Adoption and Impact of ICT on Labour Productivity in Africa: Evidence from Cross-Country Firm-Level Data

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List of abbreviations and acronyms

AfDB	African Development Bank
AIS	African Investors Survey
ATMs	Automated Teller Machines
DOI	Diffusion on Innovations
GDP	Gross Domestic Product
ICT	Information and Communications Technology
IT	Information Technology
ITU	International Telecommunication Union
LAC	Latin America and the Caribbean
MSEs	Medium-sized Enterprises
NIM	Net Interest Margin
NIS	National Institute of Statistics
OC	Organizational Changes
OECD	Organization for Economic Co-operation and Development
R&D	Research and development
ROA	Returns on Assets
ROE	Returns on Earning
SMEs	Small and Medium-sized Enterprises
SSA	Sub-Saharan Africa
TAM	Technology Acceptance Model
TOE	Technology Organization and Environment
UNIDO	United Nations Industrial Development Organization

Abstract

This paper uses a large cross-country firm-level database that contains information of about 6,300 firms from 19 sub-Saharan Africa (SSA) countries, collected by the United Nations Industrial Development Organization (UNIDO) in 2010 and 2011, to assess the determinants of adoption and use of Information and Communication Technologies (ICT) in SSA firms, while controlling for the problem of censoring that would exist in the modelling of ICT-capital adoption choice. The gain obtained from the adoption of ICT-capital investment has been examined by estimating the impact of ICT-capital on labour productivity in adopters' firms, while considering the role of Organizational Changes (OC). Compared to the Cobb-Douglas production function the Translog production function has been tested to be more adequate with our data. Unlike previous work on the estimation of a production function, and given the simultaneity between labour productivity and ICT-capital investments, the Instrumental Variables (IV) method, has been used to address this endogeneity problem. The descriptive analysis shows that East African firms, on average, adopt ICT-capital more than other Africans countries, while Southern African firms, on average, use ICT-capital more intensively than other sub-regions. Finally, we find that income, wages and firms' size are significant determinants of ICT-capital adoption. Moreover, the study reveals that the impact of ICT-capital intensity on labour productivity in SSA countries is positive and statistically significant in the presence of OC, which is robust to several different specification tests.

Keywords: Adoption; Information technology and communication; Labour productivity; Cross-country; Firm-level data; Censoring; Endogeneity; Instrumental variables; Organizational changes.

1. Introduction

Statement of the research purpose and the issue to be studied

According to the OECD (2011), Information and Communication Technologies (ICT) investment covers the acquisition of equipment and computer software used in production for more than one year. ICT has three components: information technology equipment (computers and related hardware); communications equipment; and software.[1]

Measuring ICT at the aggregate level is a daunting task. However, several ICT proxies exist at the firm-level, and depending on the availability of data. Among other measures of ICT at the firm-level, there are, for example, ICT investment expenditure and the stock of a firm's computer hardware. The role of ICT for the development of productivity has been at the forefront of development strategies (UNCTAD, 2003; 2005). ICT, broadly, allows for a reduction in transaction costs, for example, in the acquisition of intermediate inputs by deleting or by reducing the number of intermediary actors in the supply chain between a firm and its suppliers, improved communications with markets and within the supply chain, and improved information about new opportunities. ICTs can also improve the internal information systems of enterprises.

Given that investment is widely acknowledged as essential to improving labour productivity, it is also recognized that investment in non-ICT-capital (machinery, equipment and non-residential buildings) associated with adoption of ICT allow workers to improve their business processes and produce more and higher-quality goods and services. However, these investments have different uses, although they are all relevant for policy purposes since ICT and non-ICT-capital are driven by different forces. Firm-level empirical analysis reveals that both ICT and non-ICT-capital investment are strongly demand-driven, but ICT investment adjusts more rapidly to a given demand shock. Empirical literature widely demonstrated that ICT investments are flexible inputs that allow firms to fundamentally reorganize the production and distribution of goods and services to improve efficiency. In the same vein, it is recognized that ICT investment generates higher returns to growth than the other physical capital thus producing higher level of Gross Domestic Product (GDP). Further, ICT has been the driving force behind the acceleration of productivity growth in Canada and the United States of America (USA) since 1996; also, in European countries, ICT is characterized by above normal returns.[2]

Several studies have shown that ICT-capital investments contribute to returns at the firm-level. In this regard, Dedrick et al. (2003), for example, showed that although there is a significant contribution of Information Technology (IT) to the returns of the firm, the magnitude of the contribution varies extensively across firms. This means that some firms with similar investment in IT have performed differently. Strong evidence that emerged from this observation revealed that the difference in performance was influenced by Organizational Changes (OC).[3]

Several developed countries have taken a huge benefit from the adoption and use of ICT, both socially and economically. The literature on the subject emphasizes that these benefits obtained depends on the existence of telecommunication infrastructures and of the economic development of these countries. Furthermore, despite the progress and outstanding efforts observed in the adoption and diffusion of ICT in developing countries, and particularly in Africa, some works including (International Telecommunication Union [ITU], 2014) argue that Africa still lags remarkably in the adoption and use of ICT.

Like R&D, acquisition, adoption and use of new technologies, embodied in capital investment, lead to innovation. In doing so, ICT are seen as enablers of innovation, productivity and economic growth in all sectors of the economy.

The use of ICTs is very widespread among firms of all sizes. Many firms are increasingly, adopting ICTs in both developed and developing countries. Firms are also driven to adopt appropriate ICTs for improving their internal processes, improving their product through faster communication with their customers, and better promoting and distributing their goods and services through online presence.

Yet, there is a striking lack of robust empirical evidence on the drivers of ICT adoption, on the impact of ICT on productivity, and on the factors underlying the positive impacts of ICT in the African context.[4] This study seeks to fill the gap.

The observations and discussions presented above help explain why the adoption of ICT-capital by firms is not made like any other investment in physical capital, and justify the interest and choice devoted to the analysis of ICT-capital in this research. Using a large cross-country firm-level data of about 6,300 firms in 19 SSA countries, namely, African Investors Survey (AIS) 2010 collected by the UNIDO in 2010-2011, this research aims at addressing the following two research questions:

i. What are the factors that impede or discourage some African firms from adopting and using ICT-capital to increase their productivity?

ii. What is the impact of ICT-capital on labour productivity for ICT adopters at the firm-level in SSA countries?

To highlight the importance and relevance of different research objectives, we formulate three main research hypotheses concerning the adoption of ICT as well as on the impact of these technologies on labour productivity of ICT adopting firms. Firms need capital to produce goods and services. When considering investments, such as ICT-capital investment, the firm's income is one of the most interesting determinants to watch, as an increase in the level of production is likely to stimulate capital demand and therefore to increase investments. Therefore, an increase in firm's income is likely to boost investment. In a precise manner, we postulate that:

α. The ICT-capital intensity increases with the firm's income.

β. The labour productivity of adopters increases with investments in ICT-capital intensity.

χ. An increase in ICT-capital intensity is associated with an increase in labour productivity when firms have conducted a process of innovation.

The main policy relevance of this research is to contribute to a clearer understanding of what could be done to enable firms in SSA countries to take the best from ICT to improve their productivity. The results could be used as part of national strategies to promote ICT adoption by local firms, since there are still many African firms that are reluctant to engage in the new economy: a recent AIS conducted by the UNIDO in 2010 and 2011 in 19 SSA did in fact reveal that there are about 27% of firms with zero United States Dollars (USD) invested in ICT assets. Also, this research will contribute to clarifying channels through which firms could harness substantial productivity gains from their ICT investments. Finally, policy makers would be made aware of some specific levies they could use to ensure greater uptake of the ICT productivity gains by individual firms.

The reminder of the article is organized as follows. Section 2 reviews some of the relevant theoretical and empirical literature on the determinants of ICT-capital adoption and on the impact of ICT-capital on firms' productivity. Section 3 describes the methodology used for the research. Section 4 presents and discusses the results. Section 5 performs the sensitivity analyses and provides robustness checks, while Section 6 concludes and makes some recommendations.

2. Literature review

ICT adoption and its determinants

The adoption and use of ICT as a key factor for development and economic growth in society, and as a vector for the evolution of firm's performance, has been widely debated in the literature, and continues to raise great interest at the level of policy makers and scholars.

From many theoretical perspectives, Grandón et al. (2011) has studied the adoption process of new technologies. Also, Oliveira and Martins (2011) reviewed the literature on technology adoption models. However, to highlight individual as well as firm characteristics related to technology and organization as drivers of innovativeness, the authors considered the Technology Organization and Environment (TOE) framework developed by Tornatzky et al. (1990) and the Diffusion of Innovations (DOI) theory presented by Rogers (1995). The TOE identifies three aspects of the business context that influence the process by which it adopts and implements technological innovations.[6]

Moreover, Devlin and Pilat (2004) show that the diffusion of ICT differs considerably among OECD countries. The authors identify different factors that affect the diffusion of ICT, including: ICT equipment costs, installation of telecommunications, organizational change, company's ability to innovate, availability of qualified personnel, as well as factors relating to competition and the regulatory environment. Based on the analysis of per capita Internet penetration for 74 OECD countries over the period 1995-1999, Robison and Crenshaw (2002) examined the role of education, economic development and the presence of services sector in the diffusion of the Internet and found significant contributions of the level of development, education and political freedoms.

Hollenstein (2004) examined the evidence of the determinants of ICT adoption at the firm-level for Switzerland. It shows that the decision of firms to adopt ICT depends on several factors. This includes the anticipated benefits of the adoption, human capital, firm size, the new organization of work, the cost of adopting such as direct investment costs and financial constraints. At the intra-firm-level, Galliano and Roux (2008) argued that firm size does not correlate with intensity of use, and even if, for Galliano et al. (2011), the pace of diffusion of the new technology seems faster in small firms. Biswas and Baptista (2012) conclude that there is a high disparity between small and large firms in the European Union (EU) in terms of using sophisticated ICT.

Guerriri et al. (2011) evaluated the factors that determine the decision to invest in ICT using data on ten developed countries. The empirical analyses concluded that the general firm's environment where the investment is taking place matters for the investment decision. They include, among other facilitating conditions, changes in the market regulation and amount of human capital. Using data from Irish manufacturing firms over the period 2001-2004, Haller and Siedschlag (2011) analysed factors driving inter- and intra-firm diffusion of ICT. Through a method of novel firm-level panel, the authors estimated an improved econometric model to find that the path of ICT diffusion has been uneven across firms, industries and space, which is consistent with the theory of new technology adoption. The results also suggest that firms that are larger, younger, fast growing, skill-intensive, export-intensive and firms located in the capital city region have been relatively more successful in adopting and using ICT.

