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Digital capabilities in South African manufacturing firms: What matters?

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Abstract

Digitalisation continues to reshape production processes and industrial structure in the global economy. The growing evidence highlights the critical importance of digital industrialisation - the digital transformation of manufacturing processes - for South Africa's re-industrialisation and sustainable industrial development and transformation. Policy documents and preliminary evidence highlight that the adoption and use of digital technologies are contingent on the underlying foundational skills and capabilities within manufacturing firms. There is, however, limited micro analysis of how to measure, and what factors drive digital capabilities and its development in manufacturing firms. Using the digital skills survey, this paper constructs novel digital capabilities index across four main functional areas and examines the factors that influence a firm's digital capabilities. The findings suggest that different factors affect different digital capabilities of firms. These findings also hold when we consider different firm size and export activities of firms. The discussion highlights a tale of heterogeneous factors that matter for digital capabilities and discusses the policy implications of these findings for digital-driven industrialisation path in South Africa and the opportunities for future research.

Keywords: Digitalisation; Digital Capabilities; Industrialisation; Manufacturing; Firm Level; South Africa

JEL codes: O14; O55; D22; L60

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1. Introduction

The South African manufacturing sector has stagnated and prematurely de-industrialised over the last decades (Andreoni, Mondliwa, Roberts and Tregenna, 2021; Andreoni and Tregenna, 2021; Tregenna, 2009, 2015). Empirical evidence examining the causes of the poor performance of South Africa's manufacturing sector highlights the decreasing domestic manufacturing value addition, sustained decay of technological infrastructure, and the lack of innovation, technological upgrade, and dynamism (Andreoni et al., 2021; Andreoni and Tregenna, 2021). Today, South Africa is characterised by both premature deindustrialization and the 'middle income technology trap' (Andreoni &Tregenna, 2020, 2021).

Recent advancements in digital technologies and its applications offer the opportunity to reverse and re-industrialise middle-income countries such as South Africa (Avenyo, Bell and Nyamwena, 2022; Andreoni et al., 2021). This is based on the emerging evidence that digital technologies such as advanced robots, machine learning and other forms of artificial intelligence, and big data technologies and platforms and their applications offer potential opportunities for innovation, long-term productivity growth, increased competitiveness, industrial development, and digital structural transformation (Andreoni, 2019; Andreoni, Barnes, Black & Sturgeon 2021; Matthess & Kunkel, 2020). Digital industrialisation, therefore, offers a diverse range of possibilities for industrial development and structural transformation in South Africa.

However, the potential opportunities of digital industrialisation also pose unique potential costs and challenges, including raising the demand for new digital skills profiles (Baldwin and Lin, 2002; Andreoni, et al., 2021). The lack of foundational digital capabilities (Andreoni, et al., 2021) and costs of acquiring and adapting the emerging advanced digital technologies into 'traditional' production processes, identifying new workers with requisite digital capabilities, and retraining and reskilling workers with the requisite technological and foundational capabilities to adapt and use acquired advanced digital technologies for digital industrialisation pose new challenges for education systems and labour markets in middle-income countries (Baldwin & Lin, 2002).

While there is a growing number of empirical studies analysing the opportunities and challenges of digital industrialisation in developing countries, the available literature remains scant. The related literature, mainly from middle income countries, focuses on the adoption of advanced digital technologies and found that there is variance in the adoption patterns of firms and that digital technologies in themselves may not fully generate the expected gains in developing countries (Ferraz et al., 2019; Andreoni et al., 2021b; Delera et al., 2022; Avenyo et al., 2022). The literature also notes that a key factor hindering digital transformation and the manifestation of the opportunities advanced digital technologies offer in developing countries is the inadequacy of digital skills and capabilities (Delera et al., 2022; Heredia, et al., 2022; Rupeika-Apoga et al., 2022; Matthess & Kunkel, 2020). That is, middle-income countries face digital skills gaps to link industry 4.0, the changing nature of work and skills (UNIDO, 2019; Ferraz et al., 2020). In South Africa, for instance, the firm-level evidence confirms the emerging digital 'islands of excellence' and the growing digital capability and skills gap (Andreoni et al., 2021b; Avenyo et al., 2022; DHET, 2022).

Developing and expanding digital capabilities in critical fields such as large data science, robotic automation, machine learning and software development engineering is therefore fundamental for digital industrialisation and structural transformation agendas (Andreoni et al., 2021b). At the firm level, the available literature highlights digital capabilities as critical for enhancing customer service and experiences, production processes, and innovative business models of firms (Westerman et al., 2012), as well as the organisational competitiveness and innovation (Van Laar et al., 2017). According to the OECD (2016), digital skills and capabilities – digital literacy and numeracy skills and skills to work collaboratively and flexibly with digital devices, applications, and online media – are needed to thrive in the digital economy. Related evidence by Zhou and Li (2010) also shows that the accumulation and development of digital capabilities and skills determine a country's readiness to embrace digital technologies. Recent evidence by Avalos et al. (2023) also shows the key role of digital capabilities in digital technological adoption persistence. Related evidence by Heredia et al. (2022) reiterates the positive relationship between digital capabilities and firms' performance, mediated through technological capabilities. The foregoing underscores the critical role of digital capabilities in complementing the digital orientation of firms.

Despite this evidence, there is little understanding on what constitutes digital capabilities, how to measure them (de Oliveira et al., 2020), and the potential factors that drive digital capability and skills development in manufacturing firms. The available literature remains anecdotal and focuses on identifying the effect of digital capabilities on firm performance. For instance, Drnevich and Croson (2013) in their study argue that digital capabilities positively affect a firm through reduced costs and increased flexibility. On the contrary, Usai et al. (2021) posits that digital capabilities have little or no effect on firm performance. While this evidence adds to our understanding on the effect of digital capabilities on firms' readiness towards new technology adoption, it pays little attention to what underlies and constitutes digital capabilities, how to measure them, and what influences their development in manufacturing firms. The DHET (2022), for instance, recognises the importance of developing cross-cutting digital skills for economic recovery and sustained reconstruction, while the DCDT (2021) provides a national framework and measurement indicators of digital skills and capabilities in South Africa. However, these policy initiatives, while critical, remain conceptual with limited application to firm-level data.

This paper contributes to the literature by developing a micro-level measurement framework and examining the determinants of digital capabilities in South Africa. It uses the South African digital skills survey conducted in March 2021, covering 516 firms organised into three manufacturing sector education and training authorities (SETAs) - manufacturing and engineering services (MerSETA), chemicals (CHIETA), and textiles and fibre processing (FP&M) SETAs. Specifically, based on available productive capabilities framework and firm-level data, the paper develops and constructs novel multidimensional digital capabilities indices and examines the factors that influence a firm's development and requirement of digital capabilities in South African manufacturing firms. In South Africa, institutional challenges of lack of funding of training institutions and infrastructure are cited to pose a key challenge for the development of the needed digital skills (Andreoni et al., 2021). In addition to contributing to the measurement and determinants of digital capabilities, our analysis also integrates the institutional angle of digital capabilities and skills by considering variables that proxy learning systems and training institutions. Understanding what digital capabilities entail and how to measure them within South Africa's context can help to formulate realistic and consistent policy strategies to bridge the emerging digital divide.

Adapting the taxonomy of productive capabilities (Andreoni, 2011), the paper identifies four main types of digital capabilities - investment and product design; process organisation; production organisation; and linkage and cooperation. Our findings from the econometric analyses suggest that different factors affect different types of digital capabilities across firms. For instance, the results suggest the following: small firms have higher inclination towards the production organisation digital capability than large firms; availability of STEM skills makes it easier for the manufacturing firms to develop digital capabilities in product design; export, albeit weakly, enhances process organisation digital capabilities. These findings also hold when we consider different firm size and export activities of firms. Thus, the results highlight a tale of heterogeneous factors that matter for digital capabilities and provides policy implications of these findings for digital industrialisation in South Africa and the opportunities for future research.

The rest of the paper proceeds as follows. Section 2 conceptualises digital capabilities by discussing productive capabilities, more broadly, followed by digital capabilities and links to manufacturing a discussion of digital capabilities as well in the South African context. In section 3, we discuss our data and empirical strategy. In section 4, we present and discuss the results from our empirical analysis, and we conclude the paper with some policy recommendations in section 5.

2. Related literature

2.1. (Productive) Capabilities dynamics and industrial development

The development of capabilities is central to economic transformation and development (Teece, 2000, 2019; Bell and Pavitt, 1993; Lall, 1992). The economic growth literature identifies capabilities as a key determinant for the inter-firm and -country differences in growth and economic development (Teece, 2019). Hence, the development and building of capabilities is a key determinant of catching up, economic development, and entrenching structural transformation (Lall, 1992; Andreoni, 2010; Andreoni and Tregenna 2020).

