 era is insignificant, while the estimate for the post-1996 era is significant (Equation (4), Category A). The implication is that post-1996, the LP growth of the less ICT-intensive industries accelerated more relative to the pre-1996 period. Moreover, the DD estimator (βL_1) is significant, which suggests that the LP of the less ICT-intensive industries increased post-1996.

Akin to the less ICT-intensive industries, the LP growth of the more ICT-intensive industries accelerated more post-1996, compared with pre-1996. It is further notable that the DD estimator (βM_1) is significant, which proves that the LP growth of the more ICT-intensive industries increased post-1996 (i.e. Equation (5), Category A). However, it must be noted that this is applicable only with the inclusion of ICT-manufacturing industries, as the DD estimator (βM_1) is insignificant with the exclusion of ICT-manufacturing industries (i.e. Equation (5), Category C). The findings confirm that the LP growth of the more ICT-intensive industries is driven by the ICT-manufacturing industries. Our findings conform with other findings that the LP growth of industries is driven by ICT-producing industries (Engelbrecht and Xayavong 2006).

Table 7: Estimates of the relationship between LP growth and ICT intensity: Equations (3–5).

Equations	**Category A**		**Category B**		**Category C**	
Eq. (3)						
α_0	0.173 (0.004)	$Pr(T < t) = 0.997$	0.022 (0.006)	$Pr(T < t) = 0.832$	0.019 (0.004)	$Pr(T < t) = 0.987$
$\alpha_0 + \alpha_1$	0.359*** (0.007)	$Pr(T > t) = 0.003$	0.033 (0.011)	$Pr(T > t) = 0.168$	0.036** (0.006)	$Pr(T > t) = 0.014$
α_1	0.187*** (0.007)	$Pr(\|T\| > \|t\|) = 0.005$	0.012 (0.119)	$Pr(\|T\| > \|t\|) = 0.335$	0.016** (0.007)	$Pr(\|T\| > \|t\|) = 0.027$
***T*-statistic**	2.776		0.9642		2214	
No of Obs	1058		460		920	
Eq. (4)						
βL_0	0.208 (0.006)	$Pr(T < t) = 0.962$	0.023 (0.082)	$Pr(T < t) = 0.755$		
$\beta L_0 + \beta L_1$	0.411** (0.103)	$Pr(T > t) = 0.030$	0.035 (0.016)	$Pr(T > t) = 0.245$		
βL_1	0.203* (0.114)	$Pr(\|T\| > \|t\|) = 0.070$	0.012 (0.017)	$Pr(\|T\| > \|t\|) = 0.489$		
***T*-statistic**	1.776		0.692			
No of Obs	506		276			
Eq. (5)						
β_0	0.014 (0.005)	$Pr(T < t) = 0.989$	0.020 (0.020)	$Pr(T < t) = 0.764$	0.018 (0.006)	$Pr(T < t) = 0.908$
$\beta_0 + \beta M_1$	0.312** (0.006)	$Pr(T > t) = 0.011$	0.031 (0.031)	$Pr(T > t) = 0.237$	0.030* (0.007)	$Pr(T > t) = 0.091$
βM_1	0.017** (0.008)	$Pr(\|T\| > \|t\|) = 0.023$	0.011 (0.015)	$Pr(\|T\| > \|t\|) = 0.473$	0.012 (0.009)	$Pr(\|T\| > \|t\|) = 0.1829$
***T*-statistic**	2.285		0.7193		1.334	
No of Obs	552		184		414	

$*P < 0.01$, $**P < 0.05$, $***P < 0.001$. $Pr(T < t)$, $Pr(T > t)$, $Pr(|T| > |t|)$ are the P-values for the pre-1996, post-1996 and post-1996 minus pre-1996, respectively.

Notes: The dependent variable = Annual growth rate of LP. Figures in parenthesis are standard errors. No. of Obs = Number of observations.

We further applied Equations (3) to (5) to industries in Category B to test for the effect of ICT use on the non-ICT industries (i.e. agro-processing industries). The rationale for doing this is that ICT contributes directly to the growth of ICT-producing industries and indirectly to the productivity growth of ICT-using industries (Abri and Mahmoudzadeh 2015). Therefore, in accordance with van Ark (2014), we assume that the productivity effects of ICT are firstly realized by ICT-producing industries and later by other industries, as technology mushrooms across the economy. The findings are that both the pre-1996 and post-1996 estimates are insignificant. The same applies to the DD estimators for all the agro-processing industries (α_1), the less ICT-intensive agro-processing industries (βL_1), and the more ICT-intensive agro-processing industries (βM_1). These findings imply that there is no acceleration in LP growth of the agro-processing industries pre-and post-1996. This applies to both the more ICT-intensive and less ICT-intensive industry groups.

We further applied Equation (6) to test whether the difference in LP growth between the two groups of industries pre-and post-1996 can be linked to ICT. We estimated the model for each category of industries, with and without controls. Consequently, Equation (6) is further split into two wherein Equation (6)a represents the regression without controls, while Equation (6)b includes the controls.

Before estimating Equation (6)b, we tested for correlation among the controls to avoid multicollinearity. Table 8 provides the correlation results.