Many studies (Caroli & van Reenen, 2001; Zhu et al., 2003; Hollenstein, 2004; Fabiani et al., 2005; Morgan et al., 2006; Bayo-Moriones & Lera-López, 2007; Haller & Siedschlag, 2011) have been conducted in developed countries to examine factors that facilitate the adoption of ICT in firms. However, it is acknowledged that theories and management practices implemented in the context of developed countries need to be reviewed in the context of developing countries. Especially since concerns that may seem evident to the developed countries can play an important role in the adoption of ICT in developing countries.[8]

Very few studies have explored the factors influencing the adoption of ICT in firms in developing countries, especially in Africa. Studies that have examined this issue indicate that many factors can influence the adoption of ICT. Basant et al. (2006) examined the ICT adoption and its impact on the productivity of firms in the context of developing countries, specifically India and Brazil. Statistical analysis reveals that, on average, Brazilian firms use ICT more intensively than their Indian counterparts. Also, within countries, ICT intensity strongly depends on the size, ownership structure and education. Using data from the World Bank Enterprise Survey, Grazzi and Jung (2016) identified the drivers of ICT diffusion in Latin America and the Caribbean (LAC) firms and assessed the relationship between ICTs and firm performance in the region. The results show that larger, older, skill-intensive, exporter and urban firms are more likely to adopt ICTs. However, once adopted, size and location lose importance.

Giotopoulos et al. (2017) highlighted potential determinants of ICT adoption in SMEs, based on a large data set build through a survey conducted in 2012 that includes information at the firm-level on 3,500 SMEs in Greece. Emphasis is placed on the role of firms' technological competencies, human capital of workforce and internal organization in ICT adoption measured by five indicators referring to firms' intentions toward ICT implementation, ICT infrastructure, internet integration, e-sales and e-procurement. Estimation of ordered Probit models show that innovation and R&D activities and collaborations, well-educated and skilled workers, decentralized decision-making and visionary leadership increase the likelihood of adopting new technologies in SMEs. The results appear to be largely robust across different ICT adoption measures.

Also, Ntwoku et al. (2017) focused on low-income countries and used data from Cameroonian's SMEs to apply the Bass diffusion model to understand SMEs adoption of ICT in Cameroon. The Bass model was employed because of its predictive capacity. The authors found that diffusion of ICT among SMEs in the context of a low-income economy is largely driven by forces of imitation rather than forces of innovation. In doing so, the paper finds that, SMEs with greater sizes, multiple plants and whose owners have higher education have a greater tendency to adopt ICT early. The theoretical contribution of the study is in applying the well-recognized Bass model within a low-income country environment to evaluate diffusion of ICTs among SMEs in Cameroon from marketing to the IT field. In Nigeria, neighbouring country of Cameroon, using a primary data analysis in the Federal Capital Territory, Abuja, Hassan and Ogundipe (2017) investigated the determinants of ICT adoption by MSEs. The study adopted the Technology Acceptance Model (TAM) and TOE framework. The study strengthens the empirical knowledge on the usage level of ICT system and software among MSEs and likewise establishes that competitive pressure, government support, employer's skill and knowledge influence the adoption of ICT by MSEs in the Nigeria. The study recommends that in line with national ICT policy, government should ensure efforts are geared towards the attainment of full ICT adoption by MSEs in Nigeria. MSEs Owners and management should undertake periodic training in ICT in order to ensure adequate knowledge-based venture. Finally, the government should create an enabling environment for the adoption of ICT by ensuring access to affordable ICT services and facilities for businesses.

In the case of emerging countries, recent literature agrees on the fact that, the adoption of ICT has enabled local SMEs to participate in the international market. From this point of view, using the extended technology-organization-environment framework with personal innovativeness, Albar and Hoque (2017) examined the factors that influence the adoption of ICTs among SMEs in rural areas of Saudi Arabia. They found that relative advantages, top management support, culture, regulatory environment, owner/manager innovativeness and ICT knowledge had a significant relationship with ICT adoption among SMEs in Saudi Arabia, whereas compatibility, complexity and a competitive environment had no significant relationship with ICT adoption.

Investment in ICT-capital and labour productivity

The impact of ICT on the development of productivity has been the subject of much debate in the literature. Theoretically, the effect of ICT on productivity stems from the role that these technologies play as input in the production process, and from their ability to reduce transaction costs and improve coordination of different activities, not only within the firm (Dedrick al., 2002), but also externally with business partners (Kaplan & Norton, 1992). Further in 2016, in its World Development Report, the World

Bank noted that, African firms using ICT tools like the Internet, on average, have 3.7 times higher labour productivity than non-users and 35% higher total factor productivity.

However, in the early 1980s, most studies on the relationship between ICT and productivity led to the statement of the paradox of productivity (Bryjolfsson & Yang, 1996). This "lack of ICTs in the productivity statistics" ultimately turns to be a problem of measurement of ICT and of the value they create, particularly in services sectors where output is particularly difficult to identify.

Subsequent studies on manufacturing firms have in fact led to positive results (Siegel, 1994; Lichtenberg, 1995; Brynjolfsson & Hitt, 1996; Lehr & Lichtenberg, 1999), particularly because of improvements in the measurement of output to account for qualitative aspects of the impact of ICT.[9] Yet, the challenge of measuring the value created by ICTs persisted. Berndt and Morrison (1995) and Jorgensoh and Stiroh (1995) obtained contradictory results after working on the same period. But these inconsistencies indicated methodological issues, particularly in the measurement of firm performance and in the quality of data.

Studies carried out in developed countries have also suggested that several factors underlie the positive impact of ICT on productivity. Indeed, many empirical papers showed that the effect of ICT on productivity depends on the circumstances in which the ICT are used (Pilat, 2004). For example, Gretton et al. (2004) observed that the impacts of ICT use on the productivity growth in Australian firms were generally related to the level of human capital and skills within firms, as well as experience of these firms in innovation, adoption of advanced professional practices and intensity of Organizational Changes (OC).

Gera and Gu (2004) and Black and Lynch (2004) obtained similar results in the case of Canadian and USA firms, respectively. The literature on complementarity between ICT, organizational changes and skills in some European countries confirms that these variables produce positive and significant effects on labour productivity (Caroli & Van Reenen, 2001; Hempell, 2003; Bertschek & Kaiser, 2004). These results are consistent with the thesis of complementarities between ICT and OC originally highlighted by Milgrom and Roberts (1990).

Giuri et al. (2008) explored the relationships among the adoption of ICT, skills and OC, and the implications of different adoption strategies for a firm's productivity by examining 680 Italian manufacturing SMEs during 1995–2003 period. Among others, the authors examined the productivity effects of pair-wise interactions between ICT, skills and OC, and analysed the productivity gains of the interaction between the three complements together. The findings do not provide any evidence in favour of the hypothesis of complementarity between ICT, skills and OC. Instead, the results support the hypothesis of pair-wise complementarity between OC, or the use of modern workplace practices, and skills. Finally, the paper does not find any significant complementarity between ICT and skills. These results are consistent with the hypothesis that complementarity among ICT, skills and OC does not apply to SMEs.

In Spain, Díaz-Chao et al. (2015) analysed new co-innovative sources of labour productivity (ICT use, human capital and training, and new forms of work organization) in small firms that produce for local markets. The study presents an application of structural equation modelling to 2009 survey data for a representative sample of 464 SMEs in the province of Girona. Results showed that wage is the main determinant of labour productivity. Furthermore, in contrast to evidence regarding larger firms, co-innovation does not directly affect small local firms' productivity. The study established an indirect relationship between co-innovation and productivity in firms that initiate international expansion. The study also identifies guidelines for public policy to improve productivity in small local firms.

More recently, in a sample of manufacturing firms in Eastern European countries, Skorupinska et al. (2017) evaluated the relationships among ICT, management practices, innovation and human capital in a sample of manufacturing companies. Using data from the Management, Organisation and Innovation Survey 2009 for a representative sample of 444 companies in Bulgaria, Poland, Romania, Serbia and Ukraine, and using structural equation modelling and OLS, the authors examined direct and indirect determinants of labour productivity. Following Díaz-Chao et al. (2015), the principal finding that emerged from the study is that wage was the main direct determinant of labour productivity. Moreover, the relationship between ICT and its complementarities and productivity has been established indirectly, mainly by enterprise workers' use of the ICT.

In contrast to the case of developed countries, the efficiency of ICT as a factor in firm performance is still hampered by the lack of a solid empirical foundation in some developing countries, particularly in Africa, before 2010. This may be due to two factors. First and foremost, there has been a paucity of high quality data to carry out such analysis. Secondly, severe empirical issues undermined the credibility of the few empirical analyses available so far.

In the 2000s, few studies have been published in the context of developing countries and in Africa. For example, using a data set of 23 firms in Kenya and 137 firms in Tanzania, Matambalya and Wolf (2001) examined the role of ICT investments on the performance of SMEs in East Africa area. The theoretical framework used was the Cobb-Douglas production function. The estimation of empirical model by the Ordinary Least Squares (OLS) method was run for country and for the pooled data set to make use of the larger number of observations, as the number of observations for the Kenyan data set was rather low. The results show that investment in ICT has a negative sign on productivity in both countries and in pooled sample, but is never significant. A few years later, Chowdhury and Wolf (2006) analysed the impact of investments in ICTs on firms' performance for two East African countries. The survey included 165 SMEs in Kenya and Tanzania from three sectors, food processing, textiles and tourism, and the authors focused on three performance indicators—internal rate of return, labour productivity and domestic and export market expansion. Using OLS method, the authors found that investments in ICT have a positive impact on general market expansion and that investments in ICT have a negative and significant impact on labour productivity.

These results were probably due to the quality of the data used and the methodology adopted. By cons, the World Bank (2006) was already showing a positive correlation between measures of ICT and some indicators of firms' performance. However, an analysis of the works published after 2010 presents a different dynamic from the works presented in the 2000s.

Commander et al. (2011) used a unique new data set on a thousand manufacturing firms in two important developing countries, Brazil and India, to estimate production functions, augmented by ICT-capital investments. They found a strong positive association between ICT-capital and productivity in both countries that is robust to several different specification tests.

Kossaï and Piget (2014) examined the relationship between ICT use and the performance of Tunisian SMEs operating in the electrical and electronic industry based on net profit margin. Using data collected from a survey conducted in 2009 on 320 Tunisian manufacturing firms operating in the electrical and electronic industry based throughout the country, the authors implemented different methodological approaches like linear regression, Granger causality, Kruskal–Wallis test, Welch ANOVA test and post hoc tests; they found that, there is a significant and statistical relationship between the level of ICT use and the performance of Tunisian SMEs in the electrical and electronic industry.

Using a data set of 300 SMEs, randomly selected from a list of firms provided by the National Institute of Statistics (NIS) in Cameroon, Choub and Tefong (2015) surveyed 300 SMEs to analyse ICT for the development of labour productivity in Cameroun. Based on a categorization of firms by ownership structure and firms age, the authors evaluated empirically whether, and to what extent, ICT contributed to the growth of labour productivity within the firms. Using the IV method to account for the endogeneity problem with cross sectional data, the authors found a positive and significant impact of ICT-capital on labour productivity in Cameroonian firms. In the case of LAC, Grazzi and Jung (2016) found a positive relationship between broadband Internet and firm performance. Firms that adopted broadband Internet increased their probability of innovating, and those that used it intensively were found to receive an additional positive effect. Further estimations also provided evidence on the fact that broadband Internet adoption and use increased firm productivity.

Wamboye et al. (2016) evaluated the impact of several ICT indicators on labour productivity growth using a sample of 43 sub-Saharan African countries. Given that the model suffers from reverse causality and simultaneity bias, the System Generalized Method of Moments (System GMM) estimator of Arellano and Bover (1995) and Blundell and Bond (1998) is used to control for endogeneity bias, measurement bias, unobserved country fixed effects and heterogeneity bias. The authors' findings show significant increasing returns for labour productivity growth from fixed-telephone and mobile-cellular penetration, confirming the presence of network effects. Furthermore, the results point to financial inclusion as one of the possible channels through which mobile-cellular subscriptions affect labour productivity growth in sub-Saharan Africa.

Chege and Wang (2020) evaluated the association between technology innovation, environmental sustainability and its impact on small business performance in Kenya. The authors used samples of 204 small businesses and hierarchical regression models. The results show that technological innovation affects environmentally friendly owners who have a positive impact on the performance of the company. Successful companies that support environmental community projects and social wellbeing beyond their economic responsibilities can bring greater financial success. Innovation from management and employee participation in environmental protection practices can improve the firm's performance and enhance its image to stakeholders.

In the SSA banking industry, Agu and Aguegboh (2020) investigated the impact of ICT on bank performance. The data set entails panel data for 35 sub-Saharan African countries and the System Generalized Method of Moment (System GMM) estimation technique for dynamic panel models was employed. ICT variables understudied include: number of Automated Teller Machines (ATMs), ATMs per 100,000 adults, ATM per 1,000 square kilometres and mobile money transaction; while bank performance was proxied using Returns on Assets (ROA), Returns on Earning (ROE) and Net Interest Margin (NIM). The result reveals that ICT is negatively associated with bank performance except for ATMs per 100,000 adults and ATM per 1,000 square kilometres, which had positive impact on ROE and NIM. The findings suggest that ICT largely affects bank performance in the short run; in long run, these investments become very beneficial to improving bank performance.

For one thing, these studies do not address the likely issue of endogeneity. Moreover, the underlying empirical models they used did not account for the role of Organizational Changes, or, more generally, of complementary investments that condition the efficiency of ICT-capital. Finally, the size of the sample in those studies is likely to induce the issue of small sample bias. These empirical problems are addressed in our research.

3. Methodology

Data sources and descriptive statistics

To address our research questions, we will exploit a large cross-country firm-level database that contains a wide array of information on 6,373 firms from 19 SSA countries (Burkina-Faso, Burundi, Cameroon, Cape Verde, Ethiopia, Ghana, Kenya, Lesotho, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Tanzania, Uganda and Zambia). This is the first time that such data will be used to study the impact of ICT on productivity in the African context.

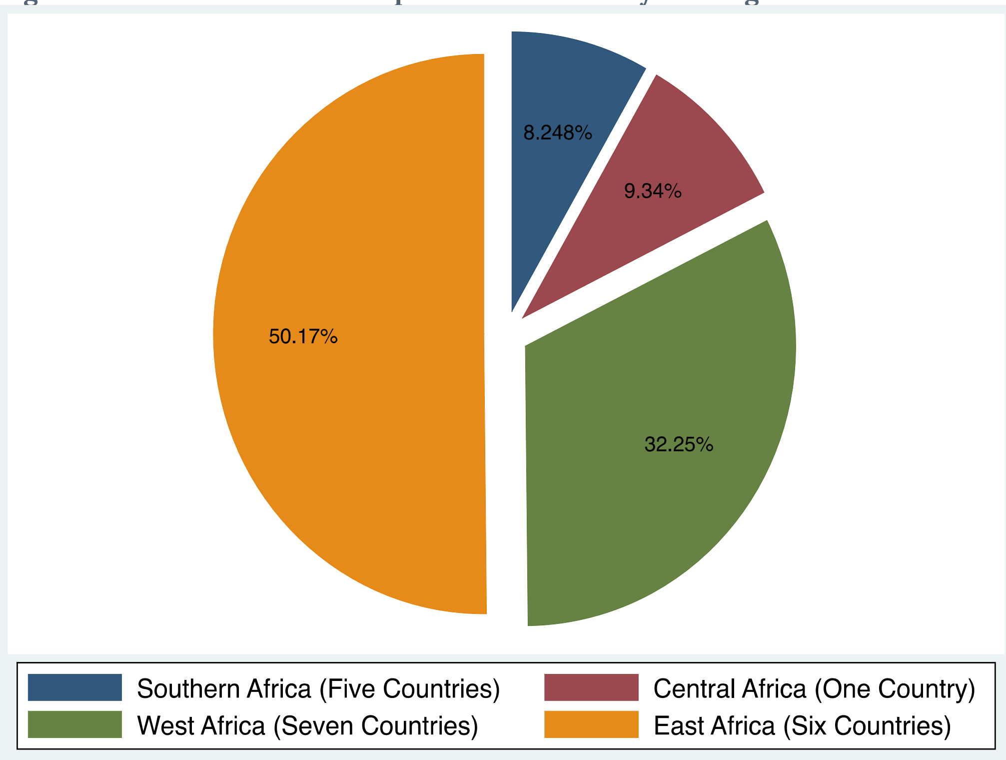
The data has been collected and harmonized through AIS (2010) across 19 SSA countries. AIS (2010) was conducted by UNIDO over the period 2010-2011, and the survey method involved face-to-face interviews with top-level managers of foreign- and domestic-owned firms active in the following sectors: agriculture,[10] manufacturing, mining, utilities, construction and services.

The survey was designed to cover a representative sample of all public and private sector, for-profit enterprises which were registered and employed more than ten people. Apart from each firm's contact details, the representative sample was built for each country by stratifying the sampling frames along the dimensions of size (number of employees, assets or output),[11] ownership status (foreign- or domestic-owned),[12] and economic sub-sector.[13]

Unfortunately, UNIDO did not publish in its reports the response rate of the companies interviewed in this rich survey. This information could have provided information on investors' interest in having a credible and reliable database for investment analysis in Africa, both by firms that participated in the surveys and by government authorities, development organizations, private sector associations and financial institutions. Also, there are no sampling weights available, despite all the efforts made to UNIDO to obtain this information; we will careful interpret any of the descriptive statistics, as they may reflect the oversampling of large firms. We will test whether any observed differences remain when controlling for size.

To assure that data collected by the enumerators was reliable, several levels of quality checks were instituted before, during and after the data collection phase. These involved human checking in the field by enumerators and supervisors and at UNIDO headquarters. Several algorithms were employed at the data collection point, as well as in subsequent stages for consistency checking. The reviews of questionnaires involved frequent re-visits and re-call of interviewees to ensure replies were accurately recorded. We filtered the data to focus on our subject of interest. The wide array of information contained in UNIDO data set is described in the figures and tables below.[14]

Figure 1: Distribution of ICT-capital investments by sub-region



Source: AIS 2010, UNIDO.

The distribution of firms by sub-region, shown in Figure 1, was inspired from the proposed distribution by the African Development Bank (AfDB) in 2014 in its report on trade financing in Africa. In the light of Figure 1, it appears that Southern Africa and Central Africa are poorly represented in terms of investment in ICT-capital, compared to East Africa and West Africa which account, respectively, for 50.17% and 32.25% of ICT-capital investments in our database.

This result suggests that there are factors that encourage or impede some firms to adopt ICT-capital. These factors will be analysed with appropriate methods, later in the paper.

Table 1: Repartition of firms by sub-region

Sub-Region	Firms	Percent
Central Africa	270	4.24
East Africa	2,766	43.40
Southern Africa	1,130	17.73
West Africa	2,207	34.63
Total	6,373	100

Source: AIS 2010, UNIDO.

Table 1 provides a distribution of the number of firms (6,373 in total) by sub-region. This distribution follows practically the same pattern as that shown at Figure 1, on the amount of investment in ICT-capital, for East Africa and West Africa. Central Africa, on the other hand, has fewer companies than Southern Africa but, moreover, has much more invested than Southern Africa in terms of ICT-capital.

In contrast, the trend is reversed for Southern Africa and Central Africa because, in terms of the distribution of the number of firms, we note that Central Africa has far fewer firms (4%) than Southern Africa that represents 18% of firms, while in respect of the volume of ICT-capital investment as highlighted in Figure 1, Central Africa has 9.34% of investments against 8.24% for Southern Africa. This interpretation justifies, once again, the interest to wonder about the various factors which could influence the adoption or not of ICT-capital in firms in SSA countries.

Table 2: Descriptive statistics for full sample in millions of US dollars

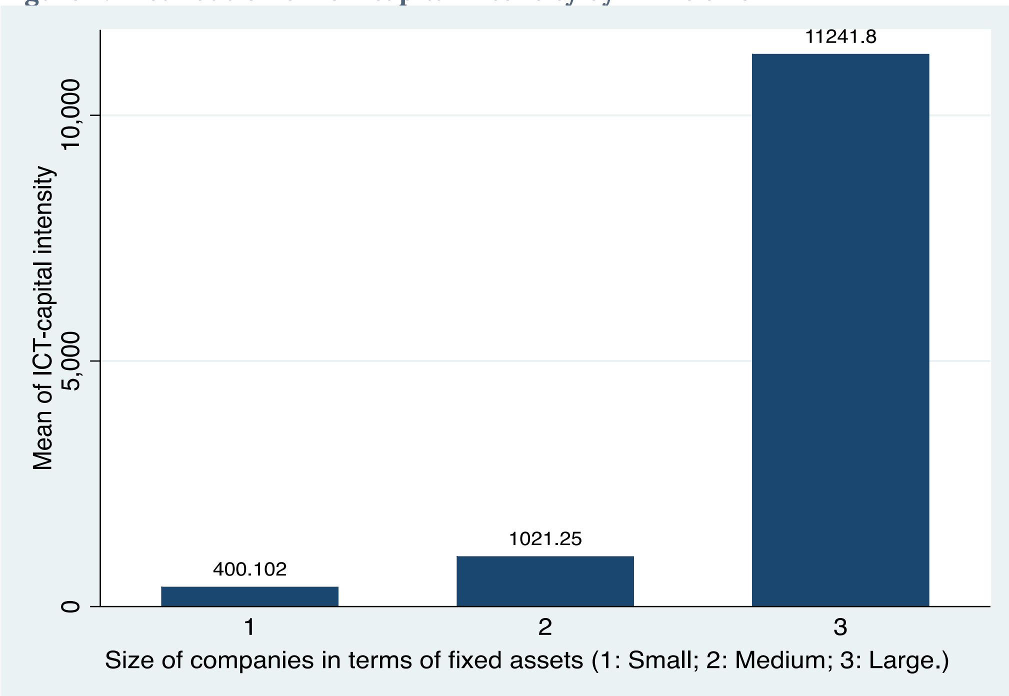
Variables	Obs.	Mean	S.D.	Min	Max
Labour productivity in USD	6,125	.09	.51	0	16.07
Ordinary-capital in USD	4,692	.05	.49	0	27.31
ICT-capital in USD	5,356	.004	.06	0	3.63
Training in USD	5,961	.02	.15	0	5.09
Female employment	6,081	25.75	21.94	0	100
Age of the firms in years	6,312	18.47	15.29	1	163
ICT/Output	5,244	.30	6.80	0	329.83

Source: Authors' calculation from AIS 2010, UNIDO. Ordinary and ICT-capital are per capita values.

From Table 2, we note that the full sample has 6,312 firms in total, with at least one year old, and 61 firms are less than one year old. Moreover, it appears from this table that the labour productivity is .09 million of USD, on average, and that the amount invested in per capita ICT-capital is .004 million of USD on average.

We also note that the total amount spent in employee training is .02 million of USD on average. Also, the average age of the firms in the total sample is 18 years old, and these firms have 26% of women in their employment, on average. Table 2 also reveals that the share of ICT-capital investment in production is 30%, on average, for the firms represented in our sample.

Figure 2: Distribution of ICT-capital intensity by firm's size



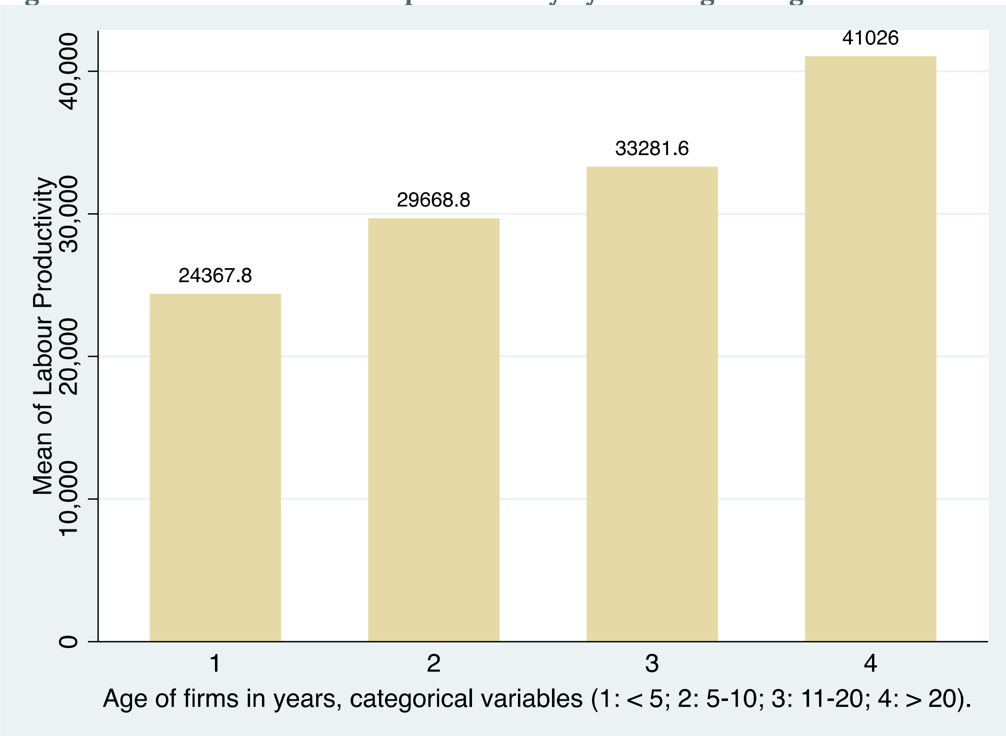
Source: AIS 2010, UNIDO.

Figure 2 presents the distribution of ICT-capital intensity in term of business size. Size is defined in terms of fixed assets: Small (fixed assets $<$ 100,000 USD); Medium (100,000 USD $\leq$ fixed assets $<$ 1,000,000 USD); Large (fixed assets ^{3} 1,000,000 USD).

In the light of Figure 2, we can notice that the ICT-capital intensity (ICT-capital over full-time employee), on average, varies according to the different companies' size. However, looking at the real values, we note that, the average ICT-capital intensity is 400.10 for the small companies; 1,021.25 for the medium firms and 11,241.8 for the large business.

If we express the percentage difference between medium and small firms, the result will be 60.82%. Also, the difference in percentage between large and medium business, will be expressed by $\frac{11241.8-1021.25}{11241.8} = 90.11\%$. This information could reveal a signal that the adoption of ICT-capital varies too much according firms' size, and one would expect that firms' size should be a significant determinant for the adoption of ICT-capital.

Figure 3: Distribution of labour productivity by firm's age categories



Source: AIS 2010, UNIDO.

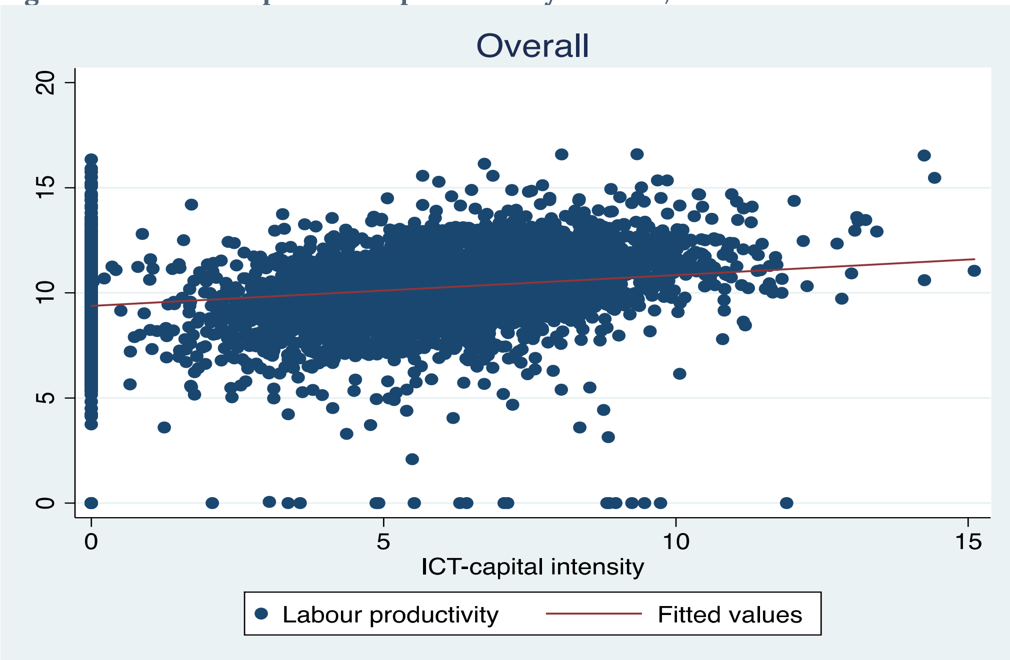
Figure 3 illustrates the distribution of labour productivity in the different age class.[15] The finding of this graph indicates, looking at the values expressed by value added per worker, that labour productivity, on average, also varies across different firm's age groups.

In doing so, the average labour productivity is 24,368 for the age group under five years; 29,669 for the age class between five and ten years; 33,282 for the age group between 11 and 20 years and 41,026 for the age group above 20 years. The calculation of the percentage difference between oldest and middle age class indicates that $\frac{41026-29669}{41026} = 28.41\%$. In the light of this information, we are inclined to believe that labour productivity varies quite a bit with time, and we could expect that the impact of age on labour productivity could be significant.

After observing the behaviour of ICT and labour productivity, with respect to size and different age groups, respectively, these behaviours suggest that, on the one hand, firms' size should be a significant determinant for the adoption of ICT-capital, and on the other hand that, the impact of age groups on labour productivity will be significant.

Therefore, it may be important to look at the statistical nature of the relationship that may exist between labour productivity and of ICT-capital intensity.

Figure 4: Relationship between productivity and ICT, overall



Source: AIS 2010, UNIDO.

Looking at Figure 4, we can note that there is a positive and upward relationship between ICT-capital intensity and labour productivity. This being the case, we can already think in this study that ICT-capital intensity will have a positive and significant impact on labour productivity.

Table 3: Descriptive statistics for Southern Africa in millions of US dollars

Variables	Obs.	Mean	S.D.	Min	Max
Labour productivity in USD	1071	.07	.23	0	4.07
Ordinary-capital in USD	856	.03	.35	0	9.27
ICT-capital in USD	947	.003	.05	0	1.54
Training in USD	1050	.008	.03	0	.54
Female employment	1078	29.83	26.26	0	100
Age of the firms	1119	18.05	14.76	1	127
ICT/Output	928	.46	10.40	0	314.05

Source: Authors' calculation from AIS 2010, UNIDO. Ordinary and ICT-capital are per capita values.

Table 3 summarizes descriptive information about the principal variables of our database. These statistics come from a set of firms located in the Southern Africa sub-region, and it is presented as follows.

Firms in this sub-region constitute only 18% of information contained in our sample, and has lower labour productivity than that observed, on average, in the full sample and in other sub-regions. Also, this sub-region devotes considerable attention to women's work with an employment rate of women, which is around 30%, higher than that observed in other sub-regions and even in the full sample.

In addition, firms in this sub-region are more ICT-capital intensive compared to firms in other sub-regions, with a 46% share, on average, of production in ICT-capital investment. According to the report of AfDB in 2011,[17] this situation is justified, among other things, by the fact that the sub-regional integration takes the lead in the wing by the fact that the countries of this area belongs to several Regional Economic Communities. In addition, this report shows that, in terms of ICT-capital investment, Southern Africa has no backbone network of high capacity able to handle the volume of traffic in the event of mass market communication.

Also, the backbone connection costs are very high (US$366 per month, against US$6-44 per month in India) and availability is limited. The report also notes that the entire sub-region is marked by glaring disparities regarding ICT-capital access, including access to the Internet connection and the availability of bandwidth. On the other hand, the training intensity in this area is, on average, lower than the training intensity in the full sample.

Table 4: Descriptive statistics for East Africa in millions of US dollars

Variables	Obs.	**Mean**	**S.D.**	**Min**	**Max**
Labour productivity in USD	2694	.09	.51	0	15.13
Ordinary-capital in USD	2243	.03	.16	0	3.02
ICT-capital in USD	2472	.005	.09	0	3.63
Training in USD	2639	.02	.15	0	4
Female employment	2684	28.78	20.21	0	100
Age	2758	17.82	15.25	1	142
ICT/Output	2427	.37	7.49	0	329.84

Source: Authors' calculation from AIS 2010, UNIDO. Ordinary and ICT-capital are per capita values.

Table 4 summarizes relevant information from firms operating in the East Africa sub-region. These statistics gives us an overview of firms' behaviour in this part of Africa. It is important to notice that, the East African sub-region is the most important of our sample in terms of number of firms (2,766) available, which represent 43% of observations contained in our database.

By doing so, the firms operating in this area are as productive, on average, as that represented in the whole sample, because the labour productivity in this sub-region is .09, on average, and is the same as the labour productivity in the full sample. However, the total amount invested in ICT-capital per employee is, on average, 0.005 million of USD, and is rather higher than what we have in the full sample, .004. The average age of firms in this East Africa sub-region is around 18 years old, and is substantially the same as that found in the full sample.

On average, firms in this sub-region are more ICT-capital intensive compared to firms in the full sample, as the share of production devoted to ICT-capital is 37%, on average, and therefore higher than what is obtained in the full sample. Firms in the East Africa sub-region have very good female employment policies, because the share of women employed in firms is more than the share presented in the full sample, on average.

Table 5: Descriptive statistics for West Africa in millions of US dollars

Variables	Obs.	Mean	S.D.	Min	Max
Labour productivity in USD	2092	.12	.63	0	16.07
Ordinary-capital in USD	1380	.09	.84	0	27.31
ICT-capital in USD	1698	.003	.02	0	.56
Training in USD	2011	.02	.19	0	5.09
Female employment	2052	20.39	21	0	100
Age	2165	19.22	15.55	1	163
ICT/Output	1655	.16	1.95	0	63.89

Source: Authors' calculation from AIS 2010, UNIDO. Ordinary and ICT-capital are per capita values.

Table 5 shows firms in West Africa with the amount invested in training, on average, which is the same as the value observed in the full sample. However, the firms' labour productivity, which is .12, on average, is higher than labour productivity in the full sample. Also, the total amount invested in per capita ICT-capital is .003 million of USD, on average, and is lower than what we have in the full sample and even in East Africa. Moreover, these firms are, on average, older than those of the full sample. Firms in West African are, however, less ICT-capital intensive relative to firms in East Africa, Southern Africa and in the full sample, as the share of production dedicated to ICT is 16%.

Table 6: Descriptive statistics for qualitative variables, full sample

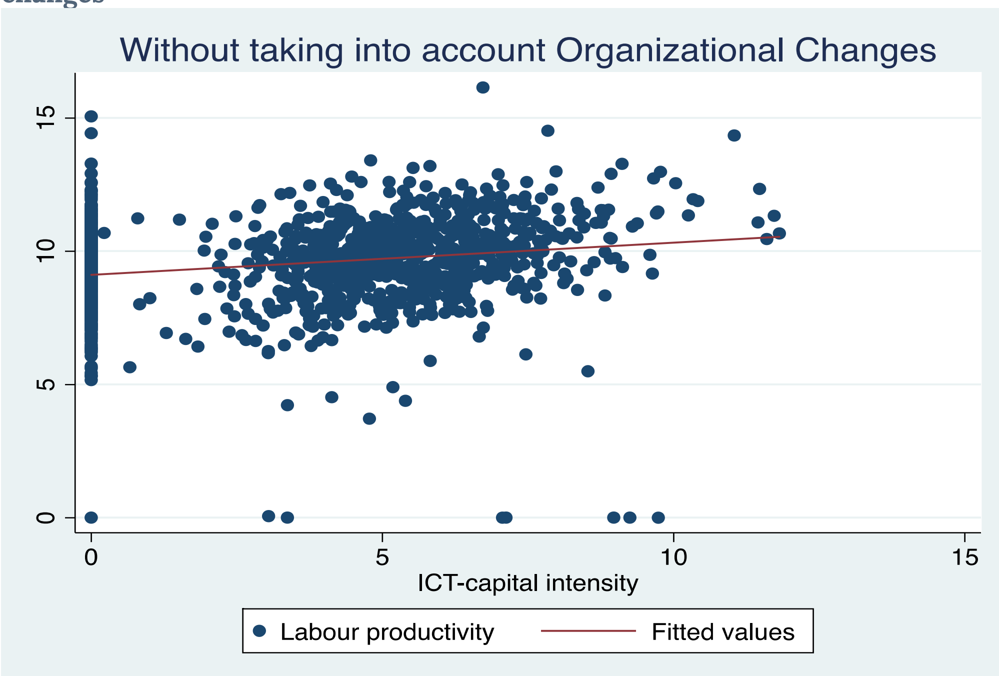
Variables	Obs.	%
Adoption	**5,365**	**100**
ICT-Adopters	3,909	72.86
Non-ICT-adopters	1,456	27.14
Ownership	**6,373**	**100**
Domestic (foreign ownership < 10%)	4,048	63.52
Foreign (10%>=foreign ownership =<100%)	2,325	36.48
Size	**6,076**	**100**
Small	1,648	27.12
Medium	2,314	38.08
Large	2,114	34.79
Market Orientation	**6,373**	**100**
Local market seeking (exports <10%)	5,333	83.68
Regional market seeking (exports >10%, SSA exports>50%)	479	7.52
Global market seeking (exports >10%, rest exports>50%)	561	8.80
Organizational Changes	**2,145**	**100**
Conducted innovation process in last 3 years	688	32.07
No innovation process in last 3 years	1,457	67.93

Source: AIS 2010, UNIDO.

Table 6 reveals that, in the full sample, 27% of firms have not adopted ICT and that about 64% of firms have a domestic ownership. Among the 27% of firms that did not invest at all in ICT assets, 27.12% are small businesses, 38.08% are from the medium-sized firm class, while 34.79% come from large firms. The sampled firms are mostly medium, and 84% of the total sampled firms export less than 10% of their production. Among the sampled firms, 68% have not yet had an opportunity to implement OC, while only 32% of the firms have already made OC in their structure by driving a process of innovation over the last 3 years.[19]

In general, we have observed that there is a positive and rising relationship between labour productivity and ICT-capital intensity in firms in our sample. However, it is very important to know and understand what would be the magnitude of this relationship in the presence or absence of OC within the firms.

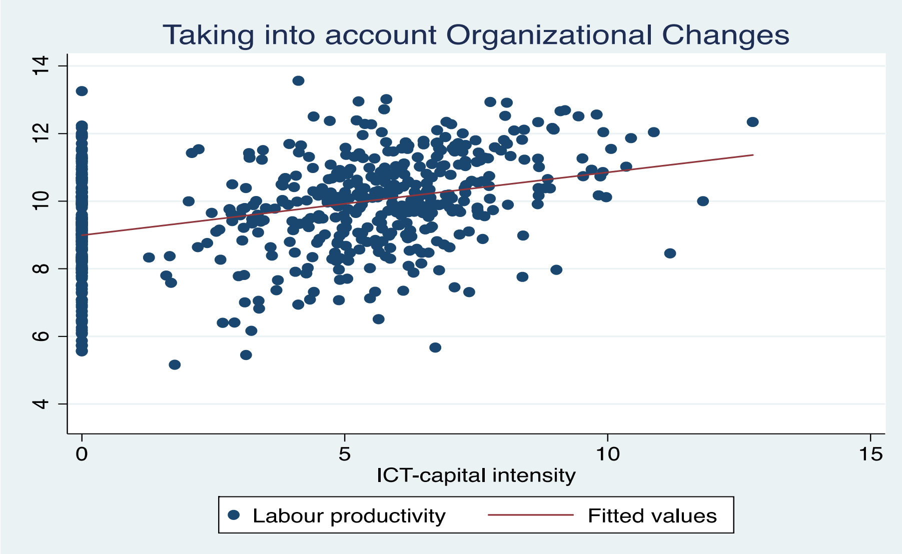
Figure 5: Relationship between productivity and ICT, without organizational changes



Source: AIS 2010, UNIDO.

To be able to identify the magnitude of the relationship between labour productivity and ICT-capital intensity in the firms in our sample, when we do not take OC into account, we can see from Figure 5 that this relationship remains positive and rising.

Figure 6: Relationship between productivity and ICT, with organisational changes



Source: AIS 2010, UNIDO.

Figure 6 illustrates that, when OC is implemented within firms, the relationship between labour productivity and ICT-capital intensity is, not only positive and upward, but also stronger. This is shown in Figure 6 by the fact that the slope of the regression line for labour productivity is steeper or stronger than the slopes observed in figures 4 and 5.

Table 7: Descriptive statistics for qualitative variables

	Southern Africa		East Africa		West Africa	
Variables	**Obs.**	**%**	**Obs.**	**%**	**Obs.**	**%**
Adoption	**951**	**100**	**2,473**	**100**	**1,702**	**100**
ICT-Adopters	683	71.82	1,914	77.40	1,144	67.22
Non-ICT-adopters	268	28.18	559	22.60	558	32.78
Ownership	**1,130**	**100**	**2,766**	**100**	**2,207**	**100**
Domestic (foreign ownership < 10%)	673	59.56	1,686	60.95	1,551	70.28
Foreign (10%>=foreign ownership =<100%)	457	40.44	1,080	39.05	656	29.72
Size	**1,078**	**100**	**2,678**	**100**	**2,055**	**100**
Small	324	30.06	681	25.43	582	28.32
Medium	453	42.02	972	36.30	787	38.30
Large	301	27.92	1,025	38.27	686	33.38
Market Orientation	**1,130**	**100**	**2,766**	**100**	**2,207**	**100**
Local market seeking (exports <10%)	942	83.36	2,166	78.31	1,997	90.48
Regional market (exports >10%, SSA exports>50%)	50	4.42	308	11.14	102	4.63
Global market (exports >10%, rest exports>50%)	138	12.21	292	10.56	108	4.49
Organizational Changes	**318**	**100**	**961**	**100**	**793**	**100**
Conducted process of innovation in last 3 years	99	31.13	307	31.95	256	32.28
No process of innovation in last 3 years	219	68.87	654	68.05	537	67.72

Source: AIS 2010, UNIDO.

Table 7 indicates that, on average, East African firms have 77% of ICT adoption rate, higher than the ICT adoption rates in Southern Africa firms (72%) and in West Africa firms (67%). The ICT adoption rate in West Africa is less than ICT adoption rate in the full sample. Moreover, only 30% of firms in West Africa belong to foreigners, which is less than what is observed in the full sample as well as in East Africa and Southern Africa. Central Africa is missing because this sub-region is represented only by one country.

However, 36% of East African firms are medium against 38% in West Africa and 42% in Southern Africa. In addition, 90% of firms in West Africa export less than 10% of their production, while in Southern Africa and in East Africa, 83% and 78% of firms, respectively, export less than 10% of their production.

The practice of OC is, on average, similar in all sub-regions in our database. However, in Southern Africa, 31% of firms have had a process of innovation over the last 3 years, which is slightly below the average in the full sample (32%). In addition, 32% of firms in West Africa have also had an innovation process, while in East Africa also 32% of firms have had a process of innovation in the last 3 years.

{B}Empirical models and estimations method

Clearly, the UNIDO database contains enough information to carry out our analysis. To address our first research question, to explore the factors that distinguish firms that have adopted ICT (ICT assets>0) from firms that have not adopted ICT at all (ICT assets=0), we will use the Tobit regression model because the ICT variable which is our dependent variable for the first model is incompletely observed, and this reflects a problem of censoring in the ICT dependent variable. In fact, descriptive statistics shows that 27% of firms in the database have invested zero USD in ICT assets and, therefore, OLS regression leads to inconsistent parameter estimates because the sample is not representative of the population. Thanks to the richness of data on firms' business environment and their characteristics, we will be able to identify factors that discriminate between firms by adoption of ICT.

Among the studies that have been conducted in the context of developing countries, very few have considered corporate governance through its ownership structure as factors that determine the adoption decision of ICT-capital by firms. In addition, these studies do not consider the problem of censoring that may exist in the estimation of the determinants of ICT-capital adoption. Particularly in Africa, no study considers the aspects mentioned above.

In this paper, ICT, our variable of interest, is incompletely observed because in our data set, 27% of firms declared that they had not invested any dollar in ICT as we mentioned above. However, the latent variable ICT^* is the one that captures investments in ICT assets in our database. Therefore, the observation rule between these two variables states that ICT=g(ICT*). Despite the existence of censoring in our dependent variable, note that we always observe all explanatory variables X. Also, we observe completely ICT^* for a subset of the possible values of ICT^*, and we observe incompletely ICT for the rest of the possible values of ICT^*.

In the case of this paper, censoring is observed from the bottom and the modelling is as follows:

$$ICT^{*} = \tau X + \epsilon \quad \text{with} \quad \epsilon \sim N(0,\sigma^{2})$$
(1)

$$ICT = \begin{cases} ICT^{*} & si\ ICT^{*} > 0 \\ 0 & si\ ICT^{*} \leq 0 \end{cases} \tag{2}$$

Moreover, we have: ICT=max{0,τX+E } , $\epsilon \sim N(0,\sigma^{2})$ and vector X represents controls variables.

Estimation method

As mentioned above, estimating the model by OLS using firms that choose to invest in ICT asset will usually result in inconsistency because the selected sample is not iid. The Tobit model identifies how each control affects both the probability of not censoring and the expectation of the dependent variable given that it is observed. Also, the Tobit model can be estimated consistently by Maximum Likelihood (ML).[21]

After highlighting the problem of censoring that exists in the ICT-capital dependent variable, in which a specific part of the sample is invested in ICT-capital, after reviewing the methodology that will allow us to deal with this problem of censoring that exists in the analysis of the determinants of ICT adoption in our study context, following the literature and the availability of the variables in the data set, we will use the Tobit procedure, through the following empirical model, to estimate consistently the determinant of ICT-capital by ML in Stata 13.00.

$$ict_j^{*} = \tau_0 + \tau_1 own_j + \tau_2 \mathrm{wages_j} + \tau_3 \mathrm{age_j} + \tau_4 size_j + \tau_5 income_j + \tau_6 expshare_j + \sum_{i=1}^{I} \theta_i \mathrm{I_i} + \sum_{i=1}^{I} \gamma_i \mathrm{C_i} + \varepsilon_j \tag{3}$$

$$\varepsilon_j \sim N(0,\sigma_j^2)$$

And

$$ict = \begin{cases} ict^{*} & if\ \ ict^{*} > 0,\ \ ICT\ Adoption \\ 0 & if\ \ ict^{*} \leq 0,\ \ No\ ICT\ Adoption \end{cases} \tag{4}$$

$$\mathrm{prob}(\mathrm{Adopt_i} = 1 |\, \mathrm{Z_i}) = \psi\left(\gamma_0 + \gamma_1 income_i + \gamma_2 \mathrm{wages_i} + \gamma_3 \mathrm{age_i} + \gamma_4 \mathrm{size_i} + \gamma_5 \mathrm{own_i} + \gamma_6 expshare_i + \sum_{j=1}^{J} \theta_j \mathrm{I_j} + \sum_{j=1}^{J} \tau_j \mathrm{C_j}\right) \tag{5}$$

Where, $\mathrm{ict_j}$ is the logarithm of ICT-capital; $\mathrm{income_j}$ represent the logarithm of firm's sales in USD; $\mathrm{wages_j}$ represent the logarithm of per capita wages; $\mathrm{age_j}$ represent the firm's age in years; $\mathrm{size_j}$ is a categorical variable representing the size of the firm; $\mathrm{own_j}$ indicates if firms have a domestic or foreign ownership structure; $\mathrm{expshare_j}$ represent the export share of the firm; I and C represents industry and country dummies variables.

The model presented in Equation 5 is an extension of numerous studies (see, for example, Bloom et al., 2010; Haller & Siedschlag, 2011; Findik & Tansel, 2015) which used it in previous empirical work to analyse the determinants of ICT adoption at the firm-level.

We used the natural logarithm of $(1 + x)$ to accommodate zero observations. In this respect, we will use in the rest of the paper the approximation $\mathrm{Ln}(1 + x) \approx \mathrm{Ln}(x)$; this approximation works best for $x >> 0$ where x is the variable of interest.[22] The approximation $Ln(1 + ICT\ capital) \approx Ln\ (ICT\ capital)$, for example, for ICT capital, is used to accommodate zero observations for ICT-capital. Note that construction and definition of all variables used are formally presented in Table A2 (in the appendix).

The theoretical framework of analysis that allows us to address our second research question is based on the framework of a production function. The production function is a specific functional form, which is used to model the production process by which inputs are transformed into outputs in firms. Inputs typically accounted for in this approach include labour and capital, including both ICT and non-ICT.[23] In addition to inputs, the production function may also vary with differences in the industry (j) in which a firm operates, and in country (c) and specified as follows:

$$Y_i = F(L_i, K_i, ICT_i; j, c) \tag{6}$$

Production Y_i is a function of labour L_i, ordinary-capital (non-ICT-capital), K_i, ICT-capital, ICT_i, industry and country variables. To examine the effect of ICT-capital on productivity, we are beginning by specifying a firm-level model where labour productivity (Y/L) is regressed on ICT-capital intensity (ICT-capital/L) and other relevant explanatory variables.

To perform this type of analysis, Cobb-Douglas or Transcendental Logarithmic functional (Translog) production functions are often used in the literature. To carry out our analyses, we will perform a hypothesis test to verify the functional form that will be more appropriate and adequate with the information available in our database. The different specifications of these production functions are presented below.

$$\frac{Y_i}{L_i} = \exp\left(\sum_{j=1}^{J} \eta_j J_j + \sum_{c=1}^{C} \lambda_c C_c\right)\left(\frac{K_i}{L_i}\right)^{\alpha}\left(\frac{ICT_i}{L_i}\right)^{\beta}, \qquad \text{for L,ICT and K} > 0 \tag{7}$$

Taking natural logarithms gives the following empirical econometric specification, where lowercase letters denote natural logarithms and $\delta_i \delta_i$ represent the error term.

$$y_i = \sum_{j=1}^{J} \eta_j J_j + \sum_{c=1}^{C} \lambda_c C_c + \alpha k_i + \beta ict_i + \delta_i \tag{8}$$

Where, $\mathbf{y_i}$ represent the natural logarithm of labour productivity, $\mathbf{k_i}$ denote the natural logarithm of ordinary-capital intensity, $\mathbf{ict_i}$ represent the natural logarithm of ICT-capital intensity and δ_i represent the error term.

- **The Translog functional form is specified as follow:**

$$y_i = \sum_{j=1}^{J} \eta_j J_j + \sum_{c=1}^{C} \lambda_c C_c + \alpha k_i + \beta ict_i + \mu (k_i)^2 + \theta (ict_i)^2 + \tau k_i * ict_i + \epsilon_i \qquad (9)$$

Where, ϵ_i represent the error term.

To check which of the two production functions mentioned (Translog or Cobb-Douglas) will be more adequate with our data, we will perform a hypothesis test, in which the null hypothesis is $H_0: \mu = \theta = \tau = 0$. If the null hypothesis is not statistically rejected, then the Cobb-Douglas specification will be the most suitable. If, on the other hand, the null hypothesis is statistically rejected, we will adopt the more general Translog specification in the rest of our analyses.

The hypothesis test will be performed using the Fisher statistic, which is formulated as follows:

$$F_{p,n-k} \frac{\left(\frac{SSR_H}{p}\right)}{\left(\frac{SSR}{n-k}\right)} \qquad (10)$$

Where, p is the number of simultaneous linear constraints which constitutes the null hypothesis, and SSR_H is the Sum of the Squares of the Residues obtained under constraints (means, when one estimates the parameters of the model by forcing to respect the null hypothesis). Also, $(n - k)$ is the number of degrees of freedom, with n the number of observations and k the number of independent variables of the model (including the constant).

The model presented in Equation 10 has been used in previous empirical studies (see, for example, Jeong & Heshmati, 2009; Constantin et al., 2009) to test whether the Cobb-Douglas or the Translog function would better represent the data at the industry or firm-level.

Using the Stata software, we obtain that the Fisher statistic is $F(3, 3098)$ = 32.94 and its p-value is $Prob > F = 0.0000$

So, the null hypothesis, $H_0: \mu = \theta = \tau = 0$ is statistically rejected, which means that the Translog production function is more adequate with our data. In this regard, we will use the Translog function model to estimate and interpret our results.

According to the literature on ICT and firms' productivity as discussed above,[24] we consider an extension of this basic framework, by introducing other firm's specific variables to allow the production function to vary by firm, instead of by industry only.

In this study, we will pay attention to address the potential issue of endogeneity in analysing the impact of ICT-capital intensity on labour productivity. Basic OLS estimates could potentially reflect simultaneity between input and output choices, or capture unobserved omitted firm-level characteristics. Addressing these issues is important to ensure that our results could be interpreted as causal. In this regard, we will adopt two main approaches.

First, we will augment our basic specification with a large battery of control variables, including various firm-specific characteristics, per capita training, share of female employment, age of the company, firms' size, ownership of the firm and the interaction term between ICT-capital intensity and main sector (industry variable). We are fortunate that the UNIDO database contains sufficient information on all these variables.

$$y_i = \sum_{j=1}^{J} \eta_j J_j + \sum_{c=1}^{C} \lambda_c C_c + \beta ict_i + \alpha k_i + +\mu(k_i)^2 + \theta(ict_i)^2 + \tau k_i * ict_i + \gamma_1 train_i + \gamma_2 femshare_i + \gamma_3 size_i + \gamma_4 age_i + \gamma_5 own_i + \gamma_6 ict_i * sect_j + \epsilon_i \quad (11)$$

The coefficient on ICT-capital intensity, β, gives the impact of ICT-capital intensity on labour productivity. To assess the factors that determine the strength of the ICT-capital–labour productivity relationship, we will introduce the OC and an interaction term between ICT-capital intensity and OC as below.[25] The measures of innovation activity offer the ways to proxy the Organizational Changes in our study.

$$y_i = \sum_{j=1}^{J} \eta_j J_j + \sum_{c=1}^{C} \lambda_c C_c + \beta ict_i + \alpha k_i + +\mu(k_i)^2 + \theta(ict_i)^2 + \tau k_i * ict_i + \gamma_1 train_i + \gamma_2 femshare_i + \gamma_3 size_i + \gamma_4 age_i + \gamma_5 own_i + \gamma_6 ict_i * sect_j + \eta OC_i + \pi ict_i * OC_i + \epsilon_i \quad (12)$$

Our second approach to tackle potential endogeneity involves using IV. Given that the bias of two-stage least squares is proportional to the degree of over-identification, Commander and Svejnar (2011), among others, suggest estimating the first-stage regressions with as few IVs as possible, while ensuring that the IVs have adequate explanatory power and pass the over-identification tests.

We use IV approach to empirically estimate our model in Equation 12. The IV estimator is used to control for the potential endogeneity of our primary variable of interest, ICT-capital. However, controlling adequately for endogeneity is not an easy task in survey data that do not come from a natural experiment.

We use two sets of instruments for ICT-capital intensity to estimate our model by the IV method. First, following Commander and Svejnar (2011), Schmidt (1988), and Marschak and Andrews (1944), we can use the skill ratio ($skillra_i$) as our first instrumental. It should nevertheless be noted that the relevance of skill ratio comes from economic optimization. However, in our study context particularly, we are working under assumption of Cobb-Douglas production function, exogeneity of input prices and we also assume that the firm maximizes profit or minimizes cost. Then, the first-order conditions indicate that the ratio of inputs equals the ratio of input prices and technological parameters. If the firm is a price taker in the input markets, the ratio of inputs reflects these exogenous factors.

Second, following Commander and Svejnar (2011) and Mahmut et al. (2011), we use the average values of ICT assets for other firms (j≠i) in a firm's main sector of economic activity for each country (av_oict_i) as our second instrumental variable, where the average is based on responses of either all other firms in one main sector in each country or all other firms of a given size in one main sector in each country.

The advantage of using the responses of other firms that are subject to the same external shocks is that the value of the constraint is not affected by the firm's own performance. Here, we assume that the main sector averages are independent of firm-specific effects (they are unaffected by firm idiosyncratic productivity or profitability shocks), these main sector-based instruments will be uncorrelated with error term, as required for valid instruments. Further, since the main sector-specific variables define the environment in which a firm operates (Jaffe, 1986), we can expect the endogenous variable and the instruments to be related.

The key identification assumptions implicit in this approach are that, on the one hand, the unobserved firm characteristics do not significantly affect skill ratio variable and sector variable, and on the other hand that, these instrumental variables are correctly excluded from the structural equations. Our analyses involving IV include tests for identification by Anderson canonical correlation statistic, weak instruments as suggested by Stock and Yogo (2005) and the Hausman (1978) test for endogeneity. Also, we perform the Hahn and Hausman (2002) weak instrument test, the Cragg-Donald (1993) test for model identification and the over-identification test of validity of all instruments proposed by Sargan (1958) and Hansen (1982).

4. Results

This research addresses an old conundrum, namely, the lack of observed productivity impacts of investments in computer equipment, in a new context, namely Africa, and using a large sample of firms covering several countries. In this sense, it has the potential to provide new evidence that would significantly enrich the existing knowledge on the relationships between ICT and productivity.

To address our first research question concerning the estimation of the determinants of the decision to adopt ICT-capital in SSA firms, Table 8 summarize the results obtained. Furthermore, the results reported in tables 9 and 10 allow us to address our second research question regarding the estimation of the impact of ICT-capital intensity on labour productivity in SSA countries when the role of Organizational Changes is considered.

Regarding Figure A1 (in the appendix), we can see certain dispersion in the data. One of the essential characteristics of the data being that, several observations for ICT-capital are zero. However, some firms have observations on age, size, ownership structure, income, but no observations on ICT-capital investments.

The sample is therefore censored, and one of the consequences being the questioning of the linearity hypothesis, reflecting the fact that OLS is not the relevant method for estimating such a relationship. In this perspective, we can apply the OLS estimator to all the observations, or we can apply it only to the observations for which $ict^* > 0$.

In doing so, the OLS estimator applied to all the observations is non-convergent and is therefore biased; while the OLS estimator applied to only observations for which $ict^* > 0$ underestimates the whole components of the gamma vector. Columns (1) and (2) of Table A3 (presented in the appendix) give an illustration of these results. The models include all the explanatory variables and a set of dummy variables for industries and countries.

First, note that Table 8 presents the estimation of the Tobit model. Columns (1) and (2) highlights the results of the estimation of the determinants of the adoption of ICT-capital when taking into account censoring problem, while controlling for dummy industries and countries. Marginal effects are presented in the last column.

Finally, after determining the factors that explain the decision to invest in the ICT-capital, tables 9 and 10 presents, on the one hand, the results of the estimation of the impact of ICT-capital intensity on labour productivity of firms in SSA countries without considering the potential endogeneity problem, and secondly, shows the results after correction of the endogeneity problem in the model.

Table 8: Estimation of Tobit regression with the censoring problem

Variables	Tobit		
	ict (1)	ict (2)	Marginal effects
income	0.268*** (0.036)	0.261*** (0.036)	0.216*** (0.029)
wages	0.532*** (0.054)	0519*** (0.055)	0.429*** (0.045)
age	-0.004 (0.003)	-0.003 (0.003)	-0.003 (0.003)
size			
Medium	1.069*** (0.154)	1.076*** (0.154)	0.866*** (0.122)
Large	1.495*** (0.187)	1.521*** (0.188)	1.246*** (0.153)
own	0.140 (0.121)	0.195 (0.121)	0.162 (0.101)
expshare	0.009*** (0.001)	0.005*** (0.001)	0.004*** (0.001)
cons	-5.291*** (0.483)	-5.306*** (0.519)	- -
Country dummy	No	Yes	Yes
Industry dummy	No	Yes	Yes
Obs.	4907	4907	4907
R-squared	-	-	-
Log likelihood	-11270.865	-11260.32	-
Pseudo R-squared	0.027	0.028	-
Left-Censored Obs. at ict<=0	1301	1301	-
Uncensored Obs.	3606	3606	-

Notes: Authors' estimations using AIS 2010, UNIDO. Standard errors reported in parentheses are robust to heteroscedasticity. *, ** and *** denote significant at 10%, 5% and 1% levels, respectively.

Columns (1) and (2) of Table A3 (in the appendix) presents the estimation of the basic model from OLS. In column (1), we account for all the values of ICT-capital and control for industries and countries and we can notice that the observations are 4,907. As explain above, OLS here produce a non-convergent and biased estimator. In column (2), we account only for the positives values of ICT-capital and control for industries and countries. The number of observations has decreased to 3,606 and R^2 has increased. However, the estimates coefficients obtained are underestimates, compared to the results obtained using the Tobit model.

Columns (1) and (2) of Table 8 presents the estimation of the determinants of the decision of adoption of ICT-capital using a Tobit model. In column (1) we do not take into account dummy variables for industries and countries, which over-estimates a little bit the estimated coefficients of income, wages and share of exports variables.

As announced in the descriptive statistics, we can notice that the coefficient of firm size is positive and highly significant. This would translate to the fact that large firms invest in ICT much more than small and medium firms because the latter have much less financial means compared to large firms.

Column (2) highlights the same estimation, and considers industries and countries dummy variables and we can observe that pseudo R-squared has increased. This estimation reveals that, when the censoring problem is corrected, the estimated coefficients of income, wages, size and share of exports remains significant, while the magnitude of the estimated parameters of income, wages and share of exports variables decline, but remained positives.

Ultimately, it emerges from this estimation that income, wages, size and share of exports are the drivers of decision to adopt ICT-capital intensity in SSA firms, and that age and ownership structure do not determine the decision to adopt ICT-capital in SSA firms. The last column presents the marginal effects for the Tobit estimation which are very close to results found in column (2).

After determining the factors influencing the decision to invest in ICT-capital, it is necessary to address our second research question, which consists in determining the impact of ICT-capital intensity on labour productivity of firms in SSA countries when taking into account the role of OC. The results of the estimations are summarized in tables 9 and 10.

Table 9: Estimation of ICT-capital intensity elasticity

Variables	Labour productivity		
	(1)	(2)	(3)
Ict	0.425*** (0.092)	0.379*** (0.093)	0.349** (0.129)
k	0.043 (0.082)	0.033 (0.084)	-0.055 (0.403)
Ict^2	0.009* (0.005)	0.007 (0.005)	0.003 (0.010)
K^2	0.035*** (0.004)	0.032*** (0.004)	0.033*** (0.006)
Ict*k	-0.043*** (0.008)	-0.037*** (0.008)	-0.026** (0.012)
Ict*sect			
Manufacturing	0.007 (0.018)	0.005 (0.018)	-0.004 (0.024)
Construction and Services	-0.002 (0.023)	0.001 (0.023)	-0.004 (0.029)
Utilities	-0.001 (0.018)	0.011 (0.019)	-0.018 (0.053)

Train		0.021** (0.009)	0.017 (0.015)
Size **Medium** **Large**		 0.212*** (0.062) 0.425*** (0.069)	 0.412*** (0.096) 0.773*** (0.114)
Age 5-10 years 11-20 years > 20 years		 0.187** (0.083) 0.262*** (0.074) 0.218*** (0.077)	 0.276** (0.133) 0.347*** (0.122) 0.229** (0.127)
Femshare		-0.251** (0.115)	-0.501*** (0.183)
OC			0.053 (0.283)
OC*Ict			-0.016 (0.048)
Cons	5.704*** (0.542)	5.594*** (0.546)	5.553*** (0.933)
Country dummy	Yes	Yes	Yes
Obs. R-squared Fisher	3007 0.436 72.18***	2963 0.451 63.56***	965 0.476 24.12***

Notes: Authors' estimations from AIS 2010, UNIDO, using OLS method. Standard errors reported in parentheses are robust to heteroscedasticity. *, ** and *** denote significant at 10%, 5% and 1% levels, respectively. We also control for industries and countries in all regressions.

Table 9 presents the determinants of labour productivity of firms in SSA countries without considering the endogeneity problem. The coefficients in column (1) are overestimated for ICT-capital intensity due to omitted variables and the endogeneity problems.

In column (2) of Table 9, the estimated coefficients decrease when adding controls variables for size, age and female share. But the estimated coefficients of ICT-capital remain higher due to the endogeneity problem which is present in the model. However, the estimated coefficients of age are significant at 1% for age groups over 11 years old and significant at 5% level of significance for female share. The estimated coefficients of interaction term between ICT-capital intensity and sector are positive and non-significant.

Column (3) of Table 9 reveals that, when considering the OC by adding OC variable and the interaction term between OC and ICT-capital intensity, the magnitude of estimated coefficients for interaction between ICT and ordinary-capital, size and age increase; while ICT-capital intensity and share of woman have decreased, reflecting the fact that the omitted variables problem has been treated.

The problem of endogeneity remains in the model and is reflected by the fact that the coefficients of ICT-capital and age remains higher even if they are decreased.

To address this potential endogeneity problem, we will use the IV method using the average levels of ICT assets for other firms (j≠i) in a firm's main sector of economic activity for each country (av_oict_i) and skill ratio ($skillra_i$) as excluded instruments.

In the light of Table 10, it appears in column (1) that the estimated coefficient of ordinary-capital intensity, ICT-capital, ordinary-capital squared and interaction between ICT-capital intensity and ordinary-capital are non-significant, proving once again the existence of omitted variables problem in this model, and requires the introduction of new relevant controls variables.

In column (2), the estimated coefficient of ICT-capital intensity remained lower, but significant at 10% level, while the estimated coefficient of ordinary-capital intensity remained non-significant and decreased a little bit when integrating in the model with other variables like size, age and share of woman.

We include in column (3) relevant control variables available in our database, including the OC and the interaction term between OC and ICT-capital. It appears that the estimated coefficients of OC and interaction term between OC and ICT-capital are not significant. This result, which is remarkable, deserves a much more in-depth analysis and could be explained by the characteristics of the firms present in our database. Also, the endogeneity problem is being solved, using the IV method with av_oict_i and $skillra_i$ as excluded instruments. Doing so, we can observe that the estimated coefficient of ICT-capital increase, but remains positive and is significant at 1%.

The coefficient of ordinary-capital squared remains positive and significant, when the coefficient of interaction between ICT-capital and ordinary-capital remains negative, but become significant at 10% level. This finding could indicate very well the substitutability between the two types of capital and the fact that, an increase in one would result in a decrease in the other.

The estimated coefficient of ordinary-capital squared, medium and large firms, firms' age between five and 20 years old have increased and are significant. These results are justified by the fact that the endogeneity problem that existed in the model has been corrected.

Table 10: Estimation of ICT-capital intensity elasticity account for the endogeneity

Variables	Labour productivity		
	(1)	(2)	(3)
Ict	0.052 (0.059)	0.065* (0.057)	0.086*** (0.054)

k	0.214 (0.281)	0.100 (0.268)	0.092 (0.311)
Ict^2	0.021 (0.084)	-0.004 (0.081)	-0.022 (0.058)
K^2	0.034*** (0.010)	0.031*** (0.010)	0.033*** (0.008)
Ict*k	-0.090 (0.059)	-0.061 (0.059)	-0.100* (0.056)
Ict*sect Manufacturing Construction and Services Utilities	 0.033 (0.021) 0.017 (0.025) 0.012 (0.019)	 0.029 (0.020) 0.015 (0.023) 0.019 (0.019)	 0.0005 (0.026) -0.0008 (0.032) 0.030 (0.067)
Train	-0.021 (0.019)	-0.013 (0.016)	-0.003 (0.023)
Size **Medium** **Large**		 0.091 (0.080) 0.186 (0.168)	 0.259** (0.118) 0.580*** (0.157)
Age 5-10 years 11-20 years > 20 years		 0.267*** (0.092) 0.315*** (0.081) 0.310*** (0.088)	 0.306** (0.141) 0.359*** (0.128) 0.387** (0.136)
Femshare		-0.299** (0.139)	-0.436** (0.207)
OC			0.393 (0.975)
OC*Ict			-0.084 (0.174)
Cons	2.462* (1.408)	2.912*** (1.341)	0.219 (2.52)
Country dummy	Yes	Yes	Yes
Obs. Centered R-squared Fisher	3006 0.286 63.76***	2962 0.333 57.58***	965 0.40 20.86***

Notes: Authors' estimations from AIS 2010, UNIDO, using IV method to account for the endogeneity problem. The average levels of ICT assets for other firms (j≠i) in a firm's main sector of economic activity for each country (av_oict_i) and skill ratio ($skillra_i$) are used as excluded instruments in all regressions. Standard errors reported in parentheses are robust to heteroscedasticity. *, ** and *** denote significant at the 10%, 5% and 1% levels, respectively.

The estimated coefficient of firms' age over 20 years old is 0.387, significant at 5% and translating to the fact that, on average, firms over 20 years old are 39% more productive than firms that are less than five years old. However, the coefficient of large-sized firms is 0.58 and significant at 1% level, which means that, on average, large-sized firms are 58% more productive than small firms. This could be explained by the fact that large firms are oversampled in our data.

The share of women is negative and significant at 5% level; specifically, when the share of women in a firm increase by 1%, labour productivity decreases by 0.44%. This could be explained by the fact that, in Africa, very few women receive training which predestined them to work in manufacturing firms, since it is very physical job for most. This result also shows that labour productivity is gender-dependent and suggests several ideas related to gender issues. It also highlights the need for adequate training of women directed towards companies; it also shows women's unequal access to have jobs in the firms.

5. Sensitivity analysis and tests of robustness

Sensitivity analysis

The sensitivity analysis consisted in subdividing our full sample into four sub-regions as shown in Table 1. After performing these manipulations, we made new estimates of Tobit model which allowed us to determine the various factors that influence the ICT-capital adoption decision, on the one hand and, on the other hand, we estimated the impact of ICT-capital intensity on firms' labour productivity using the IV method.

Given these estimations, we find that in terms of the estimation of the determinants of the ICT-capital adoption, when we correct for the censoring problem using the Tobit model, the results are practically like those found in the full sample; therefore these results are not very sensitive to the subdivisions performed. Specifically, it follows from these estimations that, share of exports, size, wages and income, are significant determinants of the decision of ICT-capital adoption. Age and ownership structure of firms determines the volume of investments in ICT-capital in two sub-regions, namely, East Africa and West Africa.

Regarding the estimation of the impact of ICT-capital intensity on labour productivity of firms performed using the IV method, it generally appears that the results reflect pretty much what we found in the full sample, and therefore, ICT-capital intensity has a positive and significant impact on firms' labour productivity. Especially in terms of the East Africa sub-region, the interaction term between ICT-capital intensity and OC is non-significant and, moreover, the impact of ICT-capital intensity on firms' labour productivity remains positive and significant at the 1% level of significance in the presence of OC.

Tests of robustness

In the light of Table A1 (in the appendix), