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The effects of digital transformation on innovation and productivity: Firm-level evidence of South African manufacturing micro and small enterprises

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A B S T R A C T

This paper studies the relationships among the use of digital communication technologies, innovation performance and productivity, using an extended version of the Crepon-Duguet-Mairesse (1998) model, for a sample of micro and small enterprises (MSEs) in a middle-income country, South Africa. Based on the results of an original survey carried out in 2019, we investigate these links for a sample of 711 manufacturing MSEs located in Johannesburg. We estimate the relationships sequentially, firstly estimating the relationship between digitalization and innovation, and secondly the relationship between innovation and productivity. Our results show that selected digital communication technologies including the use of social media and of a business mobile phone for surfing the internet have a positive effect on innovation, and that innovation conditional on the use of these technologies has a positive effect on labor productivity. The findings suggest that public programs aimed at fostering inclusive digitalization must consider the types of digital technologies that are most accessible and beneficial to small firms, including those operating informally.

1. Introduction

Digitalization is transforming economies across the world and altering the way firms develop and market goods and services. It holds many promises to spur innovation, generate efficiencies, and improve economic prospects (Dahlman et al., 2016). However, the dynamics of digitalization have not been equally spread across regions, over time, or even across firms within countries. While differences in digitalization between high- and low-income countries remain large, spurred by the declining costs of broadband from the mid to late-2000s and the increasing ease of internet access with inexpensive mobile phones, some developing countries like South Africa have expanded their digital economies exponentially over the past decade or so.[1] This paper explores the effects of the adoption of digital communication technologies on firm-level innovation and productivity in South Africa, focusing on the predominant segment of micro and small enterprises (MSEs), which includes firms operating informally.

The African Union's "*Digital Transformation Strategy for Africa 2020-2030*" argues that digital transformation is a driving force for innovative, inclusive, and sustainable growth. This strategic vision sees the current moment as offering a leapfrogging opportunity for the continent and observes that African countries with fewer legacy challenges are potentially able to adopt digitized solutions faster (African Union, 2020). South Africa, an upper-middle-income country, has made digital transformation a key component of its National Development Plan for eliminating poverty and reducing inequalities by 2030. The "*2017-2030 National e-Strategy*" aims to position South Africa as a significant player in the development of information and communication technologies (ICTs) throughout the value chain. Similarly, the "*2020 National Digital and Future Skills Strategy*" sets out a roadmap for digital skills

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[1] See the country-level digital economy diagnostics undertaken by the World Bank in the context of its Digital Economy for Africa Initiative: https://www.worldbank.org/en/programs/all-africa-digital-transformation. World Bank research estimates that through the digital transformation Sub Saharan Africa can increase its rate of growth by 2 % per year (World Bank, 2019a).

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development and stakeholder involvement in the adoption and use of new digital technologies (South African Department of Telecommunications, 2017, 2020).

There has been clear evidence of digital transformation in South Africa over the last decade or so linked to the wide adoption of mobile phones and improvements in the infrastructure for broadband internet access. Fig. 1 below shows the share of the population in South Africa using the internet and compares this to the average for high-income countries between 1995 and 2017.[2] While internet use increased rapidly in high-income countries between 1995 and 2000, it remained low in South Africa. This was linked to the limited investments in the infrastructure for fixed-line telephone systems since at the time, internet access required dialing up a connection using a modem.

Fig. 2 shows the number of fixed-line and mobile telephone subscriptions per 100 persons in South Africa compared to the average for high-income countries from 1995 to 2019. While the number of fixed-line telephone subscriptions in South Africa was under 10 per 100 persons in the mid-1990s, it was close to 50 per 100 persons on average in high-income countries. The evidence points to South Africa not benefiting substantially from the so-called ICT revolution of the 1990s that was taking hold in developed countries based on the use of personal computers and the copper wire fixed-line telecommunications infrastructure for internet access.

The number of mobile cellular subscriptions increased rapidly in South Africa after the year 2000, overtaking the number of fixed-line subscriptions. This increase occurred at a slightly faster rate than in high-income countries while starting from a lower level. In 2000, there were about 18 mobile subscriptions per 100 persons in South Africa compared to 48 per 100 on average in high-income countries. By 2011, South Africa had caught up fully and subsequently, surpassed the average rate of penetration in high-income countries. The wide diffusion of mobile phones in combination with better and cheaper access to broadband connectivity provided the basis for a rapid increase in internet use in South Africa after 2009 as shown in Fig. 1. The key institutional and infrastructural developments were an end to Telkom's

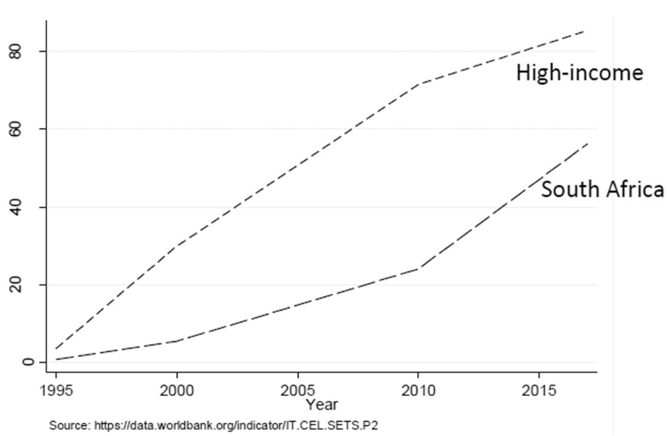

Fig. 1. Individuals using internet (in % of population).
Source: https://data.worldbank.org/IT.CEL.SETS.P2.

[2] The data for internet use and for mobile and fixed-line subscriptions are taken from the World Development Indicators series. For more information, see: https://datatopics.worldbank.org/world-development-indicators/.

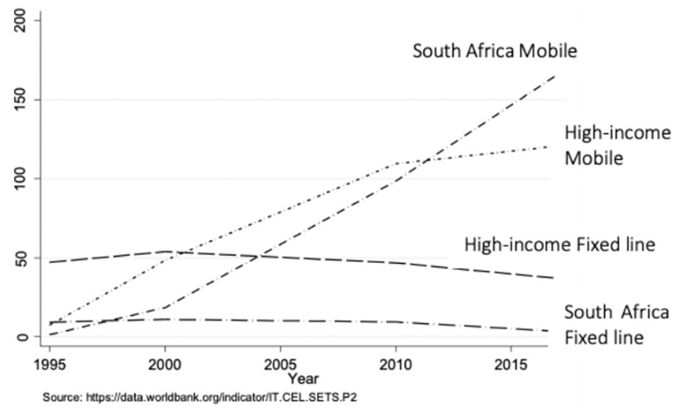

Fig. 2. Number of fixed-line and mobile cellular subscriptions per 100 persons of population.
Source: https://data.worldbank.org/IT.CEL.SETS.P2.

monopoly on international internet access combined with the landing on the African continent of several new undersea cables, resulting in an open and competitive international connectivity market contributing to significant reductions in bandwidth prices (World Bank, 2019b).[3]

In South Africa, MSEs are key drivers of the economy in terms of contributions to overall entrepreneurship, livelihoods, and play a role in alleviating poverty through employment generation (Booyens, 2011; SEDA, 2016). While there is evidence that MSEs including informal economy businesses are creative and can contribute to the generation of new products (Wunsch-Vincent and Kraemer-Mbula, 2016), there have been few quantitative studies focusing on the determinants and effects of innovation on MSEs in South Africa. The few exceptions (Booyens, 2011; Booyens et al., 2013; Kraemer-Mbula et al., 2019) are largely descriptive and none of them has focused on manufacturing activities. In part, this reflects the lack of data as the national innovation surveys carried out in South Africa and other African countries are limited to registered firms.