Table 8: Correlation results.

Corr ICT unitcost ratio rmr employ (obs = 1517)

	ICT	**Unit cost**	**Capital-labour ratio**	**Remuneration**	**Employment**
ICT	1.0000				
Unit cost	−0.0888	1.0000			
Capital-labour ratio	−0.0009	−0.0604	1.0000		
Remuneration	−0.1061	0.5838	0.3487	1.0000	
Employment	−0.0248	0.0660	−0.0884	−0.0128	1.0000

The results show that, in general, there is sufficient evidence to validate the inclusion of the controls as most of the correlation coefficients are less than 0.3.[9] This is an indication that there is no problem of multicollinearity among the controls. However, this is apart from unit costs of labour and remuneration, as they have a coefficient of 0.58, which proves the existence of a moderate correlation. In light of this, we dropped the unit cost of labour from the analysis to avoid multicollinearity. Thereafter, we estimated Equations (6)a and (6)b, respectively. The results are presented in Table 9.

The findings show that in all cases (with and without controls), the DD estimators are not statistically significant. This implies that, overall, irrespective of the category, we fail to link the difference in the LP growth between two groups to ICT. The results are contrary to studies that found a positive and significant impact of ICT on the productivity of manufacturing industries that are more ICT-intensive industries (Lee, Gholami, and Tong 2005; Abri and Mahmoudzadeh 2015; Niebel, O'Mahony, and Saam 2016). However, the results conform to the general acknowledgement that ICT-induced productivity and growth is confined to the developed world (Joseph 2002; Niebel 2018). The results further imply that ICT policies implemented post-1994 are yet to contribute to the LP growth of the

Table 9: Estimates of the relationship between LP growth and ICT intensity: Equation (6).

Equations	**Category A**		**Category B**		**Category C**	
Eq. (6)a						
δ_0	0.208 (0.006)	$Pr(T < t) = 0.962$	0.023 (0.082)	$Pr(T < t) = 0.755$	0.021 (0.006)	$Pr(T < t) = 0.962$
$\delta_0 + \delta_1$	0.411** (0.103)	$Pr(T > t) = 0.030$	0.035 (0.016)	$Pr(T > t) = 0.245$	0.041** (0.010)	$Pr(T > t) = 0.038$
δ_1	0.203* (0.114)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.070$	0.012 (0.017)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.489$	0.020* (0.011)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.076$
$\delta_0 + \delta_2$	0.014 (0.005)	$Pr(T < t) = 0.989$	0.020 (0.020)	$Pr(T < t) = 0.764$	0.018 (0.006)	$Pr(T < t) = 0.908$
$\delta_0 + \delta_2 + \delta_1 + \delta_3$	0.312** (0.006)	$Pr(T > t) = 0.011$	0.031 (0.031)	$Pr(T > t) = 0.237$	0.030* (0.007)	$Pr(T > t) = 0.091$
$\delta_1 + \delta_3$	0.017** (0.008)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.023$	0.011 (0.015)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.473$	0.012 (0.009)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.1829$
δ_3	0.054 (0.015)	$Pr > \lvert t\rvert = 0.728$	0.510 (0.282)	$Pr > \lvert t\rvert = 0.520$	0.022 (0.172)	$Pr > \lvert t\rvert = 0.898$
R^2	0.042		0.081		0.045	
No. of Obs	1058		260		533	
Prob > *F*	0.0000		0.0025		0.0000	
Eq. (6)b						
δ_0	0.208 (0.006)	$Pr\ (T < t) = 0.962$	0.023 (0.082)	$Pr(T < t) = 0.755$	0.021 (0.006)	$Pr(T < t) = 0.962$
$\delta_0 + \delta_1$	0.411** (0.103)	$Pr(T > t) = (0.030)$	0.035 (0.016)	$Pr(T > t) = 0.245$	0.041** (0.010)	$Pr(T > t) = 0.038$
δ_1	0.203* (0.114)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.070$	0.012 (0.017)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.489$	0.020* (0.011)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.076$
$\delta_0 + \delta_2$	0.014 (0.005)	$Pr(T < t) = 0.989$	0.020 (0.020)	$Pr(T < t) = 0.764$	0.018 (0.006)	$Pr(T < t) = 0.989$
$\delta_0 + \delta_2 + \delta_1 + \delta_3$	0.312** (0.006)	$Pr(T > t) = 0.011$	0.031 (0.031)	$Pr(T > t) = 0.237$	0.030** (0.007)	$Pr(T > t) = 0.011$
$\delta_1 + \delta_3$	0.0172** (0.008)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.023$	0.011 (0.015)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.473$	0.012** (0.009)	$Pr(\lvert T\rvert > \lvert t\rvert) = 0.023$
δ_3	0.0774 (0.148)	$Pr(T > t) = 0.601$	0.551 (0.270)	$Pr(T > t) = 0.602$	0.0551 (0.164)	$Pr(T > t) = 0.737$
Remuneration	0.043*** (0.005)	Pr = 0.000	0.0431*** (0.009)	Pr = 0.000	0.0441*** (0.006)	Pr = 0.000
Employment	−0.0076 (0.008)	Pr = 0.321	−0.0093 (0.016)	Pr = 0.549	−0.0001 (0.008)	Pr = 0.992
Capital: labour ratio	0.001 (0.005)	Pr = 0.816	−0.0051 (0.009)	Pr = 0.555	0.0033 (0.005)	Pr = 0.539
R^2	0.167		0.183		0.158	
No. of Obs	1058		260		533	
Prob > *F*	0.000		0.000		0.000	

*$P < 0.01$, **$P < 0.05$, ***$P < 0.001$. Pr ($T < t$), Pr ($T > t$), Pr ($|T| > |t|$) are the P-values for the estimators for the pre-1996, post-1996 and post-1996 minus pre-1996, respectively.

Notes: The dependent variable = Annual growth rate of LP. Figures in parenthesis are standard errors. No. of Obs = Number of observations. Prob > F = the overall significance of the regression model.

manufacturing industries and that the role of ICT in enhancing the LP growth of non-ICT industries is yet to be observable.

Moreover, the DD estimator (δ_3) with controls is slightly higher than the estimator without controls is, irrespective of the category group. Specifically, the derived estimate indicates that the more ICT-intensive industries' contribution to LP is 7% higher with controls, and 5% higher without controls. In other words, without the controls, the DD estimator is underestimating the contribution of the more ICT-intensive industries to LP growth. This finding validates our inclusion of other variables that explain LP growth except for ICT.

The DD estimator for Category B is also insignificant, which implies that we fail to link the difference in LP growth between the more and less ICT-intensive agro-processing industries to ICT use. This finding implies that the effect of ICT use on the LP growth of the agro-processing industries is yet to be observable. The other implication is that agro-processing industries are yet to gain from the ICT policies that have been developed in SA after 1994. This assertion is similar to that made by Kuppusamy, Raman, and Lee (2009) who concluded that agriculture in Malaysia has not benefited from technological advancement at the national level. Their conclusion was based on their insignificant findings regarding the elasticity of ICT with respect to agriculture's contribution to GDP in Malaysia.

The insignificant results for the agro-processing industries are attributable to three factors. First, ICT policies in SA are yet to focus on ensuring access to and use of ICTs by the non-ICT industries. It is notable that, comparably, previous studies found significant results for non-ICT industries that intensively use ICT (Jorgenson and Stiroh 2000; Stiroh 2002a; O'Mahony and van Ark 2003). These results vary with ours in that these studies did not explicitly focus on the agro-processing industries.

Second, the key assumption of this paper is that higher ICT-led LP growth would arise in those industries investing more highly in ICT. The descriptive results show that the agro-processing industries are investing the least in ICT, as they account for a smaller share of direct requirements for ICT intermediate inputs (i.e. 7.72%). In other terms, the agro-processing industries are not investing highly in ICT, hence the insignificant findings. This is because most, albeit not all, agro-processing industries rely on suppliers for technological innovation (i.e. they are supplier-dominated) and their production activities are resource-based rather than information-intensive (Kuppusamy, Raman, and Lee 2009; Shyam 2011; Campana and Cimatti 2015).

Third, the LP growth gains from ICT use are notable over a long period, which necessitates forecasting. However, the DD approach does not account for the future potential effects of ICT on industries over a long period. From this perspective, the insignificant findings for the agro-processing industries do not imply that ICT use yields no effect on the LP growth of the agro-processing industries. Instead, they suggest that the effect of ICT on LP growth of the agro-processing industries may be observable over a long period.

Taking into account that other factors except ICT contribute to LP growth, we estimated Equation (6)b with three controls. The findings are that, irrespective of the category, both remuneration and capital-labour ratio positively influence LP growth and vice versa for employment. However, only remuneration is significant. These findings imply that LP growth increases with an increase in wages. The findings are in conformity with previous studies that found a positive link between greater hours worked (i.e. LP) and higher wages

(Krueger 1993; Freeman 2002; Nikulin 2015). Rankin (2016) also found that SA's manufacturing industries with lower LP had the lowest average wage. Therefore, industries aiming to improve LP should consider increasing the remuneration of employees.

Conclusion

This paper serves to provide empirical evidence on whether the growth in LP in the manufacturing sector after the ICT policy reforms that occurred from 1996 can be attributed to ICT. The findings are that, in general, the LP of the manufacturing industries increased post-1996. However, the DD estimator (δ_3) for the more ICT-intensive industries is significant only with the inclusion of the ICT-manufacturing industries in the analysis. This implies that the ICT-producing industries constitute the key driver of LP growth of the more ICT-intensive industries. The results are attributable to the fact that the ICT-manufacturing industries accounted for a larger share of the direct requirements for ICT intermediate inputs.

While we fail, in general, to link the difference in LP growth between the two groups of industries to ICT use, the derived estimators proved that the more ICT-intensive industries contributed more to LP growth. Again, we fail to link the difference in the LP growth of the more ICT-intensive and less ICT-intensive agro-processing industries to ICT. This implies that the LP productivity effects of ICT on the agro-processing sub-sector are yet to be observable.

