



UNIVERSITY  
OF  
JOHANNESBURG

**CCRED**

CENTRE FOR COMPETITION,  
REGULATION AND  
ECONOMIC DEVELOPMENT



# **Determinants of digital technologies' adoption in South African manufacturing: Evidence from a firm-level survey**

Elvis K. Avenyo, Jason F. Bell, and Julius Nyamwena

CCRED-IDTT Working Paper 2022/02

April 2022

The Centre for Competition, Regulation and Economic Development (CCRED) is an academic research centre housed in the School of Economics at the University of Johannesburg's College of Business and Economics. CCRED specialises in research, teaching and advisory services for government and non-governmental organisations on competition policy, industrial development and value chains in Southern and East Africa.

The Industrial Development Think Tank (IDTT) is supported by the Department of Trade, Industry and Competition (the dtic) and is housed at CCRED in partnership with the SARCHI Chair in Industrial Development at the University of Johannesburg. CCRED Working Papers contain work in progress by CCRED and IDTT researchers. They may include documentation which is not necessarily published elsewhere. CCRED Working Papers are published under the responsibility of the author(s) alone.

## About the authors

**Elvis K. Avenyo** is a Senior Researcher for the Centre for Competition, Regulation and Economic Development (CCRED) at the University of Johannesburg.

**Jason F. Bell** is a Researcher for the Centre for Competition, Regulation and Economic Development (CCRED) at the University of Johannesburg.

**Julius Nyamwena** is a Research Intern for the Centre for Competition, Regulation and Economic Development (CCRED) at the University of Johannesburg.

---

**CCRED: Centre for Competition, Regulation and Economic Development**

6 Sturdee Avenue

Rosebank, 2196

E-mail: [infoccred@uj.ac.za](mailto:infoccred@uj.ac.za) | [www.competition.org.za](http://www.competition.org.za)

CCRED publications can be downloaded free of charge from

[www.competition.org.za/publications](http://www.competition.org.za/publications)

© CCRED 2022 and the authors



**CCRED**  
CENTRE FOR COMPETITION,  
REGULATION AND  
ECONOMIC DEVELOPMENT

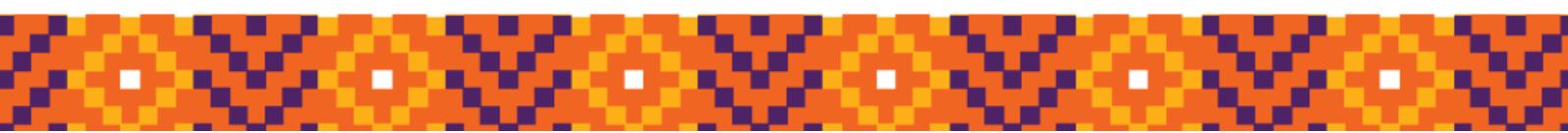


**the dtic**

Department:  
Trade, Industry and Competition  
REPUBLIC OF SOUTH AFRICA



SARCHI Chair:  
Industrial Development

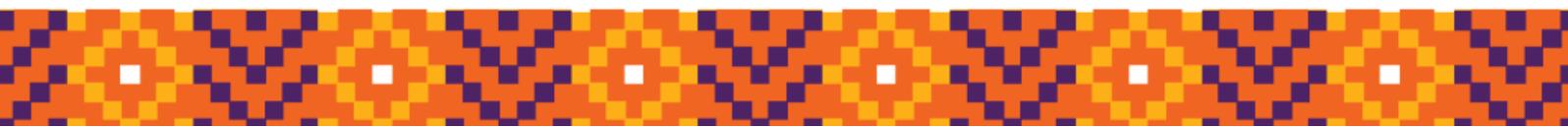


## Abstract

Digital technologies and digitalisation are emerging as the new drivers of structural transformation in developing countries. At the firm-level, the adoption of advanced digital technologies offers prospects for improved productivity and competitiveness and hence digital industrialisation. However, the determinants of adoption of digital technologies in manufacturing firms in developing countries remain anecdotal. Using unique online survey data on 516 manufacturing firms in South Africa, and a multivariate probit model, this paper examines the determinants of digital technology adoption in South African manufacturing firms. Our results show heterogeneity in the factors that explain the adoption of digital technologies across business functions. Overall, the empirical results reveal that innovation, foreign-ownership, exposure to export markets, and higher-skilled human capital push the adoption of digital technologies while the lack of capital constrains the adoption of digital technologies in our sampled firms. We discuss the possible policy implications of our findings and how they fit into the South African Digital Skills policy discourse.

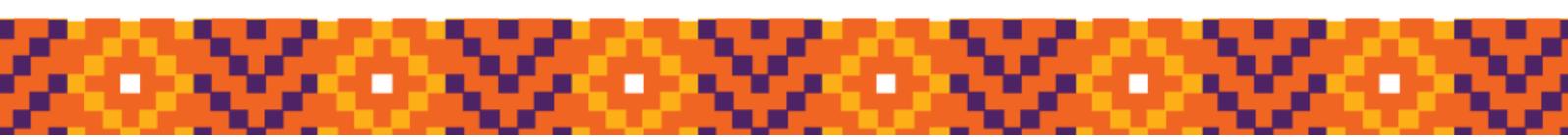
**Keywords:** Digital technology; Technology adoption; Manufacturing; South Africa

**JEL Codes:** O14



## Table of Contents

1. Introduction .....	1
2. Conceptual framework .....	3
2.1. Digital technologies and manufacturing .....	3
2.2. Digital technologies: Implications for manufacturing in developing economies .....	3
3. Methodology .....	6
3.1. Data .....	6
3.2. Empirical strategy .....	7
3.3. Basic descriptive .....	8
4. Empirical results and discussion .....	10
4.1. Evidence from firm-level survey .....	10
4.2. Determinants of technology adoption by business function .....	13
4.3. Determinants of technology adoption – complementarity of business functions... ..	18
5. Conclusions .....	19
6. References .....	20
7. Appendix.....	23
Appendix 1: Digital technology generations and business functions.....	23
Appendix 2: Definition and measurement of variables .....	24

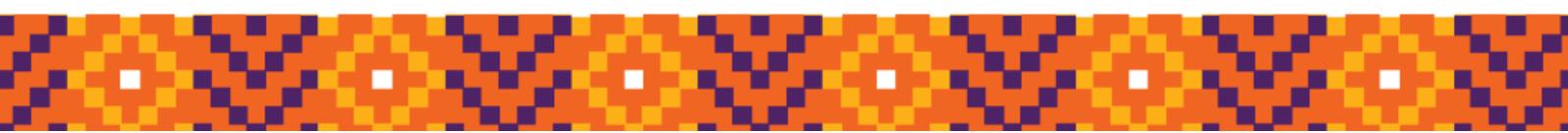


## List of figures

Figure 1: Distribution of technology adoption across business functions .....	10
Figure 2: Distribution of technology adoption across business functions by SETA.....	11
Figure 3: Firms Size and Technology Adoption .....	12

## List of tables

Table 1: Definition and descriptive statistics of key variables .....	9
Table 2: Determinants of digital technology adoption in SA manufacturing: By business function.....	15
Table 3: Determinants of digital technology adoption in SA manufacturing: Indirect mechanisms.....	17
Table 4: Determinants of digital technology in SA manufacturing: Interactions and complementarity .....	18



## 1. Introduction

The emergence of new technologies has reshaped and revolutionised industrial production and human society as a whole (Selase & Selase, 2019). Early technological innovations such as steam power, and later, computers ushered in entirely new eras of production and facilitated significant shifts in how businesses organise and conduct their operations while also broadening their reach to new markets and customers. The adoption of advanced technologies has been fundamental to both how firms and economies develop and perform.<sup>1</sup> Today, digital technologies and digitalisation are also emerging as new drivers of structural transformation. This is due to digitalisation upending traditional industries while also opening entirely new markets and influencing innovation, production, trade, consumption, and a host of business processes across industries and geographies (Barnes, et al., 2019; Andreoni, et al., 2021).

From a manufacturing perspective, the prospects and potential from the widespread diffusion and adoption of advanced digital technologies offer firms benefits that range from improved customer experiences to completely altering their existing business and organisational models for the better (Hammer, 2019, Liere-Netheler et al., 2018). The growing discussions on these new digital technological advancements (often described as Industry 4.0), driven in some degree by the Covid-19 pandemic, also allude to the potential benefits of these technologies, including increased competitiveness, and productivity among other measures of manufacturing firm performance (for instance, Barnes, et al., 2019). However, these potential benefits also come with potential costs (Baldwin & Lin, 2002). These costs may include costs of acquiring the technology, and retraining and reskilling of workers with the requisite technological and foundational capabilities to adapt and use the acquired advanced technology, among others (Baldwin and Lin, 2002; Andreoni, et al., 2021).