The theoretical and empirical literature on capabilities is advanced and draws on seminal works of authors such as Penrose (1959), Richardson (1972) and more recently Lall (1992). There is a plethora of concepts and taxonomies of firm-level capabilities in the economic literature. The main differences between the concepts and taxonomies of capabilities stem from two sources: (i) the specific functions or activities focused on; (ii) the static versus dynamic role played by capabilities under consideration (Andreoni, 2010). Based on his seminal work, Lall (1992) systematises firm-level capabilities according to different technological functions (such as process and product engineering) and the degree of complexity of different activities (from simple routines to more complex technological capabilities) to innovative activities. That is, Lall's contribution, as identified in Andreoni (2011: page 11), is centred on three main dimensions of capabilities, namely:

(1) ‘Investment capabilities: those capabilities needed to identify, prepare, obtain technology for, design, construct, equip, staff, and commission a new facility (or expansion).

(2) Productive capabilities: the skills involved in both process and product engineering as well as the monitoring and control functions included under industrial engineering.

(3) Linkage capabilities: the skills needed to transmit information, skills, and technology to and receive them from, component or raw material suppliers, subcontractors, consultants, service firms, and technology institutions.

Bell and Pavitt (1993, 1995), following Lall's contribution, made distinctions between production and technological capabilities as the static and dynamic perspectives of capabilities. Recent extensions of Lall (1992) and Bell and Pavitt (1993, 1995) made distinctions between production capabilities and technological capabilities (see for instance including Figueiredo, 2001, 2008; Ariffin, 2000). A notable extension of this discussion is by Andreoni (2011, 2010), who consolidated production capabilities and technological capabilities into the so-called productive capabilities. According to Andreoni (2011), productive capabilities encompass a combination of firms' processes, skills, structures, knowledge, and technology. The accumulation of productive capabilities (and, in particular, technological capabilities) results from deliberate in-house efforts as well as cumulative processes of learning by doing, using, and interacting, and covers from the first investment and product design phase up to the organizational and production phases (Andreoni, 2010). Productive capabilities are not simply pre-packaged stocks of codified knowledge. Instead, given a certain amount of knowledge resources, capabilities continuously develop circularly and cumulatively through micro-learning processes (Andreoni, 2010). That is, productive capabilities are built or accumulate through learning from a continuous progression of trial and error (Andreoni, 2011).

Based on the foregoing, Andreoni (2011) identifies and visualises productive capabilities as capturing both the productive and technical change activities. The author relates productive and technical change activities to five core functional areas: investment; product design; process organization; production process; and linkage and cooperation (Table 1). The investment and product design function areas refer to those attributes both financial and non-financial needed to identify, prepare, obtain new technology, design, construct, equip staff for expansion. Process organisation and production processes focus on the qualities that encompasses the manner of the overall production method. The linkage and cooperation function specifies the qualities that are essential in the transmission of information, skills and technology to and receiving them from, component or raw material suppliers or subcontractors (Andreoni, 2011). We adapt this framework for our analysis in sections 3 and 4.

Table 1: A taxonomy of productive capabilities

	Functional areas				
	Investment	Product design	Process organisation	Production process	Linkage and cooperation
Productivity activities	Feasibility studies	Replication of fixed specifications and designs	Production planning and control	Workflow scheduling and monitoring	Exchange with suppliers
	Negotiations and bargaining suitable terms and conditions	Standard design for manufacturing	International certification (ISO 9000)	Manufacture of components	Horizontal cooperation across firms
	Equipment and machinery procurement	Development of prototypes	Automation of processes	Sub-assembly and assembly of components and final goods	Distribution and marketing
	Recruitment of skilled personnel		Adoption of modern organizational techniques (e.g. just in time and total quality control)	Stretching, control and maintenance of machinery and equipment	After sale services
			Flexible and multi-skilled production	Inventory control	
			Architectural services	Productivity and quality control	
Technical change activities	Search for technology sources	Adaptions to technology driven by market needs and requests	Selection of technology and organisational formats	Efficiency improvement in tasks execution	Technological transfer and S&T linkages development
	Equipment design and adaption	improvement of product standards and quality	Minor changes to process technology to adapt it to local conditions	Improvement and cost saving in machinery and equipment	Coordinating R&D and joint ventures
	Engineering training	Development of complementary products(e.g. embedded software) or components	Improvement and development of new organisational techniques	Inverse engineering and development of machinery	Licensing own technologies to other
	Joint ventures	R&D into new product generation	Improvement to layout		
		R&D into new materials and new specifications product generation	Process oriented R&D for radical innovation		

Source: Andreoni (2011)

2.2. Digital capabilities and manufacturing: South African context

The fourth industrial revolution (4IR) and its associated advanced digital technologies have transformed the nature of work and tasks, and the skills needed to undertake these tasks. As a result, countries require a minimum base of digital skills and capabilities to embrace and advance the adoption of digital technologies and unlock the benefits of digital industrialisation (UNIDO, 2019; Andreoni et al., 2021). For latecomer countries, with generally low foundational capabilities (Andreoni et al., 2021), this is critical as the benefits from the new techno-economic paradigm shift depend on how quickly they can develop and accumulate digital capabilities and skills. The development of digital capabilities has therefore become a critical policy objective to unlock digital industrialisation in developing countries.

At the firm level, digital skills are fast becoming the main drivers of organisational competitiveness and innovation (Hirvonen & Majuri, 2020; Srivastava & Shainesh, 2015). In global value chains, for instance, firms can leverage digital capabilities, tighter integration, automation and advanced and flexible production and processes to transform their global business and operating models. In a study into the ability of South African plastic product manufacturers to embrace technological change, Bell et al. (2019) however note that firms require a requisite level of technological infrastructure as well as organisational capabilities to ensure success in the adoption of advanced digital technologies. However, the emerging evidence highlights that middle-income countries face digital skills gaps to link industry 4.0, the changing nature of work and skills (UNIDO, 2019; Kupfer et al., 2019).

In light of how digital capabilities have become a major part of today’s economy and firms, several policy strategies are being formulated to link digital capabilities and manufacturing. These policy actions are aimed at resetting and repositioning South Africa on the path of digital-driven industrial development. The ‘implementation programme guide for the national digital and future skills strategy of South Africa 2021-2025’ (DCDT, 2021) and the skills strategy (DHET, 2022) are the foremost strategic plans of Government on creating and developing a robust (digital) skills ecosystem in South Africa. The implementation guide together with other background and framework research and policy documents, for instance, recognise and emphasise the creation of a digital skills ecosystem and the development of skills as key aspects of renewing South Africa's human resource, descent jobs and industrial development growth path (DCDT, 2021; DHET, 2022). This is based on the evidence that South Africa’s economic reconstruction and sustained recovery require urgent building of dynamic future (digital) skills (DCDT, 2021; DHET, 2022). This section draws from these policy documents as well as other empirical studies on the South African economy to understand the emerging issues and the current state of the country’s digital capabilities.

As noted, South Africa has been experiencing a declining manufacturing base as well as development challenges. Given the emergence of advanced digital technologies, the creation and development of digital capabilities are purported to provide a critical complementary role in re-industrialising and making South African firms internationally competitive. This is because digital capabilities, enabled by new digital technologies such as IoT, big data analytics, artificial intelligence and cloud computing, are expected to enhance production and process operations and create new business models in South Africa (DCDT, 2021).

However, there is a growing digital capability and skills gap in South Africa (Andreoni et al., 2021b; Avenyo et al., 2022; DHET, 2022). This is mainly due to the strong demand for digital capabilities and skills (DCDT, 2021). In the digital economy, the skills gap is attributed to mismatches between employer skills needs and employee skills, due to the rapid growth of technology to training; lack of or limited access to the digital economy; brain drain; and unfitness of the education system for 21st century skills development (DHET, 2022). The specific digital skills gaps identified by the Harambee Youth Employment Accelerator (2020) are summarised in Table 2.

Table 2: Digital skills gaps in South Africa

Short-term digital skills gaps	Longer-term digital skills gaps
Cloud architecture	Artificial intelligence
Cybersecurity	Biotechnology
Data center	Block chain
Desktop	Data analysis
Enterprise architecture development	Internet of things
Design of learning management systems	Machine learning
Network Analysis	Nano technology
Software development engineering	Quantum computing
Systems engineering	Robotic automation

Source: Harambee Youth Employment Accelerator (2020) as cited in DHET (2022)

To close these digital skills gaps, there is need for a disruption of the institutions underlying South Africa's skills ecosystem the (DCDT, 2021). Specifically, DCDT (2021: page 10) recognises three main focus areas as:

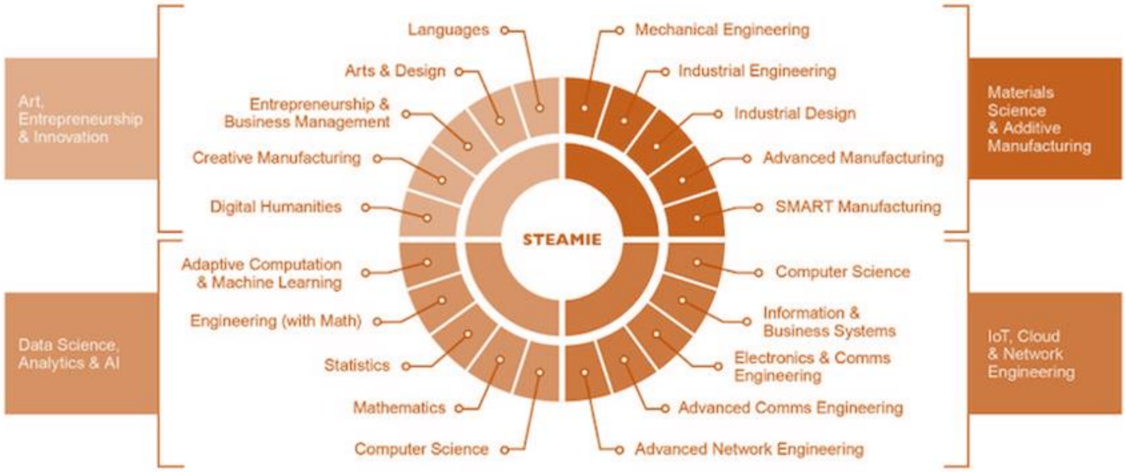
(i) *'Investing time, human effort and funding in producing strong science, technology, engineering, arts, mathematics, innovation and entrepreneurship (STEAMIE) foundations for digital and future skills at the basic education and post-school education phases;*

(ii) *Investing time, human effort and funding in shifting the inertia that pertains in the South African economy with respect to young people not-in-employment education-or-training (YNEET); and*

(iii) *Ensuring that there is equitable access to foundational STEAMIE skills by women and girls, by persons with disabilities, and by YNEET. The principles and intent of universal access design must underlie implementation'* (DCDT, 2021: page 10).

The foregoing suggests that re-orientation of South Africa's skills ecosystem from science, technology, engineering, and mathematics (STEM) skills to developing and realigning towards STEAMIE skills is fundamental for South Africa's dynamism and digital industrialisation (DCDT, 2021). Figure 1 shows the different skill sets that encompass STEAMIE skills.

Figure 1: STEAMIE skills sets (science, technology, engineering, arts, mathematics, innovation, and entrepreneurship)



Source: Abrahams and Burke (2021: page 10)

While efforts are being made by policymakers and stakeholders to understand South Africa's skills needs and the support programmes needed to drive the development of digital skills across all economic sectors, there is still limited evidence on what digital capabilities are and how to measure them in manufacturing firms. This may be due to the limited data available to accurately quantify and measure digital capabilities at the micro level. This paper aims to close this evidence gap.

3. Data and Methodology

This section discusses the digital skills survey in section 3.1, the empirical strategy employed for the analysis in section 3.2, and finally the presentation of basic descriptive statistics of key variables in the data in section 3.3.

3.1. Data

The analysis in this paper draws from the digital skills survey conducted in March 2021, covering 516 firms organised into three manufacturing sector education and training authorities (SETAs) - manufacturing and engineering services (MerSETA), chemicals (CHIETA), and fibre processing (FP&M SETA).[1] The digital skills survey aimed to understand the current and possible future levels of digital technologies adoption, and the state of digital skills and technological capabilities in South African manufacturing firms.

The survey covers a host of issues including the current and future adoption behaviours of firms across four key business functions: supplier relationship, production management, customer relations, and product development, the firm-level characteristics, employment, innovation, and export activities of firms between the 2017/18 and 2019/20 financial years. More relevant for

[1] The distribution of respondent firms across SETAs are as follows: MerSETA (67%), CHIETA (17%), and FP&M (16%).

this paper are questions seeking to understand the digital capabilities of firms and skills of workers. To understand the digital capabilities in South African manufacturing, we used related responses by firms on the specific questions that probed on digital capabilities and skills. In certain cases, we reconstructed the responses into dummies to allow for easy interpretation.[2]

3.2. Empirical strategy

As noted, this paper aims to construct novel digital capabilities indices based on the productive capabilities taxonomy (see Table 1) and examine the factors that influence a firm's digital capabilities in South African manufacturing. To do these, we follow a two-step approach: 1) Construct multidimensional digital capabilities indices; and 2) Conduct econometric analysis of the determinants of digital capabilities in South Africa. We explain each of these approaches below.

3.2.1. Construction of multidimensional digital capabilities indices

To create and develop digital capabilities, firms require a broad set of foundational skills, ranging from cognitive, non-cognitive and physical skills (Morandini et al., 2020)..To construct our digital capabilities indices, we combine a broad set of variables identified in the literature (see for instance, Khin and Ho, 2018; Teece, 2018; Heredia et al., 2022) as key dimensions of digital capabilities for which we have data. This approach is based on the assumption that different dimensions of digital capabilities are highly correlated. We follow Fagerberg and Srholec (2008, 2017) and Avenyo et al. (2021) to first generate a polyserial correlations matrix, after which we performed principal factors analyses on the polyserial correlations matrix using the oblique oblimin rotation for the digital capability indicators.

Based on the factor loadings, we identified - based on the corelations in the factor loadings - four (4) dimensions/types of digital capabilities. Based on the taxonomy of productive capabilities developed by Andreoni (2011), we grouped these dimensions/types of digital capabilities as: investment and product design; process organisation; production organisation; and linkage and cooperation. For instance, the results from the factor analysis and factor loadings show that investment in digital technological order management is strongly correlated with investment and product design, but weakly correlated with the other types of digital capabilities (see Table 3).

[2] Table A in Appendices presents these questions and provides the measures that were used in the digital skills survey.

Table 3: Dimensions of digital capabilities and results of factor loadings

Functional Dimension	Factor Loadings			
	Investment and product design	Process org.	Production org.	Linkage and cooperation
Investment in technology for order management	0.5027	0.2051	0.3995	-0.3493
Investment in technology for production management	0.7676	0.1691	0.0318	-0.1835
Investment in technology for customer relationships	0.8154	0.1706	-0.0525	-0.1183
Investment in technology for product devt	0.6575	-0.2661	0.4102	0.4518
Internal training devt	0.6991	0.1375	-0.4769	0.0322
External training devt	0.6007	0.0531	-0.2744	-0.0785
Employees with digital skills	0.6968	0.0404	-0.1596	-0.0351
Investment in fixed capital	0.7210	0.0889	-0.3319	-0.0153
Hiring employees with digital skills	0.7020	0.0489	-0.4358	0.0413
R&D department	0.5984	-0.2775	0.3790	0.4784
R&D&I	0.7440	0.0418	-0.1422	0.0840
Retrofitting management processes	0.1770	0.7987	0.4613	-0.1810
Retrofitting production processes	0.1770	0.7987	0.4613	-0.1810
Retrofitting product management processes	0.2492	0.6250	-0.0736	0.2772
Retrofitting customer relations processes	0.2493	0.5515	-0.1614	0.4303
Product devt	0.3590	-0.1816	0.7333	0.2507
Production management	0.0403	0.0732	0.9928	-0.0133
Management organisation	0.3634	-0.5021	0.5315	-0.2572
Product organisation	-0.3974	0.3250	0.5589	-0.4412

Product devt organisation	-0.3801	0.3181	0.5558	0.3092
Customer organisation	-0.2860	0.2993	0.0811	0.6195
Customer relations	0.1496	-0.1515	0.1067	0.9396
Supplier relations	0.0310	-0.1374	0.1506	0.9570

Source: Authors own elaboration

3.2.2. Empirical Strategy

To examine the determinants of digital capabilities in South African manufacturing, we formulate a simple ordinary least squares (OLS) regression model. This is based on the continuous nature of our digital capabilities and the fact that we are interested in the contemporary effects of firm, SETA, industry, and location variables. Our general model is formulated as:

$$DCI_i = f(X_i, \mathrm{I}, \mathrm{S}, \mathrm{L}) \quad (1)$$

where DCI_i is a vector of digital capabilities indices of firm i; X_i refers to firm-level characteristics of firm i; I refers to industry fixed effects; S is SETA fixed effects; and L refers to provincial fixed effects.

Specifically, our regression equation for each digital capabilities' indicator is given as:

$$DCI\_IPD_i = \gamma_0 + \gamma_1 X_i + \gamma_2 \mathrm{I} + \gamma_3 \mathrm{S} + \gamma_4 \mathrm{L} + \varepsilon_{1i} \quad (2.1)$$

$$DCI\_PrO_i = \alpha_0 + \alpha_1 X_i + \alpha_2 \mathrm{I} + \alpha_3 \mathrm{S} + \alpha_4 \mathrm{L} + \varepsilon_{2i} \quad (2.2)$$

$$DCI\_PO_i = \beta_0 + \beta_1 X_i + \beta_2 \mathrm{I} + \beta_3 \mathrm{S} + \beta_4 \mathrm{L} + \varepsilon_{3i} \quad (2.3)$$

$$DCI\_LC_i = \delta_0 + \delta_1 X_i + \delta_2 \mathrm{I} + \delta_3 \mathrm{S} + \delta_4 \mathrm{L} + \varepsilon_{4i} \quad (2.4)$$

where DCI_IPD_i, DCI_PrO_i, DCI_PO_i, and DCI_LC_i refers to investment and product design, process organisation, production organisation, and linkage and cooperation digital capabilities indices of firm i respectively. X_i, I, S and L remain as defined in equation 1. ε_{1i}, ε_{2i}, ε_{3i} and ε_{4i} are normally distributed error terms with zero means and constant variances.

Equations 2.1 - 2.4 are specified as independent models that explore the determinants of investment and product design, process organisation, production organisation, and linkage and cooperation digital capabilities. However, given that each digital capability decision of firms may not be made independently of the other/s, we model and estimate jointly equations 2.1-2.4 as a system of seemingly unrelated regression models using the conditional mixed process (cmp) (Roodman, 2011). That is, ε_{1i}, ε_{2i}, ε_{3i} and ε_{4i} are jointly normally distributed error terms with zero means and constant variances.

The set of firm-level variables in X_i are obtained from the theoretical and empirical literature (Van Laar et al., 2020, provides a systematic review of this literature). For instance, we control for variables such as: 1) age of firm (number of years in operation); 2) ownership structure of the firm; 3) number of employees as a measure of size; 4) number of STEM employees; 5) export capacity; and 6) availability of human/computer skills in the firm, amongst others. There is evidence that a firm's age has a role in determining the ability of an organisation to adopt and develop new digital technological capabilities (Meyer, 2008). Older firms tend to be less receptive in developing and adopting new technological capabilities compared to younger firms (Gagnon, 1993). Firms that employ adequately skilled employees will more easily adapt to a digitalised technological infrastructure than firms without adequately skilled employees.

The ownership structure of a firm can play a crucial role in its ability to advance their technological frontier (Minetti, Murro & Paiella, 2010). For instance, it is claimed that foreign owned companies tend to be better positioned to have access to new technologies through the parent company and tend to be more likely to develop digital technological capabilities than locally owned firms. This is often the case due to the strong Research and Development (R&D) departments of foreign owned firms, and in some cases their access to multiple markets and links to sophisticated operations in more technologically advanced economies. Firms' ability to develop and adopt new digital technological capabilities may also be determined by the number of employees and as well as the presence of STEM abilities within the workforce. Empirical evidence suggests that firms with a higher number of STEM employees tend to show a higher likelihood to have higher levels of 'foundational' capabilities and foster the development of new digital technological capabilities (Andreoni, et al., 2021). The exporting activities of a firm may also influence the development of new digital capabilities (Meyer, 2008). Firms that are involved in exports are likely to be more receptive to new technologies and capabilities (Wang, et al., 2020). This maybe a result of exposures to global value chains and standards specified by exporters that act as catalyst in adoption of new technologies.

Table A in the appendix presents the definition of all variables.

4. Empirical results and discussion

This section presents and discusses the econometric results examining the determinants of digital capabilities in South African manufacturing. In the empirical estimation, we first estimate OLS models separately, for each type of digital capabilities, followed by our preferred model – seemingly unrelated regression (SUR) - where we jointly estimate all four equations. In terms of structure of the section, we first present and discuss our baseline results on the determinants of digital capabilities in South Africa in section 4.1, followed by our extended results looking at the determinants of digital capabilities in South Africa by size of firms and export activities in sections 4.2 and 4.3, respectively. In all cases, we present results for all types of digital capabilities: investment and product design, process organisation, production organisation, and linkage and cooperation. All regressions are heteroskedasticity-robust.

4.1. Determinants of digital capabilities

The baseline results showing the determinants of digital capabilities in South Africa are reported in Table 4. Table 4 reports the estimation results from our OLS (columns 1-4) where we estimate each model independently and the SUR (5-8) estimation model. The correlation coefficients of the error terms (atanhrho_12, atanhrho_13, atanhrho_14, and atanhrho_23, atanhrho_34) across all the four equations are mostly statistically significant. In line with our earlier postulation, this evidence further highlights the importance of estimating these equations as a SUR rather than separate OLS models. In line with these results, we proceed to interpret and to discuss the results from the SUR model (columns 5-8). However, given the possible simultaneity bias between our digital capabilities indicators and firm level determinants, we interpret these identified relationships with the caveat that they are correlations, and we exercise caution in their interpretation as causal relationships.

In sum, the estimation results show that there is a level of heterogeneity in the factors that influence digital capabilities in South African manufacturing firms. For investment and product design, our results show that employing workers that possess STEM skills is important for the development of investment and product design digital capabilities. This finding further reiterates the importance of STEM skills as critical foundational capabilities that position manufacturing firms to easily develop digital capabilities in product design. Our results also show that manufacturing firms that engage in international trade, and those with employees with human computer interaction skills have higher investment and product design digital capabilities than otherwise. This relationship is found to be weak and only significant at the 10% significance level. Despite this, the results suggest the importance of trade as a medium for the exchange of digital capabilities and skills while firms with human computer interaction skills are better able to internally develop and/or externally search and adapt new investment and product design digital capabilities into their production processes. Relevant for policy is our result that firms located in or near areas with government policy on ICT ecosystem have higher levels of investment and product design digital capabilities than otherwise, highlighting the importance of deliberate policies in the building process of digital skills and capabilities.

Focusing on process organisation digital capabilities, our results show a significant but weak relationship between export activities and lack of knowledge on digital transformation. Specifically, the results show that firms that export have higher process organisation digital capabilities compared with non-exporting firms. This may imply that exporting requires firms to be innovative and efficient in order to be cost competitive in the global market. This pushes exporting firms to build and develop process organisation digital capabilities. In terms of future orientations, manufacturing firms that expect to increase their efficiency and productivity in the medium term (5-10 years) re-orient their organisational processes in ways that allow them to build process organisation digital capabilities in anticipation of increased efficiency and productivity in the future. Also, the results suggest a positive and significant effect of government's digital initiatives and programmes on process organisation digital capabilities, highlighting the key role of policy in South Africa's digital industrialisation transformation.

The estimation results for production organisation digital capabilities suggest that small firms tend to have a higher production organisation digital capability than large firms. This corroborates the literature that suggests that small firms are more receptive to new production systems and organisations since these processes are easier to transform in smaller firms than in large firms. Firms that lack knowledge on how to develop digital skills and capabilities as well as those that want quick financial recovery from investments in digital technologies and capabilities tend to invest less and have lower production organisation digital capabilities. Firms that aim to offer more customized products to their clients in the medium term (5-10) years invest and position themselves by developing digital capabilities than otherwise. In addition, firms that have access to digital training centres, benefit from government digital initiatives and are connected to a network of advanced manufacturing firms have higher production organization digital capabilities than otherwise. These findings emphasise the importance of infrastructure, policy, and network effect/co-location in South Africa's digital transformation process.

Finally, the baseline estimation results showing the determinants of linkage and cooperation digital capabilities shows medium (sales value between R51 and R250 million) and small (sales value between R11 and R50 million) firms have higher digital capabilities compared with large (sales value at more than R250 million) firms. This highlights the dynamism that size brings to capability development, with smaller firms able to reorganize their internal structures to train and develop such digital capabilities. Firms that indicate that the long time period to recovery of investments in digital capabilities is a constraint invest less and have lower linkage and cooperation, hence lower digital capabilities. Manufacturing firms that aim to open new market opportunities, offer customized products, cut short delivery times, move to the frontier of technological leadership, and have a network with other advanced manufacturing firms all have higher digital capabilities.

In sum, our results across the different types of digital capabilities suggest that there are heterogenous firm-level characteristics that affect digital capabilities in South African manufacturing firms. It is important to highlight here that the key factors identified to influence digital capabilities range from size effects, composition of skills in employees including the availability of STEM skills, and to more export exposure, infrastructure, and policy variables.