This paper has several delimitations that might have impacted on the results. First, the paper does not account for the trend in ICT use over the years. To be specific, some industries might have used ICT most intensively pre-and post-1996, but only ICT intensity for the year 1996 was considered. Second, the DD does not capture the causal relationship between ICT and LP growth of industries. Third, ICT's impact on the economy follows a Schumpeterian trend that begins with a negative or zero impact on productivity, followed by acceleration. However, the DD cannot capture how long it would take for ICT to yield positive productivity effects. Fourth, the paper focuses on manufacturing industries; therefore, the ICT intermediate inputs used, in this paper, are limited to the ICT-manufacturing industries. For this reason, contrary results could be derived if other ICT industries were to be considered.

Given the above delimitations, two areas require further analyses: (1) testing for causality between ICT and LP growth of industries; and (2) estimating how long it would take for ICT to yield positive productivity effects. Regardless of the identified drawbacks, the paper attained its purpose of testing whether the growth in LP is attributable to ICT use. The DD estimator (δ_3) is insignificant, which proves that we fail to link the LP growth of industries to ICT. This finding is attributed to the observation that SA's ICT policies are yet to ensure access to and use of ICTs by the non-ICT industries. It is for this reason that we found no evidence of ICT-led LP growth of the manufacturing sector, and of agro-processing industries in particular. The repercussion of this is that SA is likely to continue on the same sluggish economic growth trajectory. Hence, there is a need for policy measures to be put in place to increase ICT use, with the aim of improving LP performance of industries. These measures include a tax rebate on investment in ICT by industries, training of low-skilled workers (since ICT tends to be biased against low-skilled workers in favour of high-skilled workers), and reduction of ICT costs. These measures would stimulate investment in ICTs by industries and ultimately drive LP growth, which is one of the key factors of economic growth.

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Notes

1 The manufacturing sector has been identified as the sector for achieving sustainable development, given its job multiplication effect (i.e. one job in manufacturing creates 2.2 jobs in other sectors). Furthermore, the sector is the key employer, responsible for about 470 million jobs worldwide in 2009 or about 16% of the world's workforce of 2.9 billion (UNDP 2016).

2 The policies include key publicly available frameworks and exclude policy strategies/plans, programmes and projects.

3 The manufacturing sector has been chosen given its labour-intensive nature and strong backward and forward linkages with other sectors.

4 The more ICT intensive industries are assumed to be the treatment group, while the less ICT intensive industries are the control group.

5 The equations, as well as the description of variables and parameters, are adapted from Engelbrecht and Xayavong (2006).

6 Previous studies include studies by Stiroh (2002a) and Engelbrecht and Xayavong (2006).

7 Acceleration means that the mean growth of LP increased over time, and vice versa for deceleration.

8 ICT-producing industries comprise Manufacture of Printing, Publishing and Recorded Media; Manufacture of Radio, TV, instruments; and Manufacture of TV, radio, communication equipment.

9 Correlation coefficients with values of between 0.9 and 1.0 are considered very highly correlated, while those with values of between 0.7 and 0.9 are highly correlated. Coefficients of between 0.5 and 0.7 are considered moderately correlated, whereas those with values of between 0.3 and 0.5 indicate a low correlation. Coefficients of less than 0.3 indicate the absence of correlation.

References

Abri, A. G., and M. Mahmoudzadeh. 2015. "Impact of Information Technology on Productivity and Efficiency in Iranian Manufacturing Industries." *Journal of Industrial Engineering International* 11 (2015): 143–157.

Altman, M., T. van der Heijden, M. Mayer, and G. Lewis. 2005. *Employment-oriented Industry Studies: A Review of Trade in Services*. Pretoria: Human Sciences Research Council (HSRC).

Arvanitis, S., and E. N. Loukis. 2009. "Information and Communication Technologies, Human Capital, Workplace Organization and Labour Productivity: A Comparative Study Based on Firm-Level Data for Greece and Switzerland." *Information Economics and Policy* 21 (1): 43–61.

Baily, M. N., and R. J. Gordon. 1988. "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power." *Brookings Papers on Economic Activity* 19 (1998): 347–420.

Basu, S. 1997a. "Returns to Scale in U.S. Production: Estimates and Implications." *Journal of Political Economy* 105 (2): 249–283.

Basu, S. 1997b. *Aggregate Productivity and Aggregate Technology*. Federal Reserve Bank (FRB) International Finance Discussion Paper No. 593. Washington, D.C: Federal Reserve Bank.

Basu, S., and J. G. Fernald. 1995. "Are Apparent Productive Spillovers a Figment of Specification Error?" *Journal of Monetary Economics* 36 (1995): 165–188.

Becchetti, L. D., A. L. Bedoya, and L. Paganetto. 2003. "ICT Investment, Productivity and Efficiency: Evidence at Firm Level Using a Stochastic Frontier Approach." *Journal of Productivity Analysis* 20 (2): 143–167.

Berndt, E. R., and C. J. Morrison. 1995. "High-tech Capital Formation and Economic Performance in U.S. Manufacturing Industries An Exploratory Analysis." *Journal of Econometrics* 65 (1): 9–43.

Bhorat, H., and C. Rooney. 2017. *State of Manufacturing in South Africa.* Development Policy Research Unit (DPRU) Working Paper 201702. Cape Town: DPRU.

Bloom, N., R. Sadun, and J. Van Reenen. 2012. "Americans Do IT Better: US Multinationals and the Productivity Miracle." *American Economic Review* 102 (1): 167–201.

Bosworth, B., and S. M. Collins. 2008. "Accounting for Growth: Comparing China and India*." Journal of Economic Perspectives* 22 (1): 45–66.

Bouwer, G. 2002. “The Role of Supply and Use Tables in South Africa as a Tool for Economic Analysis.” Paper presented at the 14th International Conference on Input-Output Techniques, Montreal, Canada, October 10–15.

Brynjolfsson, E., and L. Hitt. 1995. “Information Technology as a Factor of Production: The Role of Differences among Firms.” *Economics of Innovation and New Technology* 3 (3–4): 183–200.

Burrows, Le R., and A. P. Botha. 2013. “Explaining the Changing Input-Output Multipliers in South African: 1980–2010.” Paper presented at the Biennial Conference of the Economic Society of South Africa, Bloemfontein, South Africa, September 25–27.

Campana, G., and B. Cimatti. 2015. “Measures and Methods for a new Taxonomy in Manufacturing Enterprises.” *Procedia CIRP* 26 (2015): 287–292.

Chen, W., T. Niebel, and M. Saam. 2016. “Are Intangibles More Productive in ICT-Intensive Industries? Evidence from EU Countries.” *Telecommunications Policy* 40 (2016): 471–484.

Commander, S., P. Harrison, and N. Menezes-Filho. 2011. “ICT and Productivity in Developing Countries: New Firm-Level Evidence from Brazil and India.” *Review of Economics and Statistics* 93 (2): 528–541.

Corrado, C., J. Haskel, and C. Jona-Lasinio. 2017. “Knowledge Spillovers, ICTand Productivity Growth.” *Oxford Bulletin of Economics and Statistics* 79 (4): 592–618.

Corrado, C., J. Haskel, C. Jona-Lasinio, and M. Iommi. 2013. “Innovation and Intangible Investment in Europe, Japan, and the United States.” *Oxford Review of Economic Policy* 29 (2): 261–286.

Datta, D. K., J. P. Guthrie, and P. M. Wright. 2005. “HRM and Firm Productivity: Does Industry Matter?” *Academy of Management Journal* 48 (1): 135–145.

Dewan, S., and K. L. Kraemer. 2000. “Information Technology and Productivity: Evidence from Country-Level Data.” *Management Science* 46 (4): 548–562.

Dimelis, S., and S. Papaioannou. 2010. “FDI and ICT Effects on Productivity Growth: A Comparative Analysis of Developing and Developed Countries.” *The European Journal of Development Research* 22 (1): 79–96.

DTPS (Department of Telecommunications and Postal Services). 2015. *Annual Report 2014–2015*. Pretoria: DTPS.

Edquist, H. 2005. "The Swedish ICT Miracle—Myth or Reality?" *Information Economics and Policy* 17 (2005): 275–301.

Edquist, H., and M. Henrekson. 2017. "Do R&D and ICT Affect Total Factor Productivity Growth Differently?" *Telecommunications Policy* 41 (2017): 106–119.

Engelbrecht, H., and V. Xayavong. 2006. "ICT Intensity and New Zealand's Productivity Malaise: Is the Glass Half Empty or Half Full?" *Information Economics and Policy* 18 (2006): 24–42.

Farooquie, P., A. Gani, A. Zuberi, and I. Hashemi. 2012. "An Empirical Study of Innovation-Performance Linkage in the Paper Industry." *Journal of Industrial Engineering International* 8 (23): 1–6.

Freeman, R. B. 2002. "The Labour Market in the New Information Economy." *Oxford Review of Economic Policy* 18 (3): 288–305.

Gallegati, M., M, Gallegati, J. B. Ramsey, and W. Semmler. 2014. "Does Productivity Affect Unemployment? A Time-Frequency Analysis for the US." In *Wavelet Applications in Economics and Finance*, edited by M. Gallegati and W. Semmler, 23–46. New York: Springer.

Gillwald, A., M. Moyo, and C. Stork. 2012. *Understanding What is Happening in ICT in South Africa: A Supply-and Demand-Side Analysis of the ICT Sector.* Evidence for ICT Policy Action Policy Paper 7. Cape Town: Research ICT Africa.

Greve, N. 2017. "Innovation Could Save SA's Economy-World Bank." *News24*. September, 20.

ILO (International Labour Organization). 2016. *Key Indicators of the Labour Market 2015 KILM*. 9th ed. Geneva:

International Labour Organization. Jorgenson, D. W., and K. J. Stiroh. 1995. "Computers and Growth." *Economics of Innovation and New Technology* 3 (3–4): 295–316.

Jorgenson, D. W., and K. J. Stiroh. 1999. "Information Technology and Growth." *The American Economic Review* 89 (2): 109–115.

Jorgenson, D. W., and K. J. Stiroh. 2000. "Raising the Speed Limit: U.S. Economic Growth in the Information Age." *Brookings Papers on Economic Activity* 2000 (1): 125–210.

Joseph, K. J. 2002. *Growth of ICT and ICT for Development Realities of the Myths of the Indian Experience.* World Institute for Development Economics Research (UNU-WIDER) Discussion Paper No. 2002/78. Finland: UNU-WIDER.

Junankar, P. N. 2013. *Is There a Trade-off Between Employment and Productivity?* Institute of Labour Economics (IZA) Discussion Paper No. 7717. Bonn: IZA.

Khan, H., and M. Santos. 2002. *Contribution of ICT Use to Output and Labour-Productivity Growth in Canada*. Bank of Canada Working Paper 2002–7. Ottawa: Bank of Canada.

Kijek, T., and A. Kijek. 2018. "Is Innovation the Key to Solving the Productivity Paradox?" *Journal of Knowledge and Innovation* 78 (2018): 1–8.

Kılıçaslan, Y., R. C. Sickles, A. A. Kayış, and Y. Ü. Gürel. 2015. *Impact of ICT on the Productivity of the Firm: Evidence from Turkish Manufacturing*. RICE INITIATIVE for the STUDY of ECONOMICS (RISE) Working Paper 15-017. Houston, Texas: RISE.

Krueger, A. B. 1993. "How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984–1989." *The Quarterly Journal of Economics* 108 (1): 33–60.

Kuppusamy, M., M. Raman, and G. Lee. 2009. "Whose ICT Investment Matters to Economic Growth: Private or Public? The Malaysian Perspective." *EJISDC* 37 (7): 1–19.

Lannelongue, G., J. Gonzalez-Benito, and I. Quiroz. 2017. "Environmental Management and Labour Productivity: The Moderating Role of Capital Intensity." *Journal of Environmental Management* 190 (2017): 158–169.

Laubscher, P. 2011. *A Macro-Economic Assessment of the Western Cape Economy's Sectoral and Industrial Growth Prospects: 2010 to 2015, Including an Assessment of Inter-Industry Linkages*. A research report prepared for the Department of Economic Development & Tourism (DEDT). Cape Town: DEDT

Lee, S.-Y. T., R. Gholami, and T. Y. Tong. 2005. "Time Series Analysis in the Assessment of ICT Impact at the Aggregate Level –Lessons and Implications for the new Economy." *Information and Management* 42 (7): 1009–1022.

Lichtenberg, F. R. 1993. “The Output Contributions of Computer Equipment and Personnel: A Firm-Level Analysis.” *Economics of Innovation and New Technology* 3 (3 –4): 201–218.

Loveman, G. W. 1994. “An Assessment of the Productivity Impact on Information Technologies.” In *Information Technology and the Corporation of the 1990s*, edited by T. J. Allen and M. S. Morton, 84–110. Oxford: Oxford University Press.

Mačiulytė-Šniukienėa, A., and E. Gaile-Sarkane. 2014. “Impact of Information and Telecommunication Technologies Development on Labour Productivity.” *Procedia –Social and Behavioral Sciences* 110 (2014): 1271–1282.

Mason, G., and M. Osborne. 2007. *Productivity, Capital-Intensity and Labour Quality at Sector Level in New Zealand and the UK.* New Zealand Treasury Working Paper 07/01. Wellington: New Zealand Treasury.

McGuckin, R. H., and K. J. Stiroh. 2001. “Do Computers Make Output Harder to Measure?” *The Journal of Technology Transfer* 26 (4): 295–321.

Mefteh, H., and L. Benhassen. 2015. “Impact of Information Technology and Communication on Economic Growth*.” International Journal of Economics, Finance and Management* 4 (2): 90–98.

Moshiri, S. 2016. “ICT Spillovers and Productivity in Canada: Provincial and Industry Analysis.” *Economics of Innovation and New Technology* 25 (8): 801–820.

Mukandla, A. 2016. “Identification of Nucleus Industries with Higher Growth Potential for Focused Interventions and Impact Evaluation: Case of South Africa.” Paper presented at the 1st Economic Research Advisory Network (ERAN) Conference, East London, South Africa, March 10–11.

Muscatelli, V. A., and P. Tirelli. 2001. “Unemployment and Growth: Some Empirical Evidence from Structural Time Series Models.” *Applied Economics* 33 (8): 1083–1088.

National Planning Commission. 2011. *National Development Plan*. Pretoria: National Planning Commission.

Ngwenyama, O., F. K. Andoh-Baidoo, F. Bollou, and O. Morawczynski. 2006. “Is There a Relationship between ICT, Health, Education and Development? An Empirical Analysis of Five West African Countries from 1997–2003.” *EJISDC* 23 (5): 1–11.

Niebel, T. 2018. “ICT and Economic Growth –Comparing Developing, Emerging and Developed Countries.” *World Development* 104 (2018): 197–211.

Niebel, T., M. O’Mahony, and M. Saam. 2016. “The Contribution of Intangible Assets to Sectoral Productivity Growth in the EU.” *Review of Income and Wealth* 63 (1): 49–67.

Nikulin, D. 2015. “Relationship Between Wages, Labour Productivity and Unemployment Rate in new EU Member Countries.” *Journal of International Studies* 8 (1): 31–40

.

OECD (Organisation for Economic Co-operation and Development). 2016. *ICTS and Jobs: Complements or Substitutes? The Effects of ICT Investment on Labour Demand by Skills and by Industry in Selected OECD Countries.* Working Party on Measurement and Analysis of the Digital Economy. Paris: OECD.

Oliner, S. D., and D. E. Sichel. 1994. “Computers and Output Growth Revisited: How Big is the Puzzle?” *Brookings Papers on Economic Activity 1994* (2): 273–317.

O’Mahony, M., and B. van Ark, eds. 2003. *EU Productivity and Competitiveness: A Sectoral Perspective; Can Europe Resume the Catching-Up Process?* Brussels: European Commission.

Papaioannou, S., and S. Dimelis. 2007. “Information Technology as a Factor of Economic Development: Evidence from Developed and Developing Countries.” *Economics of Innovation and New Technology* 16 (3): 179–194.

Perkins, D., and T. Rawski. 2008. “Forecasting China’s Economic Growth to 2025.” In *China’s Great Economic Transformation*, edited by L. Brandt and T. Rawski, 829–886. Cambridge: Cambridge University Press.

Piatkowski, M. 2004. *The Impact of ICT on Growth in Transition Economies.* Transformation, Integration, Globalization and Economic Research (TIGER) Working Paper Series No. 59. Poland: TIGER.

Pradhan, R. P., M. B. Arvin, S. Bahmani, N. R. Norman, and S. K. Bele. 2014. “Economic Growth and the Development of Telecommunications Infrastructure in the G-20 Countries: A Panel-VAR Approach.” *Telecommunications Polic*y 38: 634–649.

Quantec. 2018a. South African Standardised Industry Indicator Database. Accessed May 4, 2018. www.quantec.co.za.

Quantec. 2018b. South African Standardised Industry Indicator Database: Sources and Description. Accessed February 2, 2018. https://www.easydata.co.za/documents/IND/folder/documentation/.

Quantec. 2018c. Trend Tables of the South African Standardised Industry Indicator Database. Accessed May 4, 2018. www.quantec.co.za.

Quantec Research. 2016. The Contribution of British American Tobacco South Africa to the Gauteng Economy. Cape Town: British American Tobacco South Africa.

Rankin, N. 2016. *LP, Factor Intensity and Labour Costs in South African Manufacturing.* REDI3(3) Working paper 21. Cape Town: REDI3 (3).

Relich, M. 2017. "The Impact of ICT on Labor Productivity in the EU*." Information Technology for Development* 23 (4): 706–722.

Shyam, U. 2011. "Derived Classifications for Industrial Performance Indicators." Proceeds of the 58th World Statistical Congress of the International Statistical Institute, Dublin, Ireland, August 21–26.

Solow, R. M. 1987. "We'd Better Watch Out."New York Times Book Review. New York: New York Times.

Sriyani Dias, R. K. 1991. "Factors Affecting the Productivity of Manufacturing Sector in Sri Lanka: A Spatial Analysis." *GeoJournal* 23 (2): 113–120.

Stare, M., A. Jaklič, and P. Kotnik. 2006. "Exploiting ICT Potential in Service Firms in Transition Economies." *The Service Industries Journal* 26 (3): 287–302.

Statistics Netherlands. 2006. "Wage Costs, LP and Unit Labour Costs."Accessed May 23, 2018. https://www.cbs.nl/en-gb/news/2006/48/wage-costs-labour-productivity-and-unit-labour-costs.

StatsSA (Statistics South Africa). 2015. *Information and Communication Technology Satellite Account for South Africa, 2012*. Pretoria: StatsSA.

Steindel, C. 1992. "Manufacturing Productivity and High-Tech Investment." *Federal Bank of New York Quarterly Review* 17 (1992): 39–47.

Stevenson, T. 1991. "Telecommunications Development in Asia-Pacific: The Case for a New Australian Role." *Telecommunications Policy* 15 (6): 485–490.

Stiroh, K. J. 1998. "Computers, Productivity, and Input Substitution." *Economic Inquiry* 36 (2): 175–191.

Stiroh, K. J. 2002a. "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?" *American Economic Review* 92 (5): 1559–1576.

Stiroh, K. J. 2002b. "Are ICT Spillovers Driving the New Economy?" *Review of Income and Wealth* 48 (1): 33–57.

Szewczyk, W. 2009. "ICT in CGE Models- Modifying the Typical CGE Theoretical Structure." Paper presented at the 12th Annual Conference on Global Economic Analysis Conference, Santiago, Chile, June 10–12.

The Economist. 2002. "Reaping the Benefits of ICT, Europe's Productivity Challenge." Accessed June 4, 2018. http://graphics.eiu.com/files/ad_pdfs/microsoft_final.pdf.