This paper addresses this gap by making three important contributions. Firstly, using new evidence, it provides an analysis of the relationship between digitalization, innovation, and productivity at the firm level for a sample of 711 manufacturing MSEs in South Africa, including businesses in the informal sector. This unique database captures the innovative activities of MSEs in the Johannesburg conurbation and their use of digital technologies. Our main findings point (i) to a positive relationship between the use of selected digital communication technologies and product and process innovation, and (ii) to a positive relationship between innovation performance and labor productivity conditional on the use of these technologies. Secondly, it provides firm-level empirical evidence that informs the debates around the readiness of manufacturing MSEs in Africa to adopt more advanced fourth industrial revolution automation technologies. It does so by exploring the adoption of more accessible digital communication technologies, such as social media, internet surfing and online sales/e-commerce, which can be seen as providing an "entry-level" to more advanced technologies. Thirdly, by including informal businesses in our analysis, we provide important insights into the "inclusivity" of the digital transformation in South Africa, which are of interest to a broader set of countries in Africa and developing countries at large. The findings also provide valuable policy reflections that can guide more inclusive approaches to innovation policy and digital transformation.

[3] At present, the three largest mobile network operators in terms of market share are MTN, Vodacom and Cell C. Telekom is number four. A World Bank Report (2019b) notes that while prices in South Africa compare well to other Sub-Saharan African nations in terms of the cost of broadband as a share of per capita income, the absolute price of 1GB mobile broadband data is higher than in Kenya, Nigeria, or Mauritius.

The remainder of the paper is structured as follows. Section 2 discusses the background literature on the relationship between innovation and productivity, including the effect of digital technologies on innovation and possible direct and complementary effects of ICTs on productivity. Section 3 presents the model and explains the two-step estimation approach we adopt, firstly estimating the relationship between the use of digital communication technologies and innovation, and secondly the relationship between innovation and productivity. Section 4 describes the data and presents the sample. Section 5 discusses the results. Section 6 concludes.

2. The background literature

This paper connects with two debates in the literature. The first one is around the complex relationships between innovation, digitalization, and productivity. The second relates to the effect of ICTs on firm-level productivity.

2.1. Innovation, digitalization, and productivity

Innovation as a driver of firm performance in terms of productivity is well established in the literature. There have been several quantitative studies establishing these links based on the use of innovation survey data for both developed and developing countries. Many of these studies adopt the Crepon-Duguet-Mairesse (CDM) sequential modeling approach (1998), for which we draw inspiration in this paper.[4] In an overview of studies on eight developing countries using the CDM framework, Fagerberg et al. (2010) observed that statistically significant effects were confirmed on labor productivity of at least one of the innovation measures used. In a study of six Latin American countries, Crespi and Zuñiga (2012) found that innovation has a significant effect on productivity while noting that the determinants of firm-level investments in innovation are much more heterogeneous in the Latin American countries studied than in OECD countries. In a later study of service firms in Chile, Colombia, and Uruguay, Crespi et al. (2014) confirm the positive effect of innovation on productivity in services, although firm size appears to be a less relevant determinant of innovation in services as compared to manufacturing. In a study adopting the CDM approach using the 2005–2007 and 2008–2010 waves of the Nigerian National Innovation Survey, Edeh and Acedo (2021) find evidence for SMEs of a positive effect of product, process and marketing innovation on productivity. In one of the rare studies adopting the CDM framework that includes informal or non-registered businesses, Fu et al. (2018) found for a sample of Ghanaian manufacturing firms a positive relationship between innovation and labor productivity. Our study, which is like theirs in including informal economy firms in the sample, extends the CDM model by including the use of digital communication technologies as an input to the innovation process.

Several studies have sought to extend the CDM modeling approach in this way to include ICTs as inputs to innovation. However, there is no uniform definition of what is meant by ICTs in these studies and in interpreting the results it is important to differentiate between investments in conventional ICT capital, consisting of the computer hardware and software used in the firm's production process, from newer forms of digitalization consisting in e-commerce and broadband internet access. E-commerce took off in developing countries from the mid-1990s with the creation of online sites like Amazon and eBay, while broadband only began to replace dial-up in the early 2000s. Several studies on developed countries using data from the 2000s focus on these new digital developments and find support for the positive effects of these forms of digitalization on innovation outcomes. In a study using business survey data from Germany covering the period from 2001 to 2003, Bertschek et al. (2013) focus narrowly on the effects of broadband internet access and find that it has a positive and significant effect on innovation.[5] In a study using Community Innovation Survey (CIS) survey data from 2004 for the Netherlands, Van Leeuwen and Farooqui (2008) argue that digitalization can enable innovation for several reasons, including the use of e-commerce to roll out new products, the use of broadband internet for capturing and processing knowledge developed elsewhere and for managing knowledge flows within and between firms. They test this in a model using two measures of digital technology use: (i) the share of sales done electronically and (ii) the firms' level of broadband intensity use. Their results show that digitalization significantly increases the chances of successful product innovation and has indirect effects on productivity. Polder et al. (2010) also extend the classic CDM model by investigateing the effect of digitalization on process and organizational innovation as well as product innovation in Dutch firms. They find that in services all types of innovation are positively affected by more e-purchasing, although only marginally in the case of process and organizational innovation. Their results are more nuanced for manufacturing, broadband being an important driver of both product and organizational innovation in manufacturing while e-commerce is positively related to process innovation.

Few studies on developing countries have used extended CDM models to include ICTs as an input to innovation. Unlike the studies on developed countries referred to above, due to data limitations, ICTs are measured solely in terms of investments in computer hardware and software. These studies also lack measures of the newer forms of digitalization such as broadband intensity or e-commerce. In a study of Uruguayan firms using the 2004 to 2006 and the 2007 to 2009 waves of the Service Innovation Survey, Aboal and Tacsir (2018) focus on the distinction between technological (i.e. product and process) and non-technological (i.e. organizational and marketing) innovation. They find that ICT capital investments are more important for product and process innovation in services than in manufacturing. The reverse is true for their influence on organizational and marketing innovation. In a study of Chilean business using the 2007 and 2009 Longitudinal Enterprise Surveys, Alvarez (2016) finds that ICT capital investments have a positive effect on both technological and non-technological innovations in services and manufacturing. When predicted ICT investments are introduced into the productivity equation, however, the effect of innovation on productivity disappears. On this basis, it is concluded that the effect of ICT capital on productivity is direct rather than being indirect through innovation.

In summary, the econometric research based on national innovation surveys in developed countries finds support for the positive effect of digitalization in the form of e-commerce and broadband internet access on at least certain measures of innovation. Further, it supports the positive influence of innovation on productivity contingent on the use of these digital technologies. While the developing country studies reviewed do support the positive relationship between innovation and productivity, the analysis of the determinants of innovation does not include measures of the firms' internet bandwidth intensity use or their use of e-commerce. This limits their relevance for understanding the impact of the current digital transformation in developing regions of the world (including Africa), which has witnessed an unprecedented increase in broadband internet access based on mobile telephony (see Figs. 1 and 2). As the study by Polder et al. (2010) argues for the case of the Netherlands, broadband internet access can be a means of acquiring new knowledge inputs for innovation and for sharing knowledge between partners, while the use of e-commerce may contribute to

[4] For a discussion of the evolution of research based on the original CDM model over the 20 years following the publication of Crepon et al. (1998), see Lööf et al. (2017).

[5] In explaining their use of data for 2001 to 2003 the authors observe that as only 60 % of firms in Germany had adopted broadband at this time implying that there was sufficient variation in this variable across firms to make it useful for identifying the impact of broadband internet on innovation performance.

successfully rolling out new products and services. Furthermore, there is a large theoretical and case study-based literature on business management regarding the role of social media in driving and enabling innovation (Bhimani et al., 2019). Several cases show how social media can be used to support knowledge sharing and open innovation (Brandtzaeg et al., 2016; Hitchen et al., 2017). Social media may promote innovation by providing a tool for interacting with and drawing on users' ideas (Dong and Wu, 2015). Muninger et al. (2019) develop an organizational capabilities perspective, arguing that social media supports agile processes that facilitate rapid decision making and knowledge flows across teams within the firm.

2.2. ICTs and productivity

A related literature on firm heterogeneity in their investment patterns has investigated the direct effects of ICT capital on productivity. Much of this literature adopts a production function approach in which the standard model is augmented to include ICT capital in addition to non-ICT capital (Draca et al., 2009; Stiroh, 2005). For the case of emerging market countries, Commander et al. (2011) look at the consequences of ICT capital adoption and use on firm performance in Brazil and India. They find a strong positive association between investments in ICT capital, measured as the shares of non-production workers using either PCs or ICT-controlled machinery, and productivity in manufacturing firms. Based on these results, we expect that the intensity of ICT capital (measured as investments in computer hardware) would have a positive effect on productivity.

A strand of this literature investigates possible complementarities between investments in ICT capital, organizational innovation and R&D, arguing that the productivity gains from ICT capital would be enhanced by workplace reorganization allowing for more decentralized decision making. ICT capital is usually captured by the intensity of computer use, through indicators such as the share of employees using a PC or investments in computer hardware and software. In a study for the period 1995–1996 of firms in the USA, Brynjolfsson and Hitt (2002) find evidence of complementarities where firm productivity is higher when investments in ICT capital are combined with work reorganization and the use of skilled labor. Black and Lynch (2001), who measure ICT in terms of the percentage of non-managerial employees using computers, find evidence of positive complementarities between ICT and workplace innovations. Mohnen et al. (2018), using firm-level data for the Netherlands for the period from 2008 to 2010, similarly find that the use of ICTs measured in terms of investments in computer hardware are complementary with R&D and organizational innovation in the sense that joint investments lead to higher total factor productivity growth. In a recent study using panel data for 5511 Spanish industrial firms, Ballestar et al. (2020) extend this literature to include complementarities linked to the use of robots and e-commerce. They find evidence of positive complementarities for the combined use of robots and engaging in process innovation, and for the combination of using robots and a composite measure of e-commerce.

As discussed in Section 3.2 below, our data allow for the investigation of selected complementarities related to the use of online sales or e-commerce. We test for complementarities between this digital technology and ICT capital, and both process and product innovation.

3. Digitalization, innovation, and productivity: a sequential modeling approach

Our empirical analysis draws inspiration from the sequential modeling approach associated with the so-called Crepon-Duguet-Mairesse (1998), often known as the CDM model. The CDM literature has focused on investigating sequentially the link between R&D and innovation and the link between innovation and productivity. We extend this framework by including in the first stage of the analysis the effect of digital communication technologies on product and process innovations. The second stage of the analysis focuses on the link between innovation and productivity conditional on the use of digital communication technologies. As discussed below, to address problems of endogeneity between innovation and productivity, we employ two-stage least squares (2SLS) using one or both of two digital communication technologies (i.e. social media and internet surfing with a mobile phone) as instruments for innovation in the second stage equation. Fig. 3 below describes the extended CDM model.

3.1. The knowledge production function

Following the approach in the CDM literature, we model the relationship between inputs to the innovation process and innovation outputs with a knowledge production function (KPF), of which an early discussion can be found in Griliches (1979) and a more recent presentation in Wagner (2006). At the firm *i* level, the general form of the equation is the following:

$$\Delta K_i = f(H_i, D_i, Z_i) \tag{1}$$

where ΔK_i is growth in the knowledge of the firm, H_i equals the firm's investment in developing new knowledge (i.e. R&D expenditures), D_i equals the activities taken to source ideas and knowledge from outside the firm, and Z_i equals a vector of variables that may be important for the firms' capacity to develop new knowledge (i.e. its stock of capital, sector of activity, size). The inclusion of the variable D_i reflects that R&D is only one of several possible inputs to the process of knowledge creation and that firms may also draw from external sources of knowledge, including the knowledge they acquire through interaction with users (Lundvall, 1988).

In our empirical estimation of Eq. (1), we measure the creation of new knowledge through the introduction of a new product or a new process. The firm's internal investment in new knowledge is proxied by whether it undertakes R&D, and accessing ideas and knowledge from external sources is measured through the firm's use of various new internet-based digital communication technologies as well as its cooperation with other firms in the same sector of activity. In the first stage, our dependent variable (*Innovation*) refers to the introduction of a new or significantly improved product, or alternatively a new or significantly improved process, during the fiscal year 2019.

Since our dependent variable is dichotomous, we fit the model with a maximum likelihood probit model at the firm *i* level as specified in Eq. (2):

$$\begin{aligned} Innovation_i = c + \beta_1 Log(size_i) + \beta_2 Log(age_i) + \beta_3 Fixed\ capital_i \\ + \beta_4 ICT\ capital_i + \beta_5 RD_i + \beta_6 X_i + \beta_7 Y_i + \varepsilon_i \end{aligned} \tag{2}$$

where $Innovation_i$ is a dichotomous variable equals to 1 if the firm has introduced into the market a new or significantly improved product or alternatively has implemented a new or significantly improved process, *c* is the constant term, $Log(size_i)$ is the number of employees, and $Log(age_i)$ is the age of the firm. Both are expressed in natural logarithms. $Fixed\ capital_i$ is the intensity of fixed capital defined as the value of vehicles, furniture, and machinery (excluding ICT equipment) per employee and $ICT\ capital_i$ is the value of ICT capital per employee where ICT capital includes the firm's stock of computers, fixed-line telephones, printers, scanners, and fax machines. As discussed above in Section 2.2, a variety of research has shown that computerization can result in increased productivity by substituting for the use of manual labor in both manual and information processing tasks. Thus, we expect a higher intensity of use of ICT capital to result in higher labor productivity.[6]

RD_i refers to whether the firm has engaged in any R&D activities for the purposes of innovation. X_i is a vector of binary variables measuring

[6] See the literature on routine-biased technical change associated with the work of Autor et al. (2003).

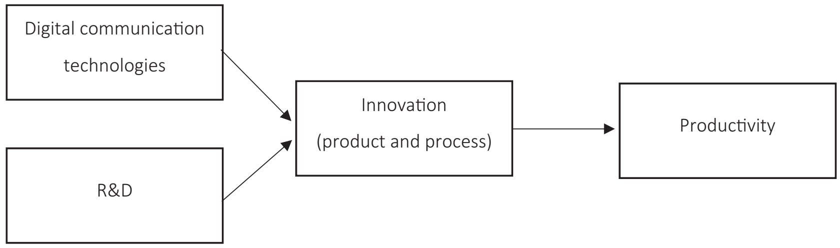

Fig. 3. The extended CDM model with digital communication technologies.

the use of four digital communication technologies: social media, making use of a business mobile phone for surfing the internet, making use of a mobile phone for interacting with customers and doing online sales. As discussed above, we expect the digital communication technology variables to have a positive effect on innovation. Y_i is a vector of controls including whether the firm is formal (viz. registered with the South African Revenue Service), whether its sector of activity is classified as high-tech (HT) or low-tech (LT), and whether it has cooperated with other firms in the same industry. As widely discussed in the innovation systems literature, an important mechanism for increasing access to knowledge that can contribute to better innovation performance is inter-firm cooperation promoting interactive learning (Lundvall, 2010; Jensen et al., 2007). Several studies focusing on African countries support the importance of inter-firm cooperation for innovation, including for small firms (Van Dijk, 2002; Oyelaran-Oyeyinka and McCormick, 2007). Correspondingly, we expect that cooperation between firms will result in improved access to knowledge and improved innovation performance. β_1 to β_7 are the coefficients associated with the previous variables and $\varepsilon_i \sim N(0,1)$ is the error term.

ICTs are transforming both the way firms produce/develop new products and the way they interact with other firms or with consumers. We expect that while the use of computers and other forms of ICT capital may have a direct effect on productivity, the influence of internet-dependent digital communication technologies would be indirect through their effect on the development and marketing of new products and services.[7]

3.2. The link between innovation and productivity

In the second stage of the sequential model, we estimate the relationship between innovation and productivity. We model productivity with an extended version of the production function, adding a measure of the knowledge created by innovative activity to the standard production function. The equation takes the following general form:

$$Q = AC^a L^b K^g \tag{3}$$

where Q is output, AC is the level of capital stock, L is labor and K is a measure of the knowledge stock. For estimation purposes the logarithm of Eq. (3) is taken at the firm i level:

$$q_i = a + \alpha c_i + \beta l_i + \gamma k_i \tag{4}$$

Following the procedure presented in Hall (2011), Eq. (4) can be expressed in revenue terms under the assumption of an isoelastic demand equation. Each firm is assumed to produce differentiated products and therefore faces its own downward sloping demand curve. The log of real revenue is denoted by r_i and the log of the firm's output price by p_i giving: $r_i = p_i + q_i$. The isoelastic demand equation facing the firm i in logarithmic form is as follows:

$$q_i = \eta p_i \tag{5}$$

where η is the (negative) demand elasticity. Combining Eqs. (4) and (5) yields the following expression for the revenue as a function of the inputs:

$$r_i = \frac{\eta + 1}{\eta}(a + \alpha c_i + \beta l_i + \gamma k_i) \tag{6}$$

The equation implies that the knowledge stock may have a positive effect on revenue and also productivity if the value of the coefficient γ is positive. As Hall (2011) notes, the equation also implies that the estimated coefficients on the inputs will be biased downward if demand is elastic ($\eta < -1$).

In the CDM literature using CIS data, the estimation of Eq. (6) is usually done by regressing the log of revenue per employee on the log of capital expenditures per employee. Firm size is measured by the number of employees and innovation activity proxied either by the share of innovative sales or by a binary variable that equals to 1 if the firm has innovated either a new product or a new process.[8] This estimation is likely to present a problem of endogeneity due to simultaneity since more productive firms may be better placed to invest additional resources in innovation activities. As it is common in the CDM literature, we address this problem by employing 2SLS using one or both of the following excluded exogenous variables from the first stage equation as instruments: (i) the use of social media and (ii) the use of a business mobile phone for surfing the internet. As discussed above, we expect these variables to have a positive and statistically significant effect on innovation. In addition, they should meet the exclusion restriction condition of only affecting productivity indirectly through their effect on innovation.

In the second stage, our dependent variable (*Productivity*) refers to labor productivity and is measured as the natural logarithm of the value of the firm's turnover per employee in 2019. Due to missing observations, data on the absolute value of turnover are only available for 273 firms. We have interval data on turnover for 318 firms, but not absolute values. On this basis, we make use of multiple imputations to generate absolute turnover values for the 318 firms for which only interval data is available. We exclude firms for which we have neither the absolute value nor an interval range for turnover. Our resulting sample for the second stage productivity regression comprises 591 firms. The second stage of the 2SLS regression model takes the following form at the firm i level as specified in Eq. (7):

[7] OECD (2019) observes that even if the gains from digitalization have been substantial, there is no consensus on the direct causality between digital communication technologies and productivity. For example, more productive firms may benefit from digitalization because they are more likely to have access to knowledge for developing new products or implementing new organization methods than other firms. Our sequential approach allows us to explore the possible indirect effect of digitalization on productivity through innovation.

[8] The literature is vast. Highly cited studies using either revenue or value added per employee in estimating the productivity relation include Crepon et al. (1998), Hall et al. (2008), Lööf and Heshmati (2006), Mairesse and Robin (2017), Griffith et al. (2006), Mairesse et al. (2005).

$$Productivity_i = c + \beta_1 Innovation_i + \beta_2 Log(size_i) + \beta_3 Log(age_i) + \beta_4 Fixed\ capital_i + \beta_5 ICT\ capital_i + \beta_6 RD_i + \beta_7 X_i' + \beta_8 Y_i + \varepsilon_i \quad (7)$$

where c is the constant term, $Innovation_i$ is the instrumented value for either product or process innovation derived from the first stage innovation Eq. (2). X_i' is a vector with the included digital communication technologies that are not used to instrument product or process innovation.[9] The vector of control variables remains the same. β_1 to β_8 are the coefficients associated with these variables and ε_i is the error term.

In the estimation of Eq. (7), we include selected interaction terms to investigate the presence of possible complementarities. This exercise is limited by the variables we have available in the data set. We lack a measure of organizational innovation that would allow us to test for complementarity between ICT capital and a measure of organizational innovation as developed in the literature reviewed above on ICT complementarities. We do investigate for complementarity between ICT capital and new digital technology in the form of online sales/e-commerce under the assumption that by increasing the volume of sales, online sales could reduce underutilization of ICT capital and so much like capital deepening result in measured increases in labor productivity. We also examine possible complementarities between online sales and both product and process innovation. By helping firms to roll out and commercialize their new product developments, online sales might increase the measured productivity gains from product innovation. Similarly for ICT capital, greater sales volumes from online sales may help amortize the costly investment in new production methods reflected in increases in measured labor productivity.

4. Data source, sample, and descriptive statistics

4.1. Data source

This paper uses a unique dataset of MSEs located in Johannesburg, South Africa, which we refer to as the "MSE Survey"[10]. The survey focused on the central business district of Johannesburg, which is the capital of Gauteng province and accounts for 16 % of South Africa's GDP and 40 % of Gauteng's economic activity. It focuses on manufacturing firms and aims to understand some of the challenges faced by MSEs in their innovation activities as well as understanding the environment in which these firms operate. This survey consists of a set of 74 questions capturing a range of information, from the background of the owner to the characteristics of the workforce and financial issues. The data collection spanned a period of three months, from June to August 2019. Finally, the sample covered 711 MSEs.

The full description of the different variables built from the survey and associated descriptive statistics are reported in Table 1. Innovation refers to the introduction onto the market of a new or significantly improved product, or alternatively a new or significantly improved process. To count as an innovation, the product (or the process) needs to be new to the firm but not necessarily new to the firm's market and, as many authors have observed, innovations introduced by firms located in low- and middle-income countries often have an imitative and incremental nature because these firms are far from the technological frontier (Crespi and Peirano, 2007; Goedhuys, 2007; Fagerberg et al., 2010; Srholec, 2011). By including incremental and imitative activities, this definition of innovation can help account for what may appear to be an exceedingly high rate of innovation success, with 49 % of the sample of 711 classified as product innovators.

The MSE survey includes both measures of investments in ICT capital and the use of digital communication technologies that depend on having internet access and may be used to increase the firm's visibility on the market or for communication and exchange with other firms and clients. These digital communication technologies include making use of

Table 1
Descriptive statistics.

	Description of variables	Type of variables	Mean (over full sample)
Dependent variables			
Product innovation	Whether the firm has introduced entirely new or significantly improved products	Binary	0.49
Process innovation	Whether the firm has introduced entirely new or significantly improved processes	Binary	0.08
Labor productivity[a]	Average value of the log of productivity over 10 imputations	Nominal	9.73
Independent variables			
Size[b]	Natural logarithm of the number of employees (full-, part-time and occasional)	Nominal	1.27
Age	Natural logarithm of the age of the firm in year	Nominal	2.35
Fixed capital	Total value of fixed assets (i.e. vehicles, furniture, machinery, etc.) in tens of thousands of Rands/Number of employees	Nominal	22.42
ICT capital	Total value of ICT equipment (i.e. computers, telephones, printers, scanners, fax machines, etc.) in tens of thousands of Rands/Number of employees	Nominal	1.58
Registration (formal or informal firm)	Whether the firm is registered with South African Revenue Service	Binary	0.27
Cooperation	Whether the firm has cooperated with other firms in the same industry	Binary	0.48
Sector	Main manufacturing activities conducted by the firm – Following the OECD classification (Hatzichronoglou, 1997), an activity is either considered as high-tech (HT) or low-tech (LT)[c]	Binary	0.09
R&D	Whether the firm has engaged in R&D activities for innovation	Binary	0.15
Digital communication technologies			
Social media	Whether the firm uses social media for the business	Binary	0.34
Internet surfing	Whether the firm uses a mobile phone for surfing the internet	Binary	0.07
Mobile customer	Whether the firm uses a mobile phone to interact with customers	Binary	0.28
Online sales/E-commerce	Whether the firm uses e-commerce or online sales	Binary	0.13

[a] The survey results provide the absolute value of sales in 2019 for 273 firms and interval data for a further 318 firms. Based on these variables and the other variables in the productivity equation, we use multiple imputations to estimate the value of turnover for the 318 firms for which only interval information on 2019 sales exists. This provides a sample of 591 firms.
[b] In calculating the total employment of the firm the number of part-time workers is weighted by a factor of 0.5.
[c] See Tables A1. HT covers high- and medium-high tech sectors. LT covers low- and medium-low tech sectors.
Source: MSE Survey, authors' calculations.

[9] We use one variable, social media, to instrument product innovation. For process innovation, we add to this the variable measuring internet surfing with a mobile phone as it serves to strengthen the instrument in terms of the value of the standard F-statistic.
[10] This survey was conducted in 2019 under the project "Community of Practice in Innovation and Inclusive Industrialisation", hosted by the DSI/NRF South African Research Chair in Industrial Development, University of Johannesburg. Accession date: February 2020.

social media (34 %), doing online sales (13 %), using a mobile phone to browse the internet (7 %) and using a mobile phone to interact with customers (28 %). As noted in the above discussion of the choice of instruments, we assume that the influence of using social media and using a mobile phone to browse the internet on productivity would be indirect, through their effects on innovation.

4.2. Differences by sector

The data collected cover only manufacturing firms, so we split our sample into high-tech (HT) and low-tech (LT) sectors (Hatzichronoglou, 1997) as explained in Table 1. Table A1 in the appendix provides descriptive statistics according to sector for the firms' size in terms of employment, its age, the capital intensities, and the use of digital communication technologies. A few salient characteristics emerge from the summary statistics. Firstly, most of the firms (90.7 %) belong to LT sectors: 27.6 % of them are active in the manufacture of wearing apparel and 17.9 % in the manufacture of furniture. The manufacturers of textiles and basic metals represent 10.1 and 9.4 % of the firms respectively. More than half of the firms in the HT sectors are distributed between the manufacture of chemicals (3.2 % of the firms) and other manufacturing (2.5 %). So, the distribution of the manufacturing firms located in Johannesburg is left-skewed towards LT sectors.

Secondly, firms have on average 16 years in the LT sectors and 21 years in the HT sectors. In general, firms in the sample seem to be mature and well-established in the productive tissue of the city. Almost half of them (0.48 cf. Table 1) cooperate with other firms in the same industry, and most of them (0.72) work predominantly in local markets, with customers located in the inner city or surrounding suburbs. So, in other words, these firms penetrate the market and develop distribution channels.

Thirdly, a quarter of the total workforce is employed in the manufacture of furniture (1349 workers). Manufactures of wearing apparel, wood, basic metals, textiles, and food products employ between 7.2 % and 12.5 % of the remaining workforce. The workforce in all sectors is made up predominantly of full-time contracts. Part-time and occasional contracts concern 14 % and 8 % of the workers respectively. As proposed by Fu et al. (2018), another way to evaluate this workforce refers to a decomposition between micro (less than or equal to 9 employees), small (10 to 29 employees), medium (30 to 99 employees) and large firms (equal or >100 employees). For each sector, we have a proxy of this decomposition by relating the number of employees to the number of total firms: 78.1 % of the firms are micro-ones and 18.4 % are small ones. So, the distribution of the number of employees is left-skewed towards MSEs (maybe artisanal ones).

Fourthly, the South African firms differ significantly in terms of the relative intensity of use of fixed capital and ICT capital. For example, the manufacture of rubber and plastic products represents 12.3 % of total fixed capital but a very small part of total ICT capital (1.4 %). The manufacturers of other non-metallic mineral products show the same gap between fixed and ICT capital (6.2 % for the former, 1.1 % for the latter). The manufactures of furniture and wearing apparel, the two largest sectors both in terms of the numbers of firms and total employment, also differ from one another in their capital intensity. While the manufacture of furniture accounts for 51.3 % of total fixed capital but only 4.9 % of total ICT capital, the manufacture of wearing apparel covers 15.2 % of total fixed capital and 24.5 % of total ICT capital. Conversely, certain sectors account for a larger share of ICT capital and a smaller share of fixed capital: this means that firms belonging to these sectors are relatively advanced in terms of computerization. Moreover, four sectors (the manufacture of food products, the manufacture of machinery and equipment, the manufacture of wearing apparel and the manufacture of wood) account for 76.4 % of the ICT capital while they account for only 23.5 % of total fixed capital and only 28.6 % of the total employment. So, the diffusion of ICT capital is very uneven. Even if firms in the HT sectors represent a small part of our sample, it is interesting to note that the manufacture of machinery and equipment accounts for 7.1 % of total ICT capital, the fourth-highest percentage.

Fifthly, looking at the use of digital communication technologies, it seems that a significant share of MSEs in South African manufacturing sectors use social media for their business (34 % of the total population, see Table 1). Social media may be used not only to increase the exposure of the firm to prospective clients but also for purposes of information exchange with other firms and organizations. In the context of South African manufacturing firms, the manufactures of wearing apparel and furniture – which have the most weight in this sample in terms of employees and capital intensities – have the most intensive use of these digital communication technologies: respectively, 29 % and 14 % for social media, 18 % and 12 % for internet surfing, 29.1 % and 12.1 % for mobile customer, 19.6 % and 22.8 % for online sales. The manufacture of textiles uses these four digital technologies in a very complementary way, between 10 % and 12.1 %. The other manufacturers mainly use one of the four digital communication technologies rather than all four combined. For example, for manufactures of chemicals and wood, the use of mobile phones for surfing the internet prevails (respectively 10 % and 14.1 %). For manufactures of wood and printing and reproduction of recorded media, online sales are the most used (5.4 % for each). For the manufacture of basic metals, the use of mobile phones for interacting with customers is clearly more used than the other three (11.1 %). So, the use of digital communication technologies is relatively heterogeneous between sectors.

These shares motivate our study of the relationship between digitalization and innovation especially compared with the R&D efforts engaged by South African MSEs: only 15 % of the firms in our sample have engaged in R&D activities for innovation (see Table 1). This might be because R&D requires substantial capital investments that are out of the reach for most MSEs. However, digital communication technologies that rely only on broadband connection seem to be more accessible for South African MSEs.

5. Econometric results

5.1. The effect of digital communication technologies on product and process innovations

In Table 2 below, we provide the results of estimating Eq. (2) for the determinants of product and process innovations. The regressions in columns (a) and (d) include only the four digital communication technologies. Columns (b) and (e) add the variables for R&D, cooperation between firms and the measures of capital intensities. Columns (c) and (f) present the complete specifications, including the different controls. Of the four digital communication technologies, internet surfing has a positive and statistically significant effect on both product and process innovation, and this result is robust when adding the different controls and other covariates. Surfing the internet, as we noted above, is a way of acquiring knowledge and ideas that can feed into the process of developing a new product or a new process. Social media has a statistically significant effect on product and process innovations in columns (a) and (d). It can be used as a tool for communities to establish online groups for purposes of discussion and knowledge exchange. The coefficient on social media is no longer significant for process innovation after adding controls while it remains significant in the case of product innovation, suggesting that social media may be of greater use in accessing external knowledge for developing new products than it is for developing new processes.

The coefficient on the variable measuring communicating with customers with a mobile phone is positive but, contrary to our expectation, is not significant Firms that cooperate with other firms in the same industry or trade have a greater propensity for product innovation, and undertaking R&D has a positive and significant efffect on both product and process innovation. The measure of non-ICT or fixed capital intensity is not statistically significant for either product or process

Table 2
Probit regression predicting product and process innovations.

	(a)	(b)	(c)	(d)	(e)	(f)
	Product innovation			Process innovation		
Social media	0.177***	0.172***	0.160***	0.0391*	0.0325	0.0198
	(0.0421)	(0.0422)	(0.0436)	(0.0232)	(0.0218)	(0.0202)
Internet surfing	0.219***	0.178**	0.186**	0.265***	0.185***	0.144**
	(0.0758)	(0.0837)	(0.0829)	(0.0751)	(0.0692)	(0.0630)
Mobile customer	0.0574	0.0532	0.0521	0.00395	0.00186	0.00342
	(0.0450)	(0.0452)	(0.0454)	(0.0225)	(0.0215)	(0.0197)
Online sales/E-commerce	0.0415	0.00636	0.000847	0.0455	0.0278	0.0101
	(0.0614)	(0.0627)	(0.0646)	(0.0346)	(0.0289)	(0.0239)
R&D		0.131**	0.132**		0.0960**	0.0515*
		(0.0579)	(0.0599)		(0.0376)	(0.0300)
Cooperation		0.0919**	0.0941**		0.00981	0.00558
		(0.0390)	(0.0390)		(0.0181)	(0.0165)
Fixed capital		8.19e−09	8.19e−09		5.20e−09	4.03e−09
		(1.25e−08)	(1.24e−08)		(3.32e−09)	(2.69e−09)
ICT capital		−3.97e−08	−2.29e−08		4.40e−08	3.18e−08
		(1.36e−07)	(1.27e−07)		(4.11e−08)	(3.51e−08)
Size			0.00353			0.0264***
			(0.0214)			(0.00841)
Age			−0.0247			−0.0119
			(0.0239)			(0.0106)
Registration			0.0443			0.00826
			(0.0475)			(0.0191)
Sector			0.103			−0.0477**
			(0.0678)			(0.0227)
Observations	711	711	711	711	711	711
Pseudo R^2	0.0424	0.0554	0.0595	0.126	0.163	0.201
Wald χ^2	39.49***	50.47***	57.52***	51.09***	66.62***	75.87***
Correctly classified	60.76 %	61.74 %	61.74 %	91.84 %	91.84 %	92.12 %

Note: Marginal effects are reported in this table. Robust standard errors are given in parentheses.
*** P < 0.01.
** P < 0.05.
* P < 0.1.

innovation, and we find no significant influence for the different control variables including the size or the age of the firms on product innovation. There is a positive and statistically significant effect of size on process innovation which may reflect that larger firms are better placed to finance costly investments in new equipment. In the context of SMEs in Sri Lanka, De Mel et al. (2009) similarly find that firm size plays a larger role in process and organizational innovations than in product innovation. So, our findings are in line with their results. Furthermore, as in the case of our sample, for manufacturing firms, they do not find a significant correlation between innovation and the age of the firm. Being registered has a small positive but statistically insignificant effect on innovation.

We find convincing evidence in support of the endogeneity of both product and process innovation to productivity. Based on both the Durbin χ^2 test and Wu-Hausman F statistic, the null hypothesis of exogeneity is rejected at the 0.06 level or better. The value of the F-statistic for the instruments is over 11 in the case of product innovation and over 24 in the case of process innovation, showing that the instruments are not weak.

5.2. The effect of product and process innovations on labor productivity

Table 3 presents the results of estimating the second stage of the two-stage least squares IV regression. Columns (a) and (e) show the results for the two regressions estimating the effect of product and process innovations respectively on productivity. The results confirm positive and statistically significant effects of both product and process innovations on labor productivity. Consistent with our expectations, the measure of the intensity of ICT capital use has a positive and statistically significant effect on productivity. This supports the literature cited above on the positive effect of the computerization of work processes and internal knowledge flows on productivity. The coefficient of the measure of fixed capital intensity is surprisingly negative but not statistically significant.

In column (a) neither of the two included digital communication technology variables (viz. the use of a mobile phone for surfing the internet and for communicating with customers) has a statistically significant effect on productivity. In the results presented in column (e), the one included digital communication technology variable (i.e. using a mobile phone to communicate with customers) similarly does not have a significant effect on productivity. These results are consistent with our argument that digital communication technologies, unlike ICT capital, only have an indirect effect on productivity through their positive influence on innovation. This is also the case with R&D and inter-firm cooperation, which our results suggest only have a significant influence on productivity through their effect on innovation. This latter finding is consistent with studies suggesting that while small African firms may draw from inter-firm relationships to innovate, their ability to transform external sources of knowledge into superior firm performance is contingent on having complementary firm-specific capabilities (skills and managerial capabilities) to do so (Zulu-Chisanga et al., 2021). This may explain why inter-firm cooperation has a positive effect on product innovation, but not on productivity in our sample. The coefficient capturing the effect of firm registration is positive but only statistically significant in the case of the regression estimating the effect of process innovation on productivity. The age of the firm has a positive and significant influence on productivity, while the size of the business has a

Table 3
2nd stage Instrumental variable regression explaining labor productivity.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
	Labor productivity							
Product innovation	0.234**	0.221*	0.208*	0.205*				
	(0.119)	(0.114)	(0.126)	(0.118)				
Process innovation					0.270***	0.273***	0.371***	0.373***
					(0.0984)	(0.0967)	(0.125)	(0.125)
Internet surfing	0.0260	0.0345	0.00842	0.0281				
	(0.0405)	(0.0389)	(0.0483)	(0.0412)				
Mobile customer	−0.0296	−0.0280	−0.0337	−0.0296	−0.0127	−0.0123	−0.0188	−0.0181
	(0.0206)	(0.0200)	(0.0222)	(0.0203)	(0.0156)	(0.0157)	(0.0167)	(0.0167)
Online sales/E-commerce	−0.0483*	−0.0645**	0.0871	−0.00377	−0.0478**	−0.0538**	−0.260*	−0.277*
	(0.0271)	(0.0280)	(0.167)	(0.123)	(0.0227)	(0.0230)	(0.144)	(0.145)
R&D	−0.0375	−0.0329	−0.0466	−0.0361	−0.0350	−0.0341	−0.0399	−0.0378
	(0.0303)	(0.0292)	(0.0340)	(0.0301)	(0.0254)	(0.0255)	(0.0264)	(0.0265)
Cooperation	−0.00598	−0.00593	−0.00123	−0.00366	0.0153	0.0147	0.0150	0.0142
	(0.0211)	(0.0206)	(0.0225)	(0.0211)	(0.0142)	(0.0142)	(0.0147)	(0.0147)
ICT capital	1.23e−07**	1.00e−07*	1.49e−07**	1.07e−07*	9.83e−08*	9.06e−08*	9.71e−08*	8.61e−08
	(5.98e−08)	(5.86e−08)	(6.99e−08)	(6.03e−08)	(5.05e−08)	(5.06e−08)	(5.23e−08)	(5.25e−08)
Fixed capital	−5.77e−09	−4.80e−09	−8.43e−09	−5.85e−09	−4.79e−09	−4.56e−09	−6.80e−09	−6.46e−09
	(5.27e−09)	(5.08e−09)	(6.47e−09)	(5.51e−09)	(4.25e−09)	(4.27e−09)	(4.63e−09)	(4.62e−09)
Size	0.0150	0.0151*	0.0226*	0.0188	0.00740	0.00738	0.00477	0.00486
	(0.00935)	(0.00912)	(0.0135)	(0.0117)	(0.00864)	(0.00862)	(0.00913)	(0.00912)
Age	0.0208**	0.0210**	0.0194*	0.0204**	0.0247***	0.0248***	0.0249***	0.0250***
	(0.0102)	(0.00993)	(0.0108)	(0.0101)	(0.00873)	(0.00872)	(0.00902)	(0.00901)
Registration	0.0278	0.0258	0.0242	0.0236	0.0365**	0.0355**	0.0359**	0.0345*
	(0.0216)	(0.0212)	(0.0231)	(0.0217)	(0.0173)	(0.0173)	(0.0179)	(0.0179)
Sector	−0.0462	−0.0376	−0.0411	−0.0332	−0.0113	−0.00846	−0.0119	−0.00830
	(0.0297)	(0.0289)	(0.0316)	(0.0302)	(0.0264)	(0.0262)	(0.0271)	(0.0270)
Online sales * ICT capital		1.20e−06**		1.48e−06**		4.18e−07		6.29e−07
		(4.88e−07)		(7.35e−07)		(3.94e−07)		(4.23e−07)
Product innovation * Online sales			−0.335	−0.159				
			(0.408)	(0.314)				
Process innovation * Online sales							0.253	0.262
							(0.168)	(0.167)
Constant	2.184***	2.173***	2.183***	2.170***	2.193***	2.188***	2.193***	2.187***
	(0.0710)	(0.0704)	(0.0742)	(0.0710)	(0.0581)	(0.0577)	(0.0598)	(0.0595)
Observations	591	591	591	591	591	591	591	591
Wald χ^2	38.96***	43.88***	36.16***	43.68***	52.09***	56.22***	50.65***	54.30***

Note: Standard errors are given in parentheses.
*** $P < 0.01$.
** $P < 0.05$.
* $P < 0.1$.

positive but non statistically significant effect on productivity.

Our data allow for selected testing for the presence of ICT complementarities influencing productivity. The regression results in columns (b), (c) and (d) estimating the effect of product innovation on productivity, test for complementarity between online sales and ICT capital, and between online sales and product innovation. Even though the estimated direct effect of online sales on productivity is negative, we find support for the argument that the measured productivity benefits of investments in ICT capital are increased by using online sales. The complementarity between ICT capital and online sales, however, is not present in the case of the regressions estimating the effect of process innovation on productivity in columns (f) and (h). Furthermore, neither the coefficient on the interaction term between process innovation and online sales in column (g) nor the coefficient on the interaction term between product innovation and online sales in column (c) are statistically significant.

These unexpected results may reflect the limited experience that MSEs in South Africa have in doing online sales, which is an emerging technology in their context. Their limited experience with digital communication technologies could also explain the unanticipated negative coefficient on the variable measuring the direct use of online sales. If this interpretation is correct, then it points to the need for policies and training programs designed to develop digital skills and competencies. We return to the question of policies to promote the adoption and effective use of digital technologies in the conclusions.

6. Conclusion

This paper explores the relationship between digitalization, innovation, and productivity for a sample of micro and small manufacturing firms in Johannesburg, South Africa. The survey of MSEs on which this study is based includes indicators of the use of social media and the use of a business mobile phone for surfing the internet, communicating with customers, and accessing markets through online sales. To our knowledge, it is the only survey in South Africa that specifically measures the adoption of these digital technologies by micro-enterprises, including non-registered businesses. Our findings show, firstly, that selected digital communication technologies, including the use of social media and using a mobile phone to browse the internet, have a positive effect on innovation. These results support the literature arguing that social media and using the internet can enable innovation by supporting interaction and knowledge exchange among firms and with consumers. Secondly, innovation conditional on the use of these digital communication technologies has a positive effect on labor productivity. This result is consistent with the large literature cited above in both developed and developing countries, showing a positive relationship between innovation and productivity.

The results of the analysis show that MSEs in a developing country context can benefit in their innovation performance from the use of these digital communication technologies and that innovation conditional on their use increases the level of labor productivity. In MSEs, where the owner-manager plays a central role in making strategic decisions, this finding supports the existing prioritization of digital technology adoption in South Africa as an important driver of firm performance.