There is a debate on the possible implications and benefits of advanced technologies for developing countries, such as South Africa, that are experiencing de-industrialisation. The debate, in fact, heralds digitalisation and the adoption of advanced digital technologies as having the potential to reignite South Africa's ailing manufacturing sector (Barnes, et al., 2019). Studies into manufacturing sub-sectors in South Africa have referenced poor and ageing technological infrastructure as key reasons for the lagging competitiveness in global markets (see Bell et al., 2019 for an assessment of technological capabilities in the plastics industry). The country is, therefore, at an important juncture and there is an urgent need to develop policy responses to these challenges and opportunities that are promotive of the broader objective of inclusive growth. In response to this and other challenges, South African policymakers have drafted policy strategies aimed at addressing the digital gaps in many South African industries (Department of Communications and Digital Technologies, 2020).

However, most of the studies on technological change approach the issues from an industry- or sector-focused analysis (Rosenberg, 1963; Blume, 1992; Brown & Campbell, 2002). Indeed, from a South African perspective too, owing to a lack of available data, studies tend to take the shape of analyses into an industry or system (see for example Reardon, et al.,

---

<sup>1</sup> Advanced digital technologies are defined to include computer-managed inventory systems, machine to machine (M2M) communication system, big data, and artificial intelligence, i.e. Generations III and IV technologies (see Delera et al., 2022; Ferraz et al., 2020).

2004 for an investigation of agrifood systems). However, there exists a crucial gap in our knowledge of the dynamics of technological change, specifically digital technological change, at the firm-level. The related empirical literature analysing the adoption and implications of digital technologies at the firm-level in developing countries is nascent. Despite this, the evidence emerging from the scant literature suggests that the adoption of advanced digital technologies remains limited, and may not fully generate the expected gains in developing countries (Ferraz et al., 2019; Delera et al., 2022). This may be due to several factors including the inadequacy of digital skills, the wide heterogeneity in the adoption patterns of firms as well as the poor integration of firms in Global Value Chains (GVCs), among others (Delera, et al., 2022).

Given the difficulties in adopting and implementing new digital technologies in developing countries, several questions on the adoption processes, and the drivers of digital technologies in manufacturing remain unanswered in the literature.<sup>2</sup> This paper adds to this body of literature by focusing on digital technology adoption across business functions in South African manufacturing firms using knowledge gleaned from a unique online survey of firms that are classified under three manufacturing sector education and training authorities (SETAs)<sup>3,4</sup>. These include the Chemicals Industry SETA (henceforth CHIETA), the Manufacturing, Engineering and Related Services SETA (MerSETA), and the Fibre Processing and Manufacturing SETA (FP&M SETA). These sectors were chosen partly because of their role as important root industries for (digital) industrialisation. This paper contributes to this growing research by evaluating the behaviours and attitudes of manufacturing firms towards the adoption of digital technologies using micro-level data. An understanding of the ongoing changes in manufacturing due to digitalisation provides policy makers an opportunity to influence and shape the digital technology adoption behaviours of manufacturing firms in South Africa. In addition, the use of micro-level data is essential for understanding the drivers and implications of advanced digital technologies in developing countries (Delera et al., 2022).

In line with the literature, we find that the adoption of digital technologies is limited across all surveyed business functions in our data. Our empirical analysis suggests that there is some heterogeneity in the factors that explain the adoption of digital technologies across business functions in sampled manufacturing firms. Overall, the empirical results reveal that innovation, foreign-ownership, and human capital push the adoption of digital technologies while the lack of capital constrains the adoption of digital technologies in our sampled firms. In addition, we find that the negative effect of capital constraints on adoption is mitigated by exports, innovation, and human capital.

The rest of the paper proceeds as follows. Section 2 conceptualises digital technologies in developing countries, followed by the discussion of our data and empirical strategy in section 3. 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.

---

<sup>2</sup> This is in exception of Delera et al. (2022), who examined the role of value chains in the adoption of digital technologies in developing countries. However, the authors analysed the determinants of technology adoption by generations while our paper examines the determinants of digital technology adoption by business functions, thereby allowing us to identify specific factors that affect the adoption of digital technologies based on their use.

<sup>3</sup> SETAs provide information and assistance on education, skills, and training in their sectors.

<sup>4</sup> The digital skills survey encompassed 516 firms across several areas of digital technologies and skills.

## 2. Conceptual framework

### 2.1. Digital technologies and manufacturing

Globally, digital technologies are changing the landscape of many sectors. Since their full-scale introduction into many sectors of the economy, technological upgrades have been a catalyst for structural transformation dating back to the computer revolution in the 1980s. While technological breakthroughs of the past have led to many significant changes for the labour force, thereby offering some level of uncertainty about the future, they have also created growth and employment opportunities in entirely new occupations and industries and augmented production in some 'traditional' manufacturing industries (Berger & Frey, 2016).

From a manufacturing perspective, digital technologies, and more broadly digitalisation, offer the promise of increasing the productivity and global connectedness of South African manufacturing industries (Barnes, et al., 2019). The adoption of upgraded technologies can also create, and in some cases, strengthen backward and forward linkages to other domestic sectors while also facilitating growth in the quality of output in these sectors (Bell, et al., 2019). Nevertheless, there is still ongoing debate about what the adoption of improved digital technologies entails for the future of work and the manufacturing sector in the context of Industry 4.0. For instance, some authors see the coming digital revolution as a "Second Machine Age" – one where technological innovations promise to radically increase productivity in a wide range of industries, but that new technologies are also having adverse effects on particularly low- and middle-skilled workers (Brynjolfsson & McAfee, 2014). These potential social consequences of the digital revolution are echoed in Krzywdzinski, et al. (2018), who argue that while this sudden technological breakthrough may in fact have positive aggregate employment effects there are more urgent issues such as the increasing inequalities and increased alienation of the workforce through greater levels of standardisation and surveillance.

Moreover, a widespread adoption of digital technologies in manufacturing has the potential to have a massive impact on the environment. However, it is unclear whether digitalisation will have an overall positive or negative environmental impact from applications in manufacturing (Chen, et al., 2020). In terms of the benefits, digitalisation results in positive environmental sustainability through increased resource efficiency from the integration of Industry 4.0 technologies over the entire product lifecycle. The negative effects on manufacturing from rapid digitalisation come in the form of waste and emissions arising from increased energy use.

The success of the adoption of advanced digital technologies (intimately linked with Industry 4.0) is keenly linked to the ability of firms to reorient their digital infrastructure around automation, the internet of things (IoT), cloud computing, and big data and analytics. Some authors have expressed hesitance about the ability of firms to properly extract benefits. Piccarozzi, et al. (2018), for example, suggest that these technologies need to be purposefully introduced into the organisation in order to experience the benefits of Industry 4.0.

### 2.2. Digital technologies: Implications for manufacturing in developing economies

In the context of a highly competitive global marketplace where firms are competing with other firms to gain market shares, digital technologies offer developing country firms the

potential to carve out niches and offer improved products and customer service. Furthermore, digital technologies can assist firms in developing economies to expand their reach regionally and internationally, and to improve the efficiency of production and supply chain processes. Digital technologies are also creating new opportunities for smaller firms to enter into GVCs, due to lower barriers to export in the digital era, even in longer and more complex GVCs (Banga, 2019).

From the perspective of individual firms, digital technologies are expected to bring about transformation along three main avenues (Hammer, 2019). Firstly, advancements in digital technologies are believed to assist firms in developing a deeper understanding of their customers through digitally-enhanced selling, predictive marketing, analytics-based marketing and streamlining. These improvements will lead to greater synergies between customers and producers. Secondly, from the perspective of improvements in the operational process, digital technologies are seen as important catalysts for performance improvement, operational transparency and data-driven decision making while also enabling workers to work better and faster through the advancements in communication and knowledge sharing. Thirdly, and perhaps most crucially from the firm perspective, is the effects that digital technologies and digitalisation will have on their business models. Firms that readily adopt and adapt to the advancements in digital technology will be able to extract the benefits of reshaped organisational boundaries while also being able to augment their products and services.

However, our understanding of the drivers of technology (specifically, digital technologies) is less concrete. This lack of understanding of the drivers of digital technology adoption is all the more pressing given the Covid-19 pandemic, which has accelerated the push towards digitalisation as firms seek to gain efficiency and improve competitiveness in response to the upending of global supply chains. At the same time, the pandemic is highlighting the challenges of the digital divide and the lack of digital skills in many African countries (the dtic, 2018).

Moreover, while the adoption of digital technologies has the potential to bring about enormous economic and social benefits in developing countries, it is crucial to recognise that the impact of digital technologies will not be homogenous across countries, regions, cities, and firms. Therefore, developing countries are facing a two-pronged problem in the digital economy centred around persistent divides in access and use of digital technologies (Banga, 2019).

The existence of a digital divide has implications that extend beyond the productivity and competitiveness of individual firms and industries. For example, the unequal adoption of digital technologies can have ramifications that weaken the capabilities and performance of the wider industry, particularly in terms of the aforementioned ability of these developing economy firms to integrate into GVCs. Moreover, the problems associated with the digital divide also tend to be exacerbated in developing countries, particularly on the African continent. This sentiment is echoed in other case studies where there appears to be a stark digital divide between developing economies themselves.