UNDP (United Nations Development programme). 2016. Goal 9: *Industry, Innovation and Infrastructure*. New York: UNDP.

van Ark, B. 2002. "Measuring the New Economy: An International Comparative Perspective." *Review of Income and Wealth* 48 (1): 1–14.

van Ark, B. 2014. *Productivity and Digitalisation in Europe: Paving the Road to Faster Growth*. Lisbon Council Policy Brief Vol. 8, No. 1, 2014. New York: The Conference Board.

van Ark, B., R. Inklaar, and R. McGuckin. 2002. 'Changing Gear'- *Productivity, ICT and Services Industries: Europe and the United States.* Economics Program Working Papers 02-02. New York: The Conference Board.

Vu, K. M. 2013. "Information and Communication Technology (ICT) and Singapore's Economic Growth." *Information Economics and Policy* 25 (4): 284–300.

Wooldridge, J. M. 2013. Introductory Econometrics: A Modern Approach. 5th ed. Mason, Ohio: South-western, Cengage Learning.

World Bank. 2012. "ICT for Greater Development Impact: World Bank Group Strategy for Information and Communication Technology, 2012–2015." Accessed May 12, 2017. https://openknowledge.worldbank.org/handle/10986/27411.

World Bank. 2016. *World Development Report 2016*. Washington, DC: World Bank.

World Bank. 2017. *South Africa Economic Update, Innovation for Productivity and Inclusiveness.* Washington, DC: World Bank.

Wu, H. X. 2016. "On China's Strategic Move for a New Stage of Development- a Productivity Perspective." In *The World Economy: Growth or Stagnation,* edited by D. Jorgenson, K. Fukao, and M. Timmer, 199–233. Cambridge: Cambridge University Press.

Wu, H. X., and D. T. Liang. 2017. *Accounting for the Role of Information and Communication Technology in China's Productivity Growth*. Research Institute of Economy Trade and Industry (RIETI) Discussion Paper 17-E-111. Tokyo: RIETI.

Yildirim, Z. 2015. "Relationships among Labour Productivity, Real Wages and Inflation in Turkey." *Economic Research-Ekonomska Istraživanja* 28 (1): 85–103.

Yousefi, A. 2011. "The Impact of Information and Communication Technology on Economic Growth: Evidence from Developed and Developing Countries." *Economics of Innovation and New Technology* 20 (6): 581–596.

Zhu, X. 2012. "Understanding China's Growth: Past, Present, and Future." *Journal of Economic Perspectives* 26 (4): 103–124.

Appendix

Table 1A: Overview of key ICT policy frameworks in South Africa from 1994 to 2016.

Policy	Objective (s)
The national information society and development (ISAD) plan	'To establish South Africa as an advanced Information Society in which Information and ICT tools are key drivers of economic and societal development.'
Sentech Act, 1996 (Act No. 63 of 1996)	To provide for the conversion of Sentech (Pty) Ltd from a private to a public company.
Telecommunications Act, 1996 (Act No. 103 of 1996)	To provide for the regulation of the telecommunication activities/sector.
Postal Service Act, 1998 (Act No. 124 of 1998)	To provide for the regulation of the postal sector to ensure accessible, efficient, equitable, effective, and affordable postal services.
State Information Technology Agency Act (SITA), 1998 (Act No. 88 of 1998)	To provide for the establishment of SITA, state-owned agency, for the provision of information systems and services to, or on behalf of the government.
Broadcasting Act, 1999 (Act No.4 of 1999)	To provide for the establishment of the state broadcaster, the South African Broadcasting Corporation (SABC) and for the licensing and regulation of the broadcasting system.
ICASA Act, 2000 (Act No. 13 of 2000)	To provide for the regulation of the broadcasting, postal and telecommunications industries to ensure access to high quality and affordable communication services.
Telecommunications Act 2001 (Act No. 64 of 2001)	To allow for the formation of competitors to Telkom (i.e. semi-state owned telecommunications company).
Electronic Communications and Transactions (ECT) Act 2002 (Act No. 25 of 2002)	Facilitate and regulate electronic communications and transactions.
Electronic Communications Act, 2005 (Act No. 36 of 2005)	To provide for the regulation of electronic communications, network and broadcasting services.
Broadband Infraco Act, 2007 (Act No. 33 of 2007)	To provide for the establishment of Broadband Infraco, state-owned agency to provide long distance connectivity to the licensed private sector.
South African Post Bank Limited Act, 2010 (Act No. 9 of 2010)	To provide for the governance and functions of the Postbank company and allow for the conversion of the Postbank from deposit-taking to a fully-fledged bank.
South African Post Office SOC Ltd Act, 2011 (Act No. 22 of 2011)	To ensure the provision of accessible, universal, affordable and reliable postal services.
National Broadband Policy and Strategy (2013)	To ensure access to reliable, fast, and available and secure internet by all citizens, particularly those living in rural areas.
Broadcasting Digital Migration Policy (2016)	To provide for the migration from analogue to digital terrestrial television broadcasting.
The National Integrated ICT Policy (2016)	To provide for alignment of ICT policies with the National Development Plan (NDP) 2030.