However, despite the increased affordability and improved access to the internet and related digital technologies, there remains a “digital divide” (UNCTAD, 2019). Larger and technologically sophisticated firms are more likely to have better access to digital resources. Although digital technologies have positive effects on MSEs' innovation and productivity, barriers to access remain and tend to be more pervasive in the context of developing countries. They typically include a combination of a lack of high-quality and affordable infrastructure (including access to reliable electricity), a shortage of digital skills, high costs and poor access to financing for smaller firms, and relatively high cost of data (Chege and Wang, 2020). These barriers can be ameliorated through policy strategies that deliberately address the needs of MSEs, especially those operating informally which are the most vulnerable.

There is a considerable debate about the impact of digitalization and Industry 4.0 technologies. A major focus in the literature on Industry 4.0 has been around automation and the use of cyber-physical systems based on the use of advanced robotics in combination with big data and artificial intelligence resulting in the development of “smart factories”. These technologies typically involve large capital investments and are adapted to the needs of large firms engaged in large scale production, notably in sectors like automobiles, chemicals and plastics and consumer electronics. The limited existing survey evidence available for developing countries shows these advanced manufacturing technologies are only adopted to a limited extent and rarely in small firms (Kupfer et al., 2019).[11] The debate on the adoption of Industry 4.0 manufacturing technologies, however, ignores the wider impact of the current digitalization process underway in developing countries which involves the use of technologies based on mobile telephones and the internet for accessing and exchanging knowledge that involve smaller capital outlays and are within reach for MSEs.

A fundamental question that emerges from the analysis is how governments can use these findings to guide the design of public programs aimed at fostering digital-technology adoption among MSEs? This is particularly important at a time when much of the post-pandemic recovery hinges on the ability of MSEs to survive and be productive, taking advantage of the accelerated digitalization trends. Public policy needs to be concerned with the types of digital technologies that are accessible to MSEs so that policy interventions and limited public resources can be most beneficial to firms that are in the most vulnerable circumstances, such as those in the informal sector.

Our original contributions are threefold. (i) We utilize a novel and up-to-date database that addresses the existing data gap in the national innovation surveys carried out in South Africa and other African countries, which are limited to registered firms. (ii) We analyze the effect of digital transformation on firm performance. In this regard, by using the CDM approach, we pay attention to the role of innovation in enhancing productivity, since these firms are creative and contribute to the generation of new products. Digitalization changes the production process, but it is also an engine of product quality improvement. In the context of digitalization, firms are more likely to have access to knowledge for developing new products or implementing new organization methods. (iii) By exploring MSEs' adoption of accessible digital communication technologies, we raise important issues related to their “readiness” that can inform broader debates about achieving an inclusive fourth industrial revolution in South Africa (Mazibuko-Makena and Kraemer-Mbula, 2020).

There are several ways in which the results of this study could be usefully extended. Firstly, we have only examined the effect of a limited range of digital communication technologies that are accessible to MSEs. Other technologies that are highlighted in the literature on digitalization include cloud computing and the use of services available on digital platforms. Secondly, the analysis could be extended to larger populations of MSEs, including service sector firms which are some of the most active users of online digital services. This points to the need for a large-scale measurement program in Africa and other developing country regions designed to investigate the adoption and effects of digital communication technologies, which account for most firms and a large share of employment. Thirdly, the survey design is cross-sectional, and we only study the relationships between the use of digital communication technologies, innovation performance and productivity in 2019, but the analysis could be extended to a longer time period. With more appropriate multi-year dataset, an interesting question to explore would be the nature of possible time lags in the effect of the introduction of digital technologies on innovation and productivity in South African manufacturing firms.

CRediT authorship contribution statement

The three co-authors contributed equally to the development of the Conceptualization, Writing - original draft, Writing - review & editing.

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[11] Kupfer et al. (2019) summarize the results of recent surveys undertaken by UNIDO on the adoption of advanced manufacturing technology is Argentina, Brazil, Ghana, Viet Nam, and Thailand. The results show that at most 1.5 % of small firms (defined as firms with less that 100 employees) have adopted advanced technology involving the use of robots, artificial intelligence, and big data.

Appendix A

Table A1
Sample description of firms according to sector for size, age, capital intensities and digital communication technologies.

	Number of firms (share)	Number of employees (share)	Mean of age	Share of fixed capital	Share of ICT capital	Share of each digital communication technology			
						Social media	Internet surf	Mobile customer	Online sales
HT sectors									
Manufacture of chemicals	23 (3.2)	305 (5.7)	20	1.4	3.4	4.1	10.0	4.5	6.5
Manufacture of pharmaceuticals	10 (1.4)	39 (0.7)	24	0.04	0.1	0.8	2.0	0.5	0.0
Manufacture of electrical equipment	5 (0.7)	22 (0.4)	36	0.3	0.1	0.4	2.0	1.0	1.1
Manufacture of machinery and equipment	6 (0.8)	57 (1.1)	26	1.1	7.1	0.8	2.0	1.0	1.1
Manufacture of motor vehicles	1 (0.1)	8 (0.2)	15	0.0	0.0	0.0	0.0	0.0	0.0
Other manufacturing (includes jewelry, musical instruments, etc.)	18 (2.5)	205 (3.9)	12	0.1	0.9	4.1	8.0	4.0	2.2
Repair and installation of machinery and equipment	2 (0.3)	6 (0.1)	16	0.04	0.02	0.0	0.0	1.0	0.0
LT sectors									
Manufacture of food products	29 (4.1)	383 (7.2)	20	2.6	16.7	6.2	8.0	4.0	2.2
Manufacture of beverages	1 (0.1)	100 (1.9)	12	0.003	0.05	0.4	0.0	0.0	1.1
Manufacture of tobacco products	1 (0.1)	25 (0.5)	7	0.0	0.0	0.4	0.0	0.0	0.0
Manufacture of textiles	72 (10.1)	390 (7.3)	11	1.3	3.4	12.4	10.0	12.1	11.0
Manufacture of wearing apparel	196 (27.6)	666 (12.5)	11	15.2	24.5	29.0	18.0	29.1	19.6
Manufacture of leather and related products	34 (4.8)	126 (2.4)	18	0.1	0.3	3.7	4.0	2.0	4.3
Manufacture of wood	46 (6.5)	414 (7.8)	14	4.6	28.1	8.3	14.0	5.5	6.5
Manufacture of paper	6 (0.8)	87 (1.6)	18	0.3	0.6	1.2	0.0	1.5	5.4
Printing and reproduction of recorded media	13 (1.8)	212 (4.0)	21	0.6	2.1	3.3	4.0	2.0	5.4
Manufacture of coke and refined petroleum products	1 (0.1)	4 (0.1)	39	0.01	0.2	0.0	0.0	0.5	0.0
Manufacture of rubber and plastic products	10 (1.4)	129 (2.4)	20	12.3	1.4	2.9	0.0	1.5	4.3
Other non-metallic mineral products	23 (3.2)	188 (3.5)	14	6.2	1.1	3.3	0.0	3.5	2.2
Manufacture of basic metals	67 (9.4)	397 (7.5)	12	0.6	0.4	3.3	2.0	11.1	2.2
Manufacture of fabricated metal products	20 (2.8)	205 (3.9)	17	2.0	4.8	1.2	4.0	3.0	2.2
Manufacture of furniture	127 (17.9)	1349 (25.4)	13	51.3	4.9	14.0	12.0	12.1	22.8
Total	711 (100)	5317 (100)	–	100	100	100	100	100	100

Source: MSE Survey, authors' calculations.

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