In India for instance, the digital divide also transcends industry and sector boundaries with digital technologies and digitalisation concentrated in a few sectors such as computers and electronics, metals, pharmaceuticals, and other transport equipment (Banga, 2019). In addition to this, differing firm-level performance in response to digitalisation is very much

linked to the firm capitalising on the benefits of digitalisation of the market as referenced in a case study of Latin American firms' experiences (Sanchez-Riofrio, et al., 2021). Another study of 240 Serbian manufacturing firms found that the use of digital technologies was limited in high-technology firms. Instead, the results of the survey found that medium sized firms were greater adopters of digital technologies (Lalic, et al., 2020).

The differing experiences and heterogeneity that exists in the adoption of digital technologies among and within developing economies highlights the need for a deeper understanding of the behaviours of firms in the digital age. Of crucial importance here is the attitudes of firms and workers in the context of the potential impacts of greater adoption of evermore advanced digital technologies. For example, of the South African workers surveyed in a PwC survey of 22,000 people in 11 countries, 70% answered positively about the future impacts of digital technologies on their jobs (PWC, 2020).

This sentiment was echoed by respondents in India and China, wherein around 8 in 10 respondents answered favourably to the impact of digital technologies. European and Australian respondents were less positive about the future impacts of digital technologies on their jobs. Similarly, around 56% of the South African respondents expressed concerns about the potential risk of jobs losses from automation. Moreover, these results highlighted a stark divide between females and male workers, with female workers expressing more concerns about the risks of the impacts of future technologies.

While the results from the PwC research offer unique insights into the attitudes of individual workers to the future uptake of digital technologies, the results do not offer any insights into the attitudes of firms to digital technologies. One high-level commentary on the potential for technology as a catalyst for growth in South Africa has argued that more positive attitudes towards technology can help the economy unlock tremendous productivity gains in many sectors (Magwentshu & Rajagopaul, 2019).

The true uptake of advanced digital technologies will most likely be mixed and in many cases uneven. This is because of differing levels of existing technological infrastructure and organisational capabilities that allow some firms to adapt to advancements in digital technologies more easily. The differing abilities of firms to integrate and extract benefits from digitalised business and production models will result in the escalation of the digital divide.

These issues are likely to increase risks of exclusion of firms in developing countries from GVCs, for instance. To combat this, firms in developing economies must begin engaging with digital technologies to improve their respective capabilities. The adoption of digital technologies can act as a starting point towards igniting this process of technological catch-up in many economies whose current technological infrastructure lags well-behind those of more developed economies. Moreover, concerns should also be on the potential for digital technologies to worsen existing divides between small and large firms (Andreoni, et al., 2021). The heterogeneity stemming from differing levels of digital technology adoption, itself a function of technological infrastructure, foundational capabilities, and financial affordability, may ultimately lead to the creation of a larger digital divide (Turianskyi, 2020).

However, at this stage, there is little known about how firms from different industries operating in South Africa's current economic climate are approaching and navigating the many complexities that come with a potential overhaul of business strategies and

operations of this magnitude. Moreover, less is known about the baseline drivers of digital technology adoption in South African firms and the relative degrees and directions of their impacts. The existing literature discussing drivers of adoption offers only some useful insights, and few from a micro-level and industry analysis, into the *a priori* directions and degree of impact of these individual factors, which can combine to determine the ability of a firm to adopt digital technologies.

This research, therefore, seeks to contribute to the knowledge base by analysing the perspectives of South African firms to the adoption of digital technologies and digital skills at different industry (or SETA) levels. The specific nuances that exist between a set of industries means that tailoring approaches and policies to a given industry's experiences and plans around the adoption of digital technologies is paramount to facilitate a smooth transition into Industry 4.0. Understanding how South African firms in different industries are approaching these complex issues is essential to deepening our current knowledge on digitalisation in the South African context. This research, thus, presents the insights gained through the first iteration of the digital skills survey conducted across three South African SETAs in 2020/21.

### 3. 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 uses the digital skills survey - a first of its kind in South Africa- that drew from similar surveys in Argentina and Brazil. The South African survey was conducted in March 2021, covering 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 SETA). The survey was conducted as part of an ongoing joint project under the IDTT supported by the Department of Trade, Industry, and Competition, and as well the SETAs that govern skills training.

The 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. There are nine sections in the digital skills survey questionnaire. The first four sections examine the current and future adoption behaviours of firms in our sample across four key business functions: supplier relationship, production management, customer relations, and product development. In this paper, we use these data to measure our digital technology variable. In sections five to seven, the survey explores the technological capabilities and skills of workers, implications of technologies on firm outcomes, and the relevant factors that affect the adoption behaviours of firms. The last two sections examine the firm-level characteristics, employment, innovation, and export activities of firms between the 2017/18 and 2019/20 financial years.

We then combine the data from the survey with data obtained from the SETAs on industry, levies, size, and location characteristics of firms. These variables were used as additional controls in our analysis.

In total, the digital skills survey obtained 516 responses from all sampled firms (about 7% response rate), with MerSETA, CHIETA, and FP&M SETA firms accounting for 67%, 17% and

16% of the responses, respectively. However, after merging with the SETAs data set, we obtained and used for our analysis data on 440 firms. The drop in the number of firms is due to our inability to uniquely link information of 76 firms in the digital skills survey to that of the SETA databases. Detailed descriptive statistics of our main variables of interest are reported in section 3.3.

### 3.2. Empirical strategy

In order to separately identify and examine the determinants of digital technology adoption across different business functions for which we have good data,<sup>5</sup> we formulate three separate simple probit models as:

$$Supplier\_relations_{iqt+5} = a_0 + X_{iqt}\delta_1 + Industry_{qt}\delta_2 + \varepsilon_{iqt} \quad (1)$$

$$Customer\_relations_{iqt+5} = b_0 + X_{iqt}b_1 + Industry_{qt}b_2 + \mu_{iqt} \quad (2)$$

$$Production\_development_{iqt+5} = b_0 + X_{iqt}b_1 + Industry_{qt}b_2 + \gamma_{iqt} \quad (3)$$

where  $Supplier\_relations_{iqt+5}$ ,  $Customer\_relations_{iqt+5}$ , and  $Production\_development_{iqt+5}$  are binary variables that equal 1 if the firm plans to introduce supplier relations, customer relations, and production development disruptive technologies in firm  $i$  of industry  $q$  in time  $t+5$  respectively, and 0 if otherwise.<sup>6</sup> In the survey, firms were asked to indicate technologies they would adopt in 5-10 years. Based on this, we define digital technology adoption in  $t+5$  as firms that have indicated that they would use digital technologies in the next 5-10 years. The use of expected adoption of digital technologies in  $t+5$  is to avoid possible bidirectional causality between our dependent variables and independent variables.  $Industry_{qt}$  is a vector of industry level classification of the firm in 2019, while  $\varepsilon_{iqt}$ ,  $\mu_{iqt}$ , and  $\gamma_{iqt}$  are multivariate normally distributed error terms with 0 mean, constant variance, and correlation  $\rho_{12}$ ,  $\rho_{13}$ , and  $\rho_{23}$ .

In line with Delera et al. (2022) and Ferraz et al. (2020), we define  $X_{iqt}$  as a vector of all firm-level and location variables that may affect the probability to introduce disruptive technologies across business functions. In addition, the literature also identifies specific factors that influence the ability of a firm to adopt digital technologies. Specifically, we control for exports given that there is a noted technology premium associated with exports, and firms with exporting capabilities are more likely able to adopt new advanced digital technologies (Lee, et al., 2020; Cirera, et al., 2021; Cirillo, et al., 2021). A multitude of foundational capabilities (that extend to general skills, infrastructure and the presence of a well-functioning industrial ecosystem) influence the adoption of digital technologies (Andreoni, et al., 2021). In this regard, we also control for a host of variables such as the

<sup>5</sup> In this paper, we define digital technologies as generation 3 and 4 technologies, following UNIDO elaboration based on *Industria 2027 Survey* (IEL 2018) and on Kupfer et al. (2019). See Appendix 1 for digital technology classifications across business functions.

<sup>6</sup> The analysis excluded production management business function due to data and convergence issues.

importance of human-computer skills and science, technology, engineering and mathematics (STEM) qualifications.

Based on Baldwin and Lin (2002), we regrouped all firm-level variables into six main categories as: institution-related constraints; cost-related constraints; information-related constraints; labour-related characteristics; organisation-related characteristics; and firm characteristics. In our analysis, institution-related constraints refer to lack of adequate digital infrastructure while cost-related constraints covers lack of capital. Specifically, institutional-related constraints emerge from the operating environment while cost-related constraints pertain to the price associated with acquiring advanced technology and its adoption. Information-related constraint covers firms' lack of information and awareness about digital technologies. Organisation-related characteristics are those attributes that require firms to make internal modifications to their operations, such as innovation, export, and research and development (R&D). Firm characteristics are the general demographic variables such as age, size of the firm, capital ownership, and the SETA of the firm. Finally, and of particular interest, are the labour-related firm characteristics that cover skills of workers including issues such as the importance of general training of workers, and human-computer interaction skills for workers as well as human capital in STEM. We consider these labour-related firm characteristics as a summary of the level of skills and capabilities within the digital ecosystem of the firm or industry in question.