Table 4: Determinants of digital capabilities

Model	OLS				SUR			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital capabilities	Investment and product design	Process organisation	Production organisation	Linkage and cooperation	Investment and product design	Process organisation	Production organisation	Linkage and cooperation
Age (log)	-0.0687	0.0230	-0.0806	-0.159*	-0.0687	0.0149	-0.126	0.147
	(0.0455)	(0.0779)	(0.0677)	(0.0868)	(0.0427)	(0.223)	(0.207)	(0.221)
Size (medium)	-0.0709	0.113	-0.0707	-0.217	-0.0709	0.0230	-0.0806	0.164**
	(0.0794)	(0.146)	(0.108)	(0.145)	(0.0745)	(0.0730)	(0.0636)	(0.0814)
Size (small)	-0.0155	0.119	-0.0279	-0.174	-0.0155	0.0607	0.0776**	0.151***
	(0.0746)	(0.126)	(0.0933)	(0.126)	(0.0700)	(0.0450)	(0.0347)	(0.0462)
Capital ownership	0.00870	-0.432***	0.357**	0.207	0.00870	0.135	0.130	-0.0338
	(0.0825)	(0.161)	(0.155)	(0.166)	(0.0774)	(0.129)	(0.108)	(0.128)
Employment (log)	0.0402	0.0607	0.0776**	0.149***	0.0402	0.113	-0.0707	-0.214
	(0.0266)	(0.0479)	(0.0369)	(0.0494)	(0.0250)	(0.137)	(0.101)	(0.136)
STEM skills	0.191***	-0.238*	0.223**	0.170	0.191***	0.119	-0.0279	-0.171
	(0.0676)	(0.134)	(0.106)	(0.131)	(0.0634)	(0.118)	(0.0875)	(0.118)
Export	0.122*	0.135	0.130	-0.0222	0.122*	0.294*	-0.0515	0.0888
	(0.0683)	(0.138)	(0.115)	(0.137)	(0.0641)	(0.162)	(0.134)	(0.171)

Lack capital	0.0417	0.0149	-0.126	0.140	0.0417	0.259	0.121	0.0170
	(0.117)	(0.238)	(0.220)	(0.238)	(0.110)	(0.161)	(0.120)	(0.164)
Lack digital infrastructure	-0.0341	0.259	0.121	0.0217	-0.0341	0.133	-0.0768	-0.188
	(0.0979)	(0.171)	(0.128)	(0.176)	(0.0918)	(0.185)	(0.123)	(0.187)
Access universal broadband	-0.0693	0.133	-0.0768	-0.182	-0.0693	0.0488	-0.000356	0.0985
	(0.115)	(0.197)	(0.131)	(0.199)	(0.108)	(0.173)	(0.137)	(0.187)
Lack human resources	0.0487	0.0488	-0.000356	0.0982	0.0487	0.0471	-0.0884	-0.175
	(0.104)	(0.184)	(0.146)	(0.200)	(0.0976)	(0.131)	(0.102)	(0.135)
Lack of awareness and knowledge	0.116	-0.294*	-0.0515	0.0966	0.116	-0.238*	-0.223**	0.175
	(0.0986)	(0.173)	(0.143)	(0.183)	(0.0925)	(0.126)	(0.0991)	(0.123)
Human computer interaction skills	0.190*	0.156	0.240**	0.267*	0.190*	-0.0387	0.0577	0.00935
	(0.111)	(0.157)	(0.100)	(0.154)	(0.104)	(0.194)	(0.110)	(0.205)
Long investment recovery	-0.0390	0.0471	-0.0884	-0.182	-0.0390	0.156	-0.240**	-0.262*
	(0.0782)	(0.140)	(0.109)	(0.144)	(0.0734)	(0.147)	(0.0941)	(0.143)
Efficiency and productivity	0.195	0.104	-0.133	-0.514*	0.195	0.432***	0.357**	0.208
	(0.178)	(0.302)	(0.203)	(0.274)	(0.167)	(0.151)	(0.145)	(0.155)
Open new opportunities	0.276**	-0.303	0.196	0.706***	0.276**	0.0223	-0.0703	0.297**
	(0.140)	(0.234)	(0.165)	(0.229)	(0.131)	(0.154)	(0.108)	(0.151)
Customization	0.0153	0.0729	0.121	-0.0225	0.0153	0.0236	0.212*	0.387**

	(0.136)	(0.243)	(0.154)	(0.203)	(0.127)	(0.164)	(0.112)	(0.151)
Delivery times	0.178	-0.215	-0.278**	0.0607	0.178	0.104	-0.133	0.580**
	(0.119)	(0.205)	(0.137)	(0.195)	(0.111)	(0.283)	(0.191)	(0.259)
Technological leadership	0.0640	0.418*	0.270	-0.0866	0.0640	-0.303	0.196	0.712***
	(0.145)	(0.221)	(0.165)	(0.218)	(0.136)	(0.220)	(0.155)	(0.215)
ICT ecosystem	0.791***	0.244	0.372**	0.628***	0.791***	0.0729	0.121	-0.0121
	(0.137)	(0.214)	(0.172)	(0.242)	(0.129)	(0.228)	(0.144)	(0.191)
Digital training centres	0.142	-0.0387	0.0577	0.0264	0.142	-0.215	0.278**	0.0880
	(0.125)	(0.206)	(0.118)	(0.219)	(0.118)	(0.192)	(0.128)	(0.185)
Digital initiatives	0.0481	0.0223	-0.0703	0.306*	0.0481	0.418**	0.270*	-0.0591
	(0.0772)	(0.164)	(0.115)	(0.162)	(0.0724)	(0.207)	(0.155)	(0.206)
Network of advanced manuf firms	-0.0798	0.0236	0.212*	-0.393**	-0.0798	-0.244	0.372**	0.629***
	(0.0787)	(0.175)	(0.120)	(0.161)	(0.0738)	(0.201)	(0.162)	(0.227)
Constant	-0.621**	-0.905	-1.254***	-0.497	-0.512*	-0.610	-0.520	-0.693
	(0.314)	(0.564)	(0.474)	(0.689)	(0.281)	(0.616)	(0.561)	(0.624)
SETA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
lnsig_1_Constant					-0.711***			
					(0.0533)			

lnsig_2_Constant						-0.0786***		
						(0.0196)		
lnsig_3_ Constant							-0.428***	
							(0.0389)	
lnsig_4_ Constant								-0.154***
								(0.0277)
atanhrho_12_ Constant					0.143***			
					(0.0519)			
atanhrho_13_ Constant						0.152***		
						(0.0458)		
atanhrho_14_ Constant							0.278***	
							(0.0520)	
atanhrho_23_ Constant								-0.222***
								(0.0474)
atanhrho_24_ Constant						-0.0125		
						(0.0500)		
atanhrho_34_ Constant							0.457***	
							(0.0515)	
Observations	435	435	435	435	435	435	435	435

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.2. Extensions: Determinants of digital capabilities by firm size and export activity

To further explore possible heterogeneity in our baseline findings, we conducted two main split sample analyses by size of the firm and export status. These analyses are important as they provide a granular understanding of whether similar factors affect the digital capability of small vis-à-vis large firms or exporting vis-à-vis non-exporting firms. Table 5 reports the estimation results when we consider size (small, and medium and large)[3] while Table 6 reports the estimation results for exporting and non-exporting firms for each category of digital capabilities.

Our estimation results when we consider the firm size sub-samples shows that, for medium and large firms, increases in the number of employees, having employees with STEM skills and human computer interaction skills, new market opportunities, and operating in an ICT ecosystem all enhance investment and design digital capabilities (Table 5: column 1). On the contrary, only improving delivery times and operating in an ICT ecosystem matter for investment and design digital capabilities in small firms (Table 5: column 5). These results are intuitive as it suggests that medium and large firms develop digital capabilities mainly through their human capital and available market opportunities, while small firms generate investment and design digital capabilities through efficiency modes of production and distribution.

For process organization digital capabilities, our results show that exporting medium and large firms have higher digital capabilities than non-exporting firms, and this does not matter for process organization digital capabilities in small firms. On the contrary, increases in the number of employees drives process organisation digital capabilities only in small firms, suggesting human capital effects. Lack of knowledge and awareness on digital transformation is detrimental to the digital capabilities of small firms while we find no effect on medium and large firms. Foreign ownership of capital in both small, and medium and large firms increase process organization digital capabilities, indicating the importance of knowledge transfer that occurs within foreign-owned firms compared with locally owned firms (columns 2 and 6). Small manufacturing firms that anticipate gains from moving to the technological frontier as well as operate in ICT ecosystems tend to have higher digital capabilities compared to those that do not (column 6). These further reiterate the importance of infrastructure and technological foresight in the digital transformation of firms.

We observe similar levels of heterogeneity of factors mattering for both production organisation, and linkage and cooperation digital capabilities in small, and medium and large firms. For instance, we observe that medium and large firms drive our results for production organisation. Our estimations show that lack of digital infrastructure and long investment recovery periods are detrimental to the development of digital capabilities in medium and large firms while medium and large firms with employees with human computer interaction skills, foreign ownership, and those that operate in a network of firms with advanced technologies have higher production organization digital capabilities. These results suggest that the financial

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[3] In the size split sample analysis, we combine both medium and large firms due to the small sample size of large firms.

and infrastructural ecosystem in which medium and large firms operate is critical for their production organisation digital capabilities' development. These imply the importance of digital connectedness that may transcend geographical barriers. The results do not hold for small firms.

For linkage and cooperation capabilities, older, and medium and large firms have lower digital capabilities likely due to their stickiness, and having a larger number of employees benefits the digital capabilities of small firms. Medium and large firms invest less in building capabilities through linkages and cooperation due to the long investment recovery period. Policy initiatives benefit small firms more than medium and large firms; and the positive externalities from operating in the network of advanced manufacturing firms and in an ICT, ecosystem increase the linkage and cooperation digital capabilities of small-sized, and medium and large-sized firms.

In sum, the foregoing discussion highlights the key roles of human computer interaction skills, foreign ownership of capital in explaining differences between firms, and prospects for new market opportunities in driving the development of most types of digital capabilities in medium and large firms, while operating in an ICT ecosystem matters for both small-sized and for medium and large-sized manufacturing firms in South Africa.

As noted, trade is a conduit through which knowledge and technological transfer occur. As a result, different factors may explain the digital capabilities in exporting firms compared with non-exporting firms. Our sub-sample analysis comparing the determinants of digital capabilities in exporting and non-exporting firms are reported in Table 6. Again, we identify similar heterogeneity in the determinants of digital capabilities, as observed in our baseline and firm size results. For instance, our results show access to universal broadband weakly increases digital capabilities in exporting firms but has no effect on non-exporting firms (columns 1 and 5). STEM skills matter only for building investment and product design digital capabilities of exporting firms, while it is important for both process organization and linkage and cooperation digital capabilities of non-exporting firms. In sum, operating in a network with advanced manufacturing firms and in an ICT ecosystem' enhance almost all types of digital capabilities in exporting firms, while our results suggest that foreign capital ownership and age matter more for almost all types of digital capabilities in non-exporting firms.

Table 5: Determinants of digital capabilities by size

Size	Medium and large				Small			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital capabilities	Investment and product design	Process organisation	Production organisation	Linkage and cooperation	Investment and product design	Process organisation	Production organisation	Linkage and cooperation
Age (log)	-0.0544	0.115	-0.140	-0.191*	-0.0482	-0.0253	0.0292	-0.0202
	(0.0552)	(0.103)	(0.0874)	(0.105)	(0.0587)	(0.110)	(0.0800)	(0.123)
Employment (log)	0.0606*	0.00504	0.0132	0.118*	0.00847	0.126**	0.0865	0.180***
	(0.0352)	(0.0713)	(0.0473)	(0.0630)	(0.0327)	(0.0633)	(0.0532)	(0.0647)
Export	0.0445	0.408**	-0.00810	-0.181	0.150	0.339	0.261	0.0295
	(0.0847)	(0.177)	(0.145)	(0.177)	(0.0928)	(0.211)	(0.162)	(0.218)
Lack capital	-0.117	0.282	-0.209	-0.211	0.175	-0.212	-0.0166	0.385
	(0.168)	(0.279)	(0.284)	(0.318)	(0.153)	(0.332)	(0.307)	(0.318)
Lack of awareness and knowledge	-0.247*	-0.184	-0.215	0.148	-0.183	-0.655***	0.0726	-0.209
	(0.130)	(0.220)	(0.152)	(0.227)	(0.129)	(0.238)	(0.177)	(0.274)
Lack digital infrastructure	-0.0832	0.133	-0.417***	0.154	-0.0147	0.264	0.0132	0.107
	(0.124)	(0.236)	(0.149)	(0.217)	(0.143)	(0.263)	(0.208)	(0.228)
Access universal broadband	-0.0402	-0.0245	-0.190	-0.335	-0.231	0.329	-0.123	-0.342

	(0.183)	(0.288)	(0.170)	(0.290)	(0.144)	(0.261)	(0.164)	(0.264)
Lack human resources	-0.0406	-0.0491	-0.0687	-0.193	0.203	0.229	-0.0323	0.179
	(0.138)	(0.245)	(0.168)	(0.257)	(0.162)	(0.280)	(0.193)	(0.302)
Long investment recovery	-0.0874	-0.168	-0.233*	-0.395**	0.0929	0.227	0.0864	0.171
	(0.0966)	(0.174)	(0.126)	(0.172)	(0.0917)	(0.196)	(0.125)	(0.185)
STEM skills	0.197**	-0.270	0.243*	0.166	0.157	-0.175	0.193	0.0990
	(0.0994)	(0.192)	(0.142)	(0.183)	(0.101)	(0.196)	(0.152)	(0.191)
Digital training centres	0.173	-0.0622	0.0704	0.113	0.138	-0.230	0.171	-0.0228
	(0.210)	(0.295)	(0.151)	(0.303)	(0.134)	(0.262)	(0.173)	(0.283)
Human computer interaction skills	0.298**	0.366*	0.299***	0.361**	0.0296	-0.147	0.183	0.0203
	(0.137)	(0.200)	(0.114)	(0.177)	(0.153)	(0.216)	(0.139)	(0.235)
Capital ownership	0.109	0.423**	0.754***	0.370*	-0.0826	0.455**	0.154	0.0674
	(0.106)	(0.212)	(0.174)	(0.211)	(0.110)	(0.230)	(0.195)	(0.239)
Digital initiatives	-0.0121	0.0370	-0.205	0.00378	0.0150	0.122	-0.00281	0.536***
	(0.0975)	(0.203)	(0.148)	(0.203)	(0.127)	(0.252)	(0.176)	(0.205)
Network of advanced manuf firms	-0.110	0.0672	0.306**	0.309*	-0.0420	-0.241	-0.191	0.517**
	(0.0849)	(0.186)	(0.140)	(0.184)	(0.146)	(0.258)	(0.180)	(0.214)
Efficiency and productivity	-0.00913	0.503	-0.386	0.628*	0.281	-0.336	-0.0361	-0.532

	(0.246)	(0.392)	(0.307)	(0.322)	(0.256)	(0.430)	(0.201)	(0.413)
Open new opportunities	0.435**	0.659*	0.468*	0.895***	0.169	-0.237	-0.0480	0.482
	(0.217)	(0.338)	(0.266)	(0.297)	(0.147)	(0.281)	(0.159)	(0.298)
Customization	0.169	0.418	0.0637	0.0595	-0.231	-0.0380	0.169	-0.0585
	(0.170)	(0.294)	(0.221)	(0.290)	(0.172)	(0.327)	(0.204)	(0.304)
Delivery times	0.145	-0.282	-0.218	-0.0795	0.389**	-0.142	-0.256	0.290
	(0.120)	(0.236)	(0.173)	(0.268)	(0.173)	(0.302)	(0.170)	(0.282)
Technological leadership	-0.128	0.0651	0.198	-0.306	0.246	0.960***	0.267	0.210
	(0.183)	(0.312)	(0.206)	(0.253)	(0.157)	(0.277)	(0.184)	(0.300)
ICT ecosystem	0.930***	0.0909	0.646***	0.686**	0.809***	0.487*	0.356	0.961***
	(0.157)	(0.275)	(0.179)	(0.308)	(0.190)	(0.295)	(0.264)	(0.316)
Constant	-0.218	-0.929	-0.879	0.241	-0.651	-0.0850	-0.484	-1.429*
	(0.438)	(0.749)	(0.613)	-1.006	(0.420)	(0.871)	(0.739)	(0.838)
SETA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
lnsig_1	-0.726***				-0.820***			
Constant	(0.0749)				(0.0805)			
lnsig_2		-0.100***				-0.162***		
Constant		(0.0281)				(0.0337)		

lnsig_3			-0.484***				-0.531***	
Constant			(0.0487)				(0.0610)	
lnsig_4				-0.245***				-0.195***
Constant				(0.0432)				(0.0412)
atanhrho_12	0.138*				0.205***			
Constant	(0.0743)				(0.0726)			
atanhrho_13		0.105*				0.174**		
Constant		(0.0535)				(0.0779)		
atanhrho_14			0.212***				0.285***	
Constant			(0.0727)				(0.0820)	
atanhrho_23				-0.133*				-0.316***
Constant				(0.0691)				(0.0593)
atanhrho_24		0.0829				-0.136**		
Constant		(0.0708)				(0.0668)		
atanhrho_34			0.348***					0.529***
Constant			(0.0718)					(0.0731)
Observations	234	234	234	234	201	201	201	201

Table 6: Determinants of digital capabilities by export activity

Export	Export				Non-export			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital capabilities	Investment and product design	Process organisation	Production organisation	Linkage and cooperation	Investment and product design	Process organisation	Production organisation	Linkage and cooperation
Age (log)	0.0261	-0.0391	-0.0419	-0.0509	-0.181***	0.185	-0.238*	-0.380***
	(0.0516)	(0.0866)	(0.0627)	(0.0956)	(0.0595)	(0.135)	(0.131)	(0.145)
Employment (log)	0.0297	0.0931	0.0622	0.0957	0.0589**	-0.0663	0.0624	0.225***
	(0.0344)	(0.0581)	(0.0443)	(0.0614)	(0.0265)	(0.0765)	(0.0694)	(0.0755)
Lack_capital	0.0738	0.0627	-0.303	0.0419	-0.0315	-0.118	0.0766	0.332
	(0.163)	(0.384)	(0.302)	(0.391)	(0.102)	(0.260)	(0.274)	(0.254)
Lack of awareness and knowledge	0.202*	-0.301	0.147	0.0447	-0.0188	-0.143	-0.163	0.388
	(0.118)	(0.234)	(0.165)	(0.205)	(0.107)	(0.255)	(0.211)	(0.298)
Lack digital infrastructure	-0.319**	0.0225	0.0759	-0.182	0.130	0.357*	0.0617	-0.197
	(0.154)	(0.268)	(0.161)	(0.252)	(0.0946)	(0.201)	(0.186)	(0.212)
Access universal broadband	0.269*	0.225	0.0420	0.311	-0.113	0.274	-0.127	-1.042***
	(0.150)	(0.258)	(0.158)	(0.239)	(0.134)	(0.302)	(0.201)	(0.290)
Lack human resources	0.0957	0.219	0.266*	0.281	0.124	-0.252	-0.280	0.0143
	(0.146)	(0.244)	(0.157)	(0.260)	(0.120)	(0.307)	(0.216)	(0.302)

Long investment recovery	-0.00440	-0.0677	-0.0585	-0.195	0.0976	0.160	-0.0565	-0.0942
	(0.112)	(0.203)	(0.134)	(0.181)	(0.0718)	(0.181)	(0.178)	(0.224)
STEM skills	0.274***	-0.165	0.138	0.114	0.0329	0.529**	0.453**	0.274
	(0.0880)	(0.167)	(0.119)	(0.160)	(0.0775)	(0.231)	(0.185)	(0.217)
Digital training centres	-0.0120	0.0328	0.0710	-0.0647	0.162	-0.222	0.187	0.107
	(0.184)	(0.258)	(0.153)	(0.293)	(0.125)	(0.279)	(0.197)	(0.300)
Human computer interaction skills	-0.0768	0.0507	0.210**	0.0925	0.462***	0.454**	0.283	0.457
	(0.137)	(0.196)	(0.104)	(0.186)	(0.106)	(0.213)	(0.207)	(0.284)
Capital ownership	0.0147	0.355	0.227	0.0941	0.100	0.470**	0.549**	0.379*
	(0.117)	(0.219)	(0.188)	(0.232)	(0.0728)	(0.238)	(0.228)	(0.226)
Digital initiatives	0.163	0.332	0.115	0.526***	0.0534	-0.415**	-0.0423	0.299
	(0.112)	(0.223)	(0.125)	(0.198)	(0.0721)	(0.208)	(0.182)	(0.207)
Network of advanced manuf firms	-0.192*	-0.364	-0.124	-0.585***	0.00944	0.351*	-0.541***	-0.526**
	(0.111)	(0.233)	(0.142)	(0.187)	(0.0696)	(0.182)	(0.171)	(0.220)
Efficiency and productivity	-0.153	0.133	-0.274	-0.049***	0.185	0.362	0.268	0.369
	(0.221)	(0.374)	(0.208)	(0.338)	(0.157)	(0.453)	(0.608)	(0.560)
Open new opportunities	0.425***	-0.253	0.253	0.901***	0.0368	-0.882**	0.207	0.153
	(0.147)	(0.253)	(0.154)	(0.253)	(0.137)	(0.374)	(0.493)	(0.409)
Customization	0.103	0.0320	0.121	0.0876	-0.0391	0.0458	0.0402	-0.428

	(0.172)	(0.273)	(0.156)	(0.233)	(0.108)	(0.353)	(0.347)	(0.336)
Delivery times	0.372**	-0.375	-0.164	0.235	-0.0347	0.447	-0.472	0.144
	(0.153)	(0.245)	(0.150)	(0.252)	(0.101)	(0.341)	(0.319)	(0.288)
Technological leadership	0.132	0.423	0.286*	-0.0242	0.141	0.587*	0.0603	-0.232
	(0.182)	(0.263)	(0.166)	(0.259)	(0.112)	(0.323)	(0.381)	(0.398)
ICT ecosystem	0.726***	0.200	0.368**	0.723**	0.489**	-0.889*	0.493	0.500
	(0.152)	(0.258)	(0.182)	(0.305)	(0.235)	(0.463)	(0.324)	(0.385)
Constant	-0.862**	0.0179	-0.225	-0.120	-0.180	-0.586	-0.333	-0.791
	(0.387)	(0.933)	(0.946)	(0.800)	(0.298)	(0.779)	(0.809)	-1.101
SETA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
lnsig_1	-0.702***				-1.282***			
Constant	(0.0641)				(0.0770)			
lnsig_2		-0.0895***				-0.306***		
Constant		(0.0241)				(0.0520)		
lnsig_3			-0.553***				-0.379***	
Constant			(0.0503)				(0.0591)	
lnsig_4				-0.194***				-0.251***
Constant				(0.0366)				(0.0531)

atanhrho_12	0.197***				0.0694			
Constant	(0.0573)				(0.0978)			
atanhrho_13		0.134**				0.219**		
Constant		(0.0543)				(0.0857)		
atanhrho_14			0.227***				0.436***	
Constant			(0.0623)				(0.0813)	
atanhrho_23		-0.186***						-0.307***
Constant		(0.0609)						(0.0920)
atanhrho_24			0.0310		-0.0966			
Constant			(0.0602)		(0.0910)			
atanhrho_34				0.526***		0.321***		
Constant				(0.0579)		(0.104)		
Observations	313	313	313	313	122	122	122	122

5. Conclusion

The digital revolution continues to drive transformations in global production processes. The theoretical and empirical literature emphasise the importance of (digital) capabilities and skills as critical for sustainable re-industrialisation and industrialisation of emerging and developing economies. There is, however, scant micro-level understanding of what constitutes digital capabilities, how it can be measured, and what drives digital capabilities in manufacturing firms in middle income countries. This is important given that firms with the requisite digital skills would be best placed to manage and adopt advanced digital technologies and able to commit to converting these technologies into new products. Using a unique South African digital skills survey on 435 manufacturing firms, the paper constructs novel digital capabilities indices, and examines the key determinants that influence a firm's digital capabilities and skills.

Estimating a simple seemingly unrelated regression model for four types of digital capabilities indices, our findings highlight that there is a tale of heterogeneous factors that matter for digital capabilities and transformation in South African manufacturing firms. These factors range from immediate firm-level characteristics to aspirational factors. This general finding holds even when we consider firms by size and export activity. Our findings suggest that firms that have more affinity towards the future develop and have higher digital capabilities, highlighting the importance of aspirations to the development of today's digital capabilities. The foregoing findings highlight the key role of policy in driving the digital aspirations of manufacturing firms through active and targeted digital industrial policy. The targeted interventions need to take into consideration the heterogeneity in size, composition of skills in employees and including the development of STEM skills, and infrastructure and policy effects. Our finding that heterogenous factors matter for different types of digital capabilities reinforces this viewpoint. Given these results, policy must pre-empt the different effects of policy and develop counter policies that could help to mitigate the emerging inequalities in the digital transformation.

In the context of digital-driven development, these findings raise significant issues regarding the development and implications of digital capabilities and skills. The response to the rise in digitalisation is resulting in a mixed (and in many cases uneven) uptake of advanced digital technologies. This is because advanced digital technologies are skill-biased (Matthess and Kunkel, 2020), and firms have differing levels of existing technological infrastructure and organisational capabilities. The differing abilities of firms to integrate and extract benefits from digitalised business and production models pose risks to the distribution of gains, but also inter-firm linkages (Matthess and Kunkel, 2020) further creating and widening the digital divide.

To close the digital divide, there is need for policy to shape the digital capabilities and skills ecosystem, and make sure that firms and their workers can be nurtured and be allowed to participate and learn new skills, have equal opportunities in labour markets through regulations and the benefits from digital industrialisation are fairly redistributed through tax incentives and social benefit systems, for instance, in line with the 2022 skills strategy. The findings in general also reinforce the emerging call for and the relevance of consolidated digital industrial policy in

South Africa.[4] Given that digital skills and capabilities are at the heart of the future of industrial development and transformation, an effective and consolidated digital industrial policy has the potential to drive South Africa's digital and structural transformation and catching up process and agendas. In promoting the creation and development of digital capabilities, digital industrial policy must also position firms to innovatively mobilise and use digital capabilities more effectively. The foregoing policy issues, including understanding the consequences of inequalities in digital capabilities on manufacturing industries and the contribution of digital capabilities to decent jobs and quality of work using a representative firm-level data are all possible areas of future research.

[4] See, for instance, Barnes, J., Black, A., Roberts, S. Andreoni, A., Mondliwa, P. & Sturgeon, T. 2019.Towards a Digital Industrial Policy for South Africa: A Review of the Issues.https://www.competition.org.za/idtt/digital-industrial-policy

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7. Appendices

Table 7: Specific questions and measures in the digital skills survey

Questions	Measure
On a scale from 1 to 5, to what extent would you say your company is engaging in each of the following?	a) Internal employee training and development; b) Employee training and development by business chambers, universities or others; c) Hiring employees with specific skills associated with digital technologies; d) Investment in fixed capital (machinery and equipment); e) Research, development and innovation (R, D &I)
How important are each of the following abilities when hiring an employee to work at your company?	a) Soft skills; b) Human-computer interaction skills; c) STEM abilities (science, technology, engineering and maths); d) Manual and/ or repetitive skills
Does your firm have a department responsible for research and development?	a) Yes; b) No
Which of the following activities is your company engaging in to prepare for this future (order management) technology?	a) Adapting existing technologies (retrofitting); b) Conducting initial studies or pilot experiments; c) Developing or have formal action plan or approved projects, that are not yet initiated; d) Formal action plan or projects initiated; e) Committed to invest in the technology; f) Not performing any action

Table 8: Definition of variables

Variables	Definition and measurement
Investment in technology for order management	A dummy variable that measures if the company is engaging in activities to prepare for order management technologies in the future, with 1 representing yes and 0 representing no.
Investment in technology for production management	A dummy variable that measures if the company is engaging in activities to prepare for production management technologies in the future, with 1 representing yes and 0 representing no.
Investment in technology for customer relationships	A dummy variable that measures if the company is engaging in activities to prepare for future technologies to manage relationships and communicate with customers, with 1 representing yes and 0 representing no.
Investment in technology for product devt	A dummy variable that measures if the company is engaging in activities to prepare for future technologies to manage product development, with 1 representing yes and 0 representing no.
Internal training devt	A dummy variable that measures if the company engages in internal training development, with 1 representing yes and 0 representing no.
External training devt	A dummy variable that measures if the company engages in external training development, with 1 representing yes and 0 representing no.
Employees with digital skills	A dummy variable that measures if the company has employees with digital skills, with 1 representing yes and 0 representing no.
Investment in fixed capital	A dummy variable that measures if the company is investing in fixed capital, with 1 representing yes and 0 representing no.
Hiring employees with digital skills	A dummy variable that measures if the company is employing or looks to employ workers with digital skills, with 1 representing yes and 0 representing no.
R&D department	A dummy variable that measures if the company has a Research and Development department, with 1 representing yes and 0 representing no.
R&D&I	A dummy variable that measures if the firm is engaging in Research and Development and Innovation, with 1 representing yes and 0 representing no.
Retrofitting management processes	A dummy variable that measures if the company is engaged in retrofitting of advanced management processes, with 1 representing yes and 0 representing no.

Retrofitting production processes	A dummy variable that measures if the company is engaged in retrofitting of advanced production processes, with 1 representing yes and 0 representing no.
Retrofitting product management processes	A dummy variable that measures if the company is engaged in retrofitting of advanced customer relations processes, with 1 representing yes and 0 representing no.
Retrofitting customer relations processes	A dummy variable that measures if the company is engaged in retrofitting of advanced customer relations processes, with 1 representing yes and 0 representing no.
Product devt	A dummy variable that takes value of 1 if technology firm uses is virtual development systems (such as manufacturing) or integrated data product system (such as product data management and/or product lifecycle management) and 0 otherwise.
Production management	A dummy variable that takes value of 1 if firm uses is advanced production management technologies and 0 otherwise.
Management organisation	A dummy variable that takes value of 1 if firm uses advanced management organisation technologies and 0 otherwise.
Product organisation	A dummy variable that takes value of 1 if firm uses advanced product organisation technologies and 0 otherwise.
Product devt organisation	A dummy variable that takes value of 1 if firm uses advanced product development organisation technologies and 0 otherwise.
Customer organisation	A dummy variable that takes value of 1 if firm uses advanced customer organisation technologies and 0 otherwise.
Customer relations	A dummy variable that takes value of 1 if firm's primary method of managing of production is through machine to machine(M2M) communication system and 0 if manages production is through Partially or fully automated process or Simple automation with unconnected machines.
Supplier relations	A dummy variable that takes value of 1 if firm's primary method of communicating with suppliers (to place orders) is through real-time monitoring of orders and logistics of suppliers (e.g., computer-managed inventory systems) and 0 if firm places orders manually (e.g., over the phone or via email) or through electronically using computerised systems.
Digital capabilities	A continuous variable that measures the degree of digital capabilities in a firm, computed using principal factors analyses on the polyserial correlations matrix using the oblique oblimin rotation. Based on the factor loadings, we identified four types of digital capabilities: investment and product design, process organisation, production organisation, and linkage and cooperation.

Lack capital	A dummy variable that takes value of 1 if a firm's lack of capital/funds is an obstacle to digital technology adoption.
Age (log)	Continuous variable measuring the age of firm in years (logged)
Employment (log)	Continuous variable measuring the number of employees in the firm (logged)
Export	A dummy variable that measures if the company is an exporter, with 1 representing yes and 0 representing no.
Lack of awareness and knowledge	A dummy variable that measures if the company lacks awareness and knowledge about digital technologies, with 1 representing yes and 0 representing no.
Lack digital infrastructure	A dummy variable that measures if the company indicates it lacks digital infrastructure, with 1 representing yes and 0 representing no.
Access universal broadband	A dummy variable that measures if the company indicates it has access to universal broadband, with 1 representing yes and 0 representing no.
Lack human resources	A dummy variable that measures if the company indicates it lacks access to human resources, with 1 representing yes and 0 representing no.
Long investment recovery	A dummy variable that measures if the company indicates that it lacks investment in digital technologies due to long investment recovery, with 1 representing yes and 0 representing no.
STEM skills	A dummy variable that measures if the company indicates that it has employees with STEM skills, with 1 representing yes and 0 representing no.
Digital training centres	A dummy variable that measures if the company indicates that it has access to a digital training centre, with 1 representing yes and 0 representing no.
Human computer interaction skills	A dummy variable that measures if the company indicates that it has employees with human computer interaction skills, with 1 representing yes and 0 representing no.
Capital ownership	A dummy variable that measures if the company is foreign owned, with 1 representing yes and 0 representing no.
Digital initiatives	A dummy variable that measures if the company indicates that it benefits from digital initiatives, with 1 representing yes and 0 representing no.
Network of advanced manuf firms	A dummy variable that measures if the company indicates that it is connected with manufacturing firms with advanced processes, with 1 representing yes and 0 representing no.

Efficiency and productivity	A dummy variable that takes value of 1 if a firm considers increasing efficiency and productivity important in 5-10 years from now and 0 otherwise.
Open new opportunities	A dummy variable that takes value of 1 if a firm considers opening new opportunities important in 5-10 years from now and 0 otherwise.
Customization	A dummy variable that takes value of 1 if a firm considers customizing its products important in 5-10 years from now and 0 otherwise.
Delivery times	A dummy variable that takes value of 1 if a firm considers improving its delivery times important in 5-10 years from now and 0 otherwise.
Technological leadership	A dummy variable that takes value of 1 if a firm considers becoming a technological leader important in 5-10 years from now and 0 otherwise.
ICT ecosystem	A dummy variable that measures if the company indicates that it operates in an ICT ecosystem, with 1 representing yes and 0 representing no.
Size	A categorical variable that measures firm size, with 1= large (sales value at more than R250 million); 2 = medium (sales value between R51 and R250 million); and 3= small (sales value between R11 and R50 million).