Given that firms may simultaneously introduce all or a combination of digital technologies for business functions under consideration, we estimate equations 1-3 with a multivariate probit model where the error terms across the different models are correlated (in line with Delera et al., 2022). In extension, we also analysed the determinants that influence the introduction of digital technologies for at least one business function. This analysis helps us to examine heterogeneity in the factors that may influence the simultaneous introduction of the digital technologies across all business functions under consideration.

To estimate our multivariate probit model simultaneously, we employ the flexible conditional mixed process (cmp) estimator framework developed by Roodman (2011). The cmp allows us to fit the three multi-probit equations in a mixed process with digital technology adoption behaviours across three different business functions that have different observations. Using the cmp framework, we conduct the analysis in a full-information maximum likelihood (FIML) where errors from all equations are correlated and normally distributed. This estimation of our equations jointly using maximum-likelihood estimation uses the full covariance matrix of the residuals across our models and is hence identified to be more efficient (Roodman, 2011).

### 3.3. Basic descriptive

Table 1 shows the definition and descriptive statistics of all variables in our model. As noted, we use data on 440 firms in our data.<sup>7</sup> Given missing observations, our data show that most of our sampled firms are small (54%), and about 25% and 21% are medium-sized and large firms respectively.<sup>8</sup> Only a small proportion of our sampled firms are fully or partly owned by

<sup>7</sup> See Table 5 in appendices for the definition and measurement of all variables.

<sup>8</sup> The size of firms were determined by annual sales value. Micro (sales valued at below R10 million per financial year), Small (sales valued at between R11 and 50 million per financial year), Medium (sales valued at between R51 and R250 million per financial year), and Large (sales valued at more than R250 million per financial year).

foreigners (about 15%). A large proportion of sampled firms export (about 45%), innovate (about 51%), are relatively old (average of 56 years since establishment), and lack financial capital (90%). In terms of human capital, about 63% of firms have employees with STEM qualifications.

**Table 1: Definition and descriptive statistics of key variables**

>	Definition	N	Mean	SD	Min	Max
<b>Digital technologies</b>						
<i>Supplier relations</i>	A dummy variable that takes value of 1 if firm's primary method of communicating with suppliers (to place orders) in 5-10 years 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.	426	.370	.483	0	1
<i>Customer relations</i>	A dummy variable that takes value of 1 if firm's primary method of managing of production in 5-10 years 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 5-10 years.	321	.140	.347	0	1
<i>Product development</i>	A dummy variable that takes value of 1 if technology firms would use in 5-10 years 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.	106	.613	.489	0	1
Human capital	A dummy variable that takes the value 1 if firm has employees with STEM qualifications and 0 otherwise.	260	.630	.483	0	1
Lack of capital	A dummy variable that takes the value 1 if firm considers the lack of capital /funds as an obstacle and 0 otherwise.	257	.898	.302	0	1
Age	A continuous variable defined as the total number of years firm has been in operation, constructed as the natural logarithm of the total number of years plus 1.	435	56.078	38.071	1	100
Capital ownership	A dummy variable that takes the value 1 if the firm is partly or fully foreign-owned, and 0 otherwise in 2019/2020 financial year.	268	.145	.353	0	1
Export	A dummy variable indicating if the firm exports (1) and 0 if otherwise in 2019/20 financial year.	270	.451	.498	0	1
Innovation	A dummy variable indicating if the firm has introduced new production process or made significant improvements to products between 2017/18 and 2019/20 financial years.	344	.508	.500	0	1
Industry	A categorical variable that shows the 20 South African industrial classifications of the firms in our sample.	435			1	20
Size of firm	A categorical variable that takes value 1 if the size of the firm is large (21%), 2 if medium (25%), 3 if small (54%) in 2019/2020 financial year.	435			1	3
Province	A categorical variable that assumes a value between 1 and 9 indicating the province in which firm is located.	435			1	9

Our data further show that out of 426 firms that responded to the question on the adoption of advanced digital technologies for supplier relations, about 37% indicated that they would use digital technologies in the next 5-10 years. For customer relations and product development, we find 14% and 61% future adoption of advanced digital technologies rates respectively. These suggest some level of heterogeneity in the expected adoption of digital technologies across the three business functions in our data in the next 5-10 years. Given that the decision to adopt advanced digital technologies is dependent on the expected net benefits (Baldwin and Lin, 2002), we examine the specific factors that drive advanced digital technologies adoption and the observed heterogeneity across business functions.

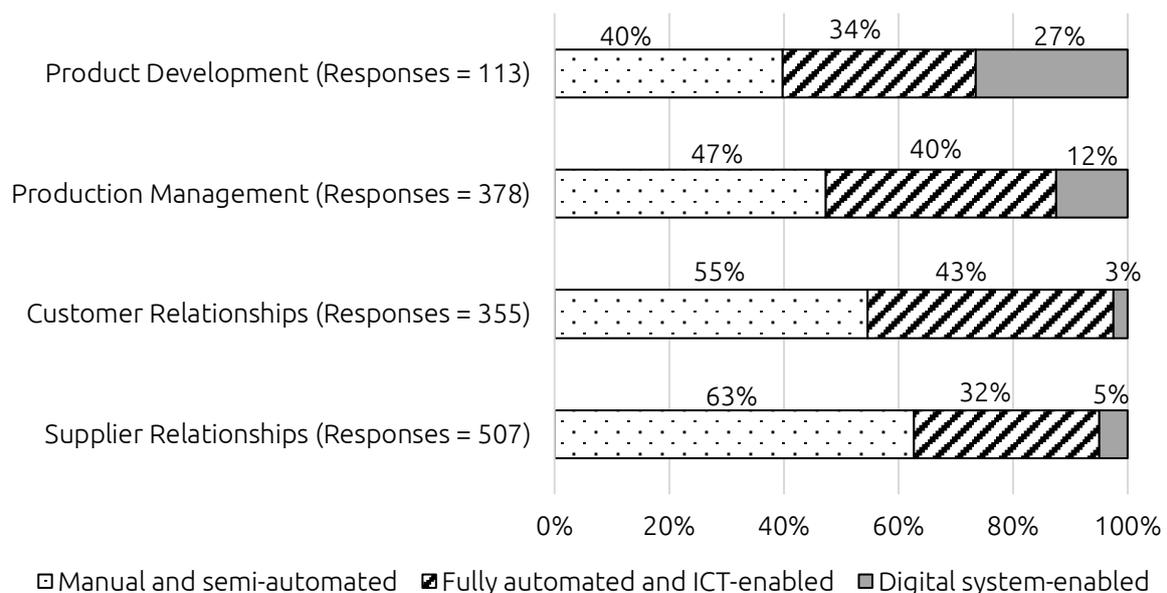
## 4. Empirical results and discussion

This section presents and discusses the evidence from our online survey data for all business functions (section 4.1), and the econometric analysis where we examine the determinants of technology adoption across three business functions (supplier relationships, customer relationships, and product development) in sections 4.2 and 4.3. In the empirical estimation, we first estimate, separately, probit models for each business function, followed by our preferred model – multivariate probit - where we jointly estimate all three equations as a seemingly unrelated regression (SUR). All correlations are heteroskedasticity-robust.

### 4.1. Evidence from firm-level survey

Here, we first provide basic graphical representations and description of some of the variables in our data. Figure 1 shows the distribution by types of technologies firms employ in the four respective business functions. Of the firms surveyed, there is some level of heterogeneity in their technological infrastructures with some business functions displaying greater affinity towards fully-automated, ICT-enabled and digital-enabled systems (Figure 1). The production management business function, for example, displays the highest degree of technological heterogeneity while the supplier and customer relationship business functions display the least technological heterogeneity.

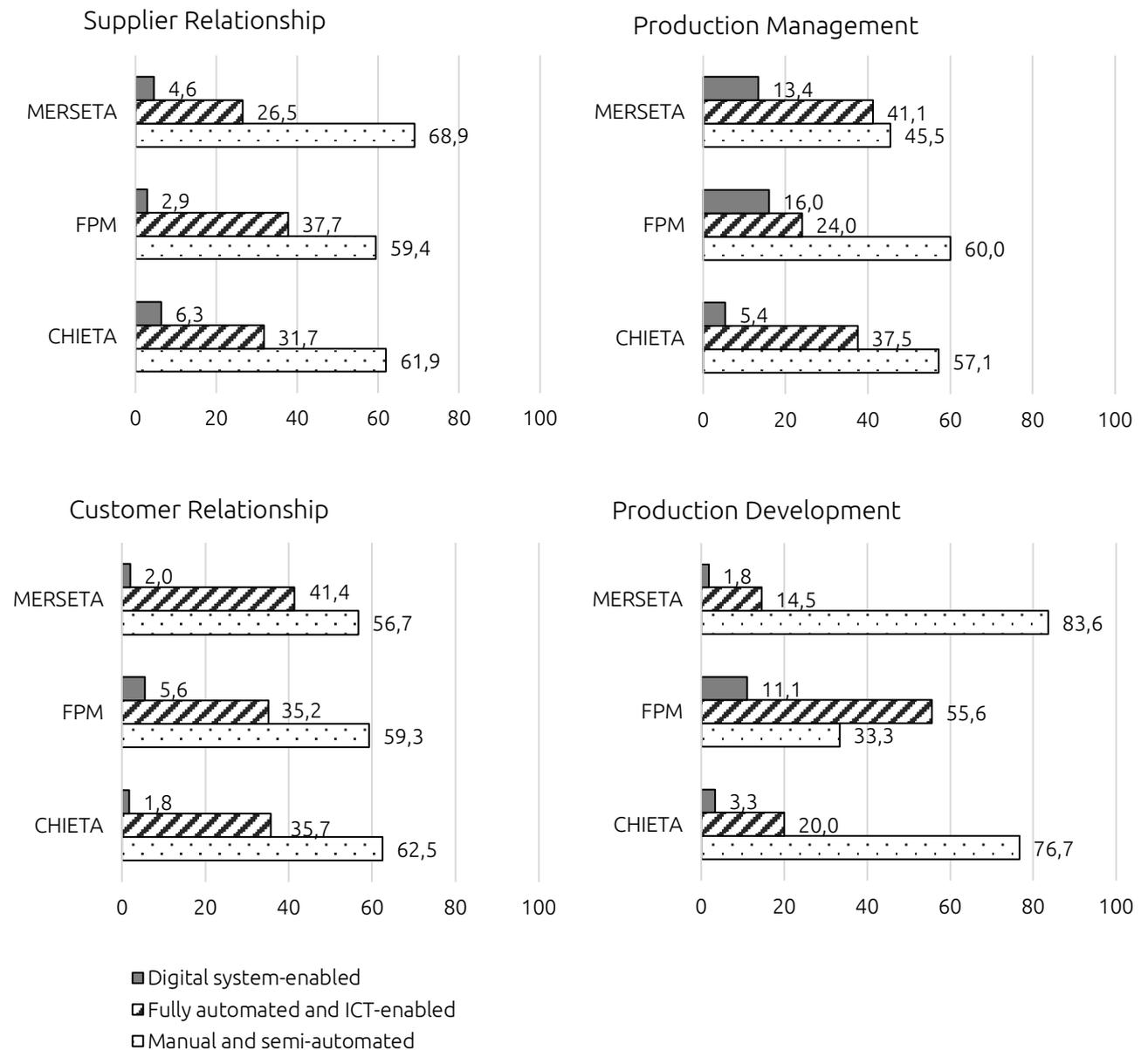
Figure 1: Distribution of technology adoption across business functions



Source: Authors

The current rate of technology adoption across the three SETAs within business functions shows that technology is concentrated in manual and semi-automated processes (Figure 2). Among the three SETA groupings, MerSETA's surveyed firms appear to have the highest affinity toward advanced levels of technology. However, this finding appears to be specific to the production management business function with at least 54% of its processes are fully-automated and ICT-enabled, or digitally-enabled. On the other hand, across the three business functions, MerSETA's surveyed firms are overwhelmingly dependent on manual and semi-automated processes.

Figure 2: Distribution of technology adoption across business functions by SETA

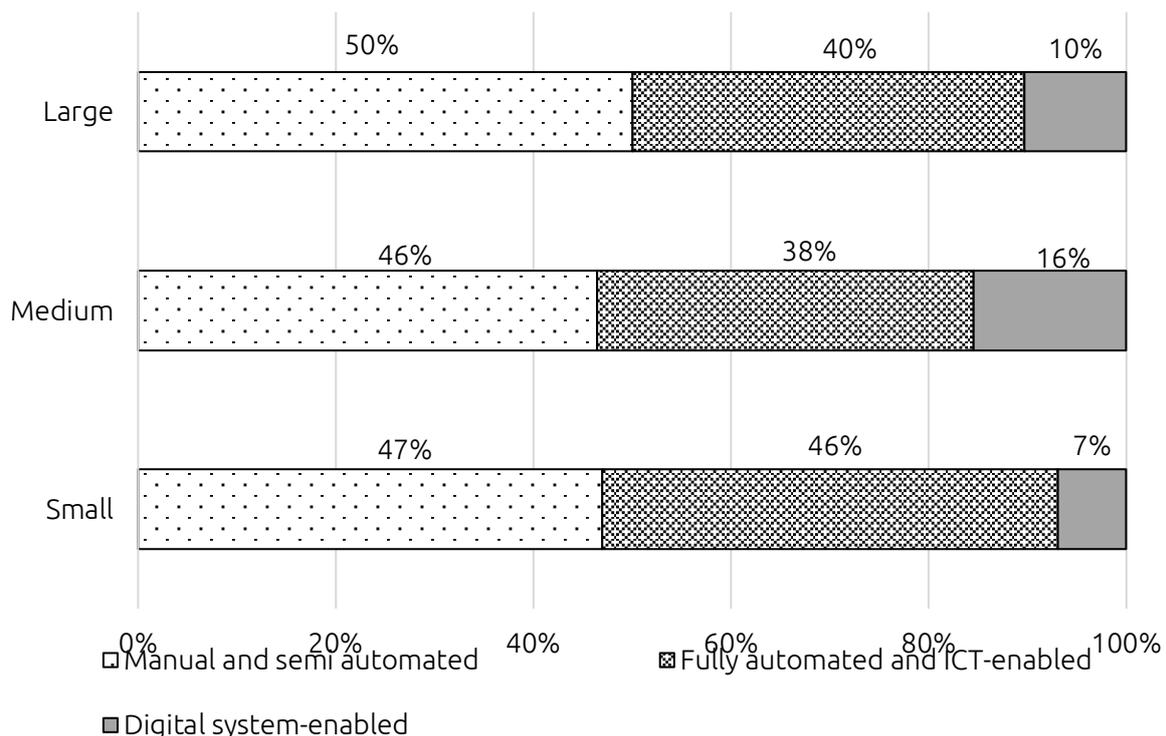


Source: Authors

The FP&M SETA's surveyed firms displays slightly less heterogeneity than MerSETA with, on average, a majority of its product development business function employing fully-automated and ICT-enabled technologies (66.7%). However, this uptake of advanced technology is seemingly only occurring in isolated pockets as the other three business functions of FP&M SETA's firms' employ manual and semi-automated processes and technologies most often on average. CHIETA's technological infrastructure, according to the surveyed firms, is the least technologically advanced across all business functions with CHIETA firms subjectively reporting to be conducting their operations across all of the four business functions with manual and semi-automated technologies, displaying the least heterogeneity across the three SETAs.

Evaluating the current technological infrastructure across firms according to size is critical to understanding the technological adoption and innovation affinity in future (Figure 3). It further offers explanatory power for how differing degrees of technological heterogeneity might affect the industries and SETA groupings dominated by a specific size of firm. From the surveyed firms, the vast majority (85%) classified themselves as either micro, small, or medium-sized enterprises. There are, however, significant variations and nuances within and across these different firm size classifications in terms of their respective affinity towards, and ability to engage in, technological upgrading.

**Figure 3: Firm size and technology adoption**



Source: Authors

Notes: Small - Sales valued at between R11 and R50 million in the 2019/20 financial year, Medium - Sales valued at between R51 and R250 million 2019/20 financial year, and Large - Sales valued at more than R250 million 2019/20 financial year.

Based on our sample, all firms display some technological heterogeneity with medium and large firms having the most diverse technological infrastructure. Small firms display the least heterogeneity and affinity towards the adoption of sophisticated technology infrastructures when compared strictly to medium and large firms. This could be due several reasons that are specific to the exact nature of these small firms and the specific business or industry in which they operate. If an expanded grouping combining both fully-automated, ICT-enabled, and digital-enabled systems is taken, all the firms across all sizes display high affinity towards technology adoption in their current operations. However, at this high-level, there is little nuance and depth of understanding about the technology adoption habits of different sizes of firms.

#### **4.2. Determinants of technology adoption by business function**

Table 3 reports the estimation results from our probit (columns 1-3) and multivariate probit (4a-4c) estimation procedures. The correlation coefficients of the error terms ( $\text{atanhrho}_{12}$ ,  $\text{atanhrho}_{13}$ , and  $\text{atanhrho}_{23}$ ) across all the three equations are positive and statistically significant (see column 4a). This highlights the importance of estimating the three equations as a SUR rather than separate probit models. Based on this, we proceed to interpret and to discuss the results from the multivariate probit estimation (columns 4a-4c).

The basic estimation results showing the determinants of digital technologies across the three business functions are reported in Table 3. Our results show that a mix of factors influence the adoption of digital technologies across the three business functions under consideration. For all business functions, our results identify cost-related constraints as key determinants of digital technology adoption in our sampled firms. Specifically, we find that the lack of financial capital negatively affects the likelihood to adopt digital technologies for supply relations and customer relations business functions, suggesting that the technologies for these business functions and their adoption are cost-intensive. Our results also suggest that organisation-related characteristics such as investments in R&D matter for the likelihood to adopt advanced technologies for supply relations while innovation is found to matter for customer relations. These suggest the important roles of innovation activities and investment in capabilities in the adoption of new digital technologies, in line with Delera et al. (2022).

Contrary to our expectations, our results show that institution-related constraints (specifically lack of infrastructure) and labour-related constraints such as the lack of digital training centres tend to lead to a higher probability to adopt supplier relations and customer relations digital technologies respectively. These suggest that institution-related and labour-related constraints force firms to invest in in-house training and infrastructure leading to higher levels of digital technology adoption. Firms may also require bespoke technological systems for supplier-related and customer-related technologies, hence higher levels of investment and digital technology adoption. This is in contrast with product development where labour-related constraints such as lack of human computer interaction skill reduces the likelihood to adopt digitalisation. Firms with skilled human capital – firms with higher proportions of employees with STEM qualifications – are identified to have a higher likelihood to adopt customer relations digital technologies in SA manufacturing firms, suggesting the importance of emphasising the generation of STEM skills in the labour force. Also, these results highlight the importance of ‘foundational’ capabilities (Andreoni, et al., 2021) in fostering the adoption of new digital technologies.

For product development, our analysis shows that older firms tend to have a higher likelihood to introduce digital technologies while manufacturing firms with foreign ownership tend to have a higher likelihood to adopt digital technologies for supply relations and customer relations business functions, suggesting the key role of experience and foreign linkages in (stimulating) digitalisation of production processes. The result that foreign ownership of capital enhances the adoption of digital technologies is in contrast with the findings by Delera et al. (2022), who found a negative but statistically insignificant effect.

To understand the possible indirect mechanisms that may influence the determinants of adoption, we interact the main variables of interest: export, innovation, lack of capital, and capital ownership. Our results are reported in Table 4. For supplier relations, our results show that firms with lack of capital tend to have a lower likelihood to adopt digital technologies, but this negative effect is mitigated in firms that have skilled human capital. That is, having a STEM employee in a firm moderates the negative effect that lack of capital generates on the digital technology adoption behaviours of firms. We find similar indirect mechanisms between lack of capital and human capital when we consider customer relations and product development business functions. We do not find other indirect mechanisms for supplier relations.

In addition, our results show that skilled human capital tends to enhance exporting firms' likelihood to adopt customer related digital technologies, while it enhances innovative firms' ability to adopt product development oriented digital technologies. Also, our results show that firms that export products but lack capital tend to have a higher likelihood to adopt product development digital technologies than those that do not export, suggesting the importance of the participation in international markets in the adoption of advanced digital technologies. The favourable adoption behaviours of these firms may be due to the revenue and/or the knowledge generated from selling in international markets.

In sum, our results suggest that firms that possess a certain level of internal (skills and innovation) and external (foreign-ownership and exports) 'foundational' capabilities tend to have a higher likelihood to adopt digital technologies. In line with the literature, our findings corroborate the evidence that foundational capabilities are crucial in fostering the adoption of new digital technologies at the firm-level (Andreoni, et al., 2021).



Table 2: Determinants of digital technology adoption in SA manufacturing: By business function

	(1)	(2)	(3)	(4a)	(4b)	(4c)
	Probit			Multivariate probit		
	Supplier relations	Customer relations	Product development	Supplier relations	Customer relations	Product development
Age (log)	0.120 (0.90)	-0.128 (-0.69)	0.290 (0.62)	0.0966 (0.74)	-0.189 (-0.99)	0.591* (1.90)
Size- medium	-0.0748 (-0.23)	-0.298 (-0.66)	-0.0919 (-0.10)	-0.0275 (-0.09)	0.0151 (0.03)	-0.440 (-0.44)
Size- small	-0.254 (-0.89)	-0.531 (-1.31)	3.653** (2.54)	-0.247 (-0.86)	-0.245 (-0.56)	0.627 (0.70)
Export	0.287 (1.21)	0.128 (0.42)	0.226 (0.37)	0.318 (1.33)	0.138 (0.43)	0.0868 (0.17)
Innovation	0.374 (1.57)	1.111*** (3.71)	0.399 (0.53)	0.371 (1.59)	0.678** (2.38)	0.473 (0.93)
Lack capital	-1.376*** (-2.78)	-1.882*** (-3.54)	-1.400 (-1.40)	-1.112** (2.50)	-1.352*** (2.59)	-0.339 (-0.33)
Lack awareness	0.138 (0.46)	0.00902 (0.02)	-0.833 (-0.88)	-0.0620 (-0.21)	-0.161 (-0.43)	-0.232 (-0.35)
Lack digital infrastructure	0.575* (1.85)	0.0477 (0.13)	4.999*** (2.72)	0.527* (1.75)	-0.0399 (-0.10)	1.507 (1.59)
RD&I- Initial	1.294** (2.08)	-0.725 (-1.10)		1.109** (2.04)	-0.212 (-0.30)	
RD&I- Approved	1.739*** (2.76)	1.149* (1.88)	2.968** (2.36)	1.487*** (2.72)	0.870 (1.21)	0.234 (0.27)
RD&I- Execution	1.603*** (2.61)	0.287 (0.47)	0.468 (0.32)	1.427*** (2.68)	0.187 (0.26)	1.820 (1.05)
Human capital	0.442 (0.72)	3.072*** (2.94)	7.006** (2.38)	0.492 (0.80)	1.882* (1.96)	3.355 (1.40)
Training centre- indifferent	-0.0763 (-0.08)	8.008*** (4.75)		-0.337 (-0.40)	1.960* (1.81)	
Training centre-	0.620	7.117***	-4.038	0.309	1.339	-1.232

important						
	(0.71)	(4.04)	(-0.51)	(0.40)	(1.36)	(-1.00)
Human-computer skills_ indifferent	0.626	-1.254	-3.408***	0.225	-0.674	-2.000**
	(0.99)	(-1.59)	(-2.79)	(0.38)	(-0.93)	(-2.34)
Human-computer skills_ important	1.077*	-0.257		0.649	-0.0384	
	(1.85)	(-0.38)		(1.20)	(-0.06)	
Capital ownership	0.751**	0.971***	0.956**	0.741**	0.845**	0.953
	(2.32)	(2.65)	(2.48)	(2.42)	(2.30)	(1.02)
atanhrho_12 _cons				0.476*** (3.00)		
atanhrho_13 _cons				0.0502** (2.13)		
atanhrho_23 _cons				0.0239** (2.38)		
pseudo $R^2$	0.257	0.307	0.636			
$N$	212	188	63	212		

*t* statistics in parentheses; \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Note: All regressions include sector and province controls, and all coefficients are probit regression coefficients.

Table 3: Determinants of digital technology adoption in SA manufacturing: Indirect mechanisms

Multivariate probit	(1a)	(2a)	(3a)	(4a)	(1b)	(2b)	(3b)	(4b)	(1c)	(2c)	(3c)	(4c)
	Supplier relations				Customer relations				Product development			
Export	0.342 (1.42)	0.319 (1.34)	1.685 (1.36)	0.0548 (0.06)	0.164 (0.57)	0.137 (0.48)	1.316* (-1.95)	1.742** (-2.18)	0.0838 (0.16)	0.496 (1.00)	1.836 (0.58)	1.486 (1.35)
Innovation	0.385 (1.63)	0.361 (0.33)	0.339 (1.46)	0.373 (1.60)	0.659** (2.55)	2.587 (1.57)	0.763** (2.50)	0.756** (2.76)	0.470 (0.93)	1.980** (1.98)	0.577 (1.10)	0.679 (0.91)
Lack capital	-1.866* (-1.84)	-1.113** (-2.53)	-1.133*** (-2.59)	-0.843 (-1.28)	-1.077* (-1.95)	-1.325*** (2.95)	-1.353** (2.44)	-1.122** (2.11)	-0.343 (-0.36)	-0.113 (-0.10)	-0.332 (-0.30)	-3.863** (2.33)
Human capital	0.994* (-1.93)	0.488 (0.62)	0.255 (-0.34)	0.486 (0.79)	3.111 (-1.23)	1.017 (0.95)	0.303 (0.24)	0.277 (0.24)	3.350 (1.54)	8.167 (1.39)	4.183 (1.37)	4.218 (0.91)
Capital ownership	0.734** (2.34)	0.741** (2.39)	0.771** (2.46)	0.732** (2.36)	0.832** (2.44)	0.858*** (2.63)	0.944** (2.52)	0.933** (2.75)	0.953 (1.14)	0.813 (0.88)	0.871 (0.92)	1.393 (1.48)
Human capital * Lack capital	0.548** (2.14)				1.043* (1.94)				1.133** (2.59)			
Human capital *Innovation		0.0111 (0.01)				1.975 (1.22)				1.378* (1.79)		
Human capital *Export			2.018 (1.64)				0.437** (2.11)				-1.721 (-0.57)	
Lack capital*Export				0.413 (0.45)				0.381 (0.45)				1.876*** (-2.72)
N	212	212	212	212								

*t* statistics in parentheses; \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Note: Table controlled for same set of variables as presented in Table 3, and all coefficients are probit regression coefficients.

### 4.3. Determinants of technology adoption – complementarity of business functions

As discussed above, firms can adopt digital technologies for one or more business functions. To analyse the determinants of the possible complementary adoption of technologies for either one of the business functions under consideration, we constructed a new dependent variable as a dichotomous dummy (1 if the firm adopted digital technologies for at least two business function and 0 otherwise). Our empirical results using the new dependent variable are reported in Table 4.

Column 1 examines the determinants of digital technology adoption using our new construct. Columns 2-5 introduce interaction terms to examine possible indirect factors that influence adoption of digital technologies. In all, our results are similar to our previous findings with R&D, lack of digital infrastructure, human capital, human competitive skills, and capital ownership emerging as the key determinants of digital technology adoption.

**Table 4: Determinants of digital technology in SA manufacturing: Interactions and complementarity**

Multivariate probit	(1)	(2)	(3)	(4)	(5)
	Supplier_customer_product				
Age (log)	0.0159 (0.11)	0.0159 (0.11)	0.00656 (0.04)	0.0116 (-0.08)	0.0435 (0.28)
Size- medium	-0.0234 (-0.07)	-0.0234 (-0.07)	-0.0151 (-0.05)	-0.0715 (-0.21)	-0.0243 (-0.07)
Size- small	0.194 (0.63)	0.194 (0.63)	0.250 (0.81)	0.128 (0.42)	0.302 (0.95)
Export	0.0420 (0.17)	0.0420 (0.17)	0.0449 (0.18)	1.639** (1.99)	1.048** (2.09)
Innovation	0.313 (1.28)	0.312 (1.28)	-0.451 (-0.30)	0.263 (1.08)	0.330 (1.32)
Lack capital	-0.520 (-1.12)	-7.987 (-1.57)	-0.774 (-1.39)	-0.635 (-1.38)	-2.219** (-2.52)
Lack awareness	0.346 (1.15)	0.346 (1.15)	0.366 (1.21)	0.356 (1.19)	0.306 (1.03)
Lack digital infrastructure	0.980* (1.95)	0.980* (1.95)	0.908* (1.83)	0.806 (1.57)	0.981* (1.94)
RD&I- Initial	1.826*** (3.67)	1.826*** (3.67)	1.700*** (3.48)	1.850*** (3.61)	1.945*** (3.85)
RD&I- Approved	1.441*** (3.06)	1.441*** (3.06)	1.418*** (3.03)	1.388*** (2.88)	1.486*** (3.18)
RD&I- Execution	0.793** (2.47)	0.793** (2.46)	0.841*** (2.62)	0.783** (2.43)	0.858** (2.56)
Human capital	1.141* (1.82)	7.938*** (11.12)	0.580 (0.69)	0.0799 (0.11)	1.227* (1.91)
Training centre- indifferent	-0.596 (-0.82)	-0.595 (-0.82)	-0.705 (-0.98)	-0.628 (-0.88)	-0.620 (-0.83)
Training centre- important	-0.194 (-0.31)	-0.194 (-0.31)	-0.301 (-0.49)	-0.0754 (-0.13)	-0.263 (-0.41)
Human-computer skills_	0.710	0.710	0.723	0.839	0.754

indifferent					
	(1.06)	(1.06)	(1.11)	(1.21)	(1.09)
Human-computer skills_important	1.315**	1.315**	1.271**	1.318**	1.297**
	(2.15)	(2.15)	(2.12)	(2.10)	(2.06)
Capital ownership	1.650***	1.650***	1.665***	1.771***	1.864***
	(3.43)	(3.43)	(3.32)	(3.36)	(3.60)
Human capital * Lack capital		6.797***			
		(-16.04)			
Human capital *Innovation			1.268		
			(1.05)		
Human capital *Export				2.759**	
				(2.05)	
Lack capital*Export					2.148**
					(-2.05)
pseudo $R^2$		0.328	0.333	0.343	0.339
$N$		212	212	212	212

*t* statistics in parentheses; \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Note: All regressions include sector and province controls, and all coefficients are probit regression coefficients.

The additional analyses (columns 2-5) identify that the adoption behaviours of firms are influenced by similar indirect mechanisms that were identified in the previous section: firms with capital constraints tend to adopt digital technologies if they have STEM employees; firms that export tend to have a higher likelihood to adopt digital technologies if they have STEM employees; firms that have capital constraints have a higher likelihood to adopt digital technologies if they export. These findings suggest that human capital (STEM employees) on the one hand and export activities on the other hand, mitigate the negative effect of capital constraints while human capital reinforces the positive effect of exporting on digital technology adoption in our sampled manufacturing firms.

## 5. Conclusions

Digital technologies and digitalisation are fundamental to structural transformation and industrialisation of middle-income countries. However, the literature on the factors that affect the adoption of digital technologies remain nascent and anecdotal, particularly in developing countries such as South Africa. This paper contributes to this growing literature on digital industrialisation by analysing the determinants of advanced digital technology adoption in South African manufacturing firms, using unique firm-level data on three SETAs covering 516 manufacturing firms, and a simple multivariate probit model for the empirical analysis.

Our findings highlight the key drivers of digital technologies adoption in our sampled manufacturing firms in South Africa. Our results identify lack of capital, and lack of digital infrastructure as the main factors that inhibit the adoption of digital technologies while human capital, foreign ownership of capital, exporting, and innovation enhance adoption of digital technologies. However, these factors are identified to affect firms' digital technology adoption across business functions differently. These findings are important baseline results

that confirm the evidence from other countries and existing qualitative/case study-based evidence from South Africa.

The findings bring some level of awareness of what determines the adoption of digital technologies in South Africa, and as a result, have the potential to influence policy discussions on the specific firm- and industry-level characteristics that drive digital transformation in South African manufacturing. Based on the findings, for instance, we find that there exists heterogeneity in the factors affecting the adoption of digital technologies across business functions. In light of this finding, we suggest the need for targeted policy actions for specific functions of firms, rather than blanket sector-based digital policies, to resolve the diverse array of constraints firms face in the adoption of digital technologies. This is confirmed by the empirical literature that also identifies heterogeneity in similar constraints across industries and different categories of firms.

In promoting the adoption of digital technologies in manufacturing firms, our findings also highlight the need for the development of targeted 'foundational' capabilities in STEM skills across different firms and industries. Policy and relevant skill-based institutions could help to promote the re-training and re-skilling of employees to meet the human capital demand for digital transformation. Deliberate policies that enable 'local' manufacturing firms to collaborate and leverage on the experience and know-how of foreign-owned firms, for instance, are critical. Collaborations between foreign-owned firms and lead-local firms can help to shape a new "industrial ecosystem" in which the opportunities of digital industrialisation can be fully captured.

Given that the area of research is in its early stages, several aspects of our paper can be extended. For instance, the analysis of the industry and size of firm heterogeneities in digital technologies adoption are natural extensions of the paper. Also, our data is not representative of the SETAs we considered and hence our conclusions cannot be generalised to the SETAs and/or the manufacturing sector in South Africa. A follow-up survey that covers a representative sample of manufacturing firms across SETAs would provide a more useful data and evidence for policy. Despite these caveats, the paper provides first-level empirical evidence that has the potential to stir the conversation around digitalisation in manufacturing, but also provide evidence-based direction towards digital technologies and skills policy in South Africa.

## 6. References

- Andreoni, A., Chang, H. & Labrunie, M., 2021. Natura Non Facit Saltus: Challenges and Opportunities for Digital Industrialisation Across Developing Countries. *The European Journal of Development Research*.
- Baldwin, J. & Lin, Z., 2002. Impediments to advanced technology adoption for Canadian manufacturers. *Research policy*, 31(1), pp. 1-18.
- Banga, K., 2019. Digital technologies and "value" capture in global value chains: Empirical evidence from Indian manufacturing firms (No. 2019/43). *WIDER Working Paper*.
- Barnes, J., Black, A. & Roberts, S., 2019. *Towards a Digital Industrial Policy for South Africa: A Review of the Issues*, Rosebank: Industrial Development Think Tank (IDTT).
- Beck, T. & Demirguc-Kunt, A., 2006. Small and medium-size enterprises: Access to finance as a growth constraint. *Journal of Banking & finance*, 30(11), pp. 2931-2943.

- Bell, J., Mondliwa, P. & Nyamwena, J., 2019. Technological change and productive capabilities in the plastics industry. *CCRED Working Paper 2/2019*.
- Berger, T. & Frey, C., 2016. *Structural transformation in the OECD: Digitalisation, deindustrialisation and the future of work*, s.l.: OECD.
- Blichfeldt, H. & Faullant, R., 2021. Performance effects of digital technology adoption and product & service innovation—A process-industry perspective. *Technovation*.
- Blume, S., 1992. *Insight and industry: on the dynamics of technological change in medicine*. s.l.:MIT Press.
- Brown, C. & Campbell, B., 2002. The impact of technological change on work and wages. *Industrial Relations: A Journal of Economy and Society*, 41(1), pp. 1-33.
- Brynjolfsson, E. & McAfee, A., 2014. *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. s.l.:WW Norton & Company.
- Chen, X., Despeisse, M. & Johansson, B., 2020. Environmental sustainability of digitalization in manufacturing: A review. *Sustainability*, Volume 24, p. 12.
- Cirera, X., Cruz, M., Davies, E., Grover, A., Leonardo, L., Lopez, C, Jose,E., Medvedev, D., Okechukwu,M., Franklin, N., Gaurav, R.O. & Santiago,T.J., 2021. Policies to Support Businesses through the COVID-19 Shock : A Firm-Level Perspective. Policy Research Working Paper;No. 9506. World Bank, Washington, DC. © World Bank.  
<https://openknowledge.worldbank.org/handle/10986/35012> License: CC BY 3.0 IGO.
- Cirillo, V., Fanti, L., Mina, A. & Ricci, A., 2021. Digitalizing firms: Skills, work organization and the adoption of new enabling technologies (No. 2021/04). *LEM Working Paper Series*.
- Delera, M., Pietrobelli, C., Calza, E. & Lavopa, A., 2022. Does value chain participation facilitate the adoption of Industry 4.0 technologies in developing countries?. *World Development*, Volume 152.
- Department of Communications and Digital Technologies, 2020. *National digital and future skills strategy*, s.l.: s.n.
- Ferraz, J. C., Kupfer, D., Torracca, J. & Britto, J.N.P.,2020. ‘Snapshots of a state of flux: how Brazilian industrial firms differ in the adoption of digital technologies and policy
- Fowowe, B., 2017. Access to finance and firm performance: Evidence from African countries. *Review of development finance*, 7(1), pp. 6-17.
- Hammer, M., 2019. Digitization perspective: impact of digital technologies in manufacturing. In: *Management Approach for Resource-Productive Operations*. Gabler, Wiesbaden: Springer, pp. 27-68.
- Kuntchev, V., Ramalho, R., Rodríguez-Meza, J. & Yang, J., 2012. What have we learned from the Enterprise Surveys regarding access to finance by SMEs. *Enterprise Analysis Unit of the Finance and Private Sector Development, The World Bank Group*.
- Lalic, B., Marjanovic, U., Rakic,S., Pavlovic, M.,Todorovic,T. & Medic,N., 2020. Big data analysis as a digital service: evidence form manufacturing firms. In: *Proceedings of 5th International Conference on the Industry 4.0 Model for Advanced Manufacturing* . s.l.:Springer, Cham, pp. 263-269.
- Lee, K., Malerba, F. & Primi, A., 2020. The fourth industrial revolution, changing global value chains and industrial upgrading in emerging economies. *Journal of Economic Policy Reform*, 23(4), pp. 359-370.

- Lee, Y., Falahat, M. & Sia, B., 2020. Drivers of digital adoption: a multiple case analysis among low and high-tech industries in Malaysia. *Asia-Pacific Journal of Business Administration*.
- Krzywdzinski, M., Gerber, C. & Evers, M., 2018. The social consequences of the digital revolution. *Le grandi questioni sociali del nostro tempo: a partire da Luciano Gallino*, pp. 101-120.
- Magwentshu, N. & Rajagopaul, A., 2019. *How to harness technology for growth in South Africa*. [Online]  
Available at: <https://www.mckinsey.com/featured-insights/middle-east-and-africa/how-to-harness-technology-for-growth-in-south-africa>  
[Accessed 14 October 2021].
- Mustafa, H. & Yaakub, S., 2018. Innovation and technology adoption challenges: impact on SMEs' company performance. *International Journal of Accounting*, 3(15), pp. 57-65.
- Piccarozzi, M., Aquilani, B. & Gatti, C., 2018. Industry 4.0 in management studies: A systematic literature review. *Sustainability*, 10(3821).
- PWC, 2020. *Fear of automation greatest among those getting fewest opportunities to upskill*. [Online]  
Available at: <https://www.pwc.co.za/en/press-room/digital-skills.html>  
[Accessed 14 October 2021].
- Rodrik, D., 2018. New technologies, global value chains, and developing economies (No. w25164). *National Bureau of Economic Research*.
- Rosenberg, N., 1963. Technological change in the machine tool industry, 1840–1910. *The journal of economic history*, 23(4), pp. 414-443.
- Sanchez-Riofrio, A., Lupton, N. & Rodríguez-Vásquez, J., 2021. Does market digitalization always benefit firms? The Latin American case. *Management Decision*.
- Selase, A. & Selase, A., 2019. The Pros and Cons of Adopting Technology as a Business Pilot: Global Perspective. *Indian Journal of Finance and Banking*, 3(2), pp. 1-4.
- Skare, M. & Soriano, D., 2021. How globalization is changing digital technology adoption: An international perspective. *Journal of Innovation & Knowledge*.
- the dtic, 2018. *Industrial Policy Action Plan IPAP 2018/19-2020/21*, Pretoria: dtic.
- Turianskyi, Y., 2020. *COVID-19: Implications for the 'digital divide' in Africa*. [Online]  
Available at: <https://saiia.org.za/research/covid-19-implications-for-the-digital-divide-in-africa/>  
[Accessed 29 September 2021].
- Yildiz, O., Bozkurt, Ö., Kalkan, A. & Ayci, A., 2013. The relationships between technological investment, firm size, firm age and the growth rate of innovational performance. *Procedia-Social and Behavioral Sciences*, Volume 99, pp. 590-599.

## 7. Appendix

### Appendix 1: Digital technology generations and business functions

Generations of digital technologies		Business function				
		Supplier relationship	Product development	Production management	Client relationship	Business management
G 4.0	Fourth generation: smart production	Real time web-based relation	Virtual development systems (such as manufacturing)	Machine-to-machine system, robots, augmented reality, additive manufacturing	Client relationship based online monitoring product use (such as artificial intelligence in customer services)	Business management supported by big data analytics
	Third generation: integrated production	Digital system for processing orders, stocks and payments	Integrated data product system (such as product data management and/or product lifecycle management) Computer-aided design and computer-integrated manufacturing, computer-aided engineering, computer-aided process planning	Computerised process execution system	Internet based support for sales and after services (such as mobile app, customer data analytics)	Integrated platform to support decision making (such as advanced enterprise resource planning)
G 2.0	Second generation: lean production	Automated electronic transmission of orders (such as email)	Stand-alone computer-aided design	Partially or fully integrated computer-aided manufacturing	Automated devices to support sales (such as customer relationship management)	Enterprise resource management in few areas (such as enterprise resource planning)
G 1.0	First generation: rigid production	Manual electronic transmission of orders (such as email) Manual transmission of orders (such as personal contact, telephone)	Manual generation of designs (such as 2D/3D drawings in 2D space)	Stand-alone automation	Electronic contact (such as spreadsheet registry, email)	Information systems by area/department
G 0.0	Zero generation: analogue production	Manual transmission of orders (such as personal contact, telephone)	Manual generation of designs (such as 2D/3D drawings in 2D space)	Non-micro-electronic based machinery	Manual handling of contacts (such as personal contact, telephone)	No software support to business management

Source: UNIDO elaboration based on *Indústria 2027 Survey (IEL 2018)* and on *Kupfer et al. (2019)*.

## Appendix 2: Definition and measurement of variables

Variable	Definition and measurement
Supplier relations technologies	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 in 5-10 years.
Customer relations	A dummy variable that takes value of 1 if firm's primary method of managing of production in 5-10 years 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 5-10 years.
Product development	A dummy variable that takes value of 1 if technology firms would use in 5-10 years 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.
Age (log)	A continuous variable defined as the total number of years firm has been in operation, constructed as the natural logarithm of the total number of years plus 1.
Size	A categorical variable that assumes the value of 1 if the firm is large (sales valued at more than R250 million per financial year), 2 if firm is medium ((sales valued at between R51 and R250 million per financial year), 3 if firm is small ((sales valued at between R11 and R50 million per financial year), and 4 if firm is micro (sales valued at below R10 million per financial year) in 2019/2020 financial year.
Export	A dummy variable indicating if the firm exports (1) and 0 if otherwise in 2019/20 financial year.
Innovation	A dummy variable indicating if the firm has introduced new production process or made significant improvements to products between 2017/18 and 2019/20 financial years.
Lack of capital	A dummy variable that takes the value 1 if firm considers the lack of capital /funds as an obstacle and 0 otherwise.
Lack awareness	A dummy variable that takes the value 1 if firm indicates lack of awareness and knowledge as an obstacle to adopting digital technologies and 0 otherwise.

Lack of adequate digital infrastructure	A dummy variable that takes the value 1 if firm considers the lack of adequate digital infrastructure as an obstacle and 0 otherwise.
RD&I	A categorical variable that assumes the value of 1 if the firm is not engaged in research, development and innovation, 2 if there are initial studies, 3 if plans are approved, and 4 if plans are in execution.
Human capital	A dummy variable that takes the value 1 if firm has employees with STEM qualifications and 0 otherwise.
Training centre	A categorical variable that takes the value 1 if firm considers as not important digital training centres on skills development, 2 if indifferent, and 3 if important.
Human-computer skills	A categorical variable that takes the value 1 if firm considers as not important human-computer interaction skills when hiring employees, 2 if indifferent, and 3 if important.
Capital ownership	A categorical variable that takes value 1 if the capital ownership of the firm is foreign-owned, 2 if fully South African-owned, 3 if mixed (South African and foreign-owned), and 4 if state-owned in in 2019/2020 financial year.
SETA	A categorical variable that takes value of 1 if firm belongs to MERSETA, 2 if FP&M, and 3 if it belongs to CHIETA.
Industry	A categorical variable that shows the 20 South African industrial classifications of the firms in our sample.
Province	A categorical variable that assumes a value between 1-9 indicating the province in which the firm is located.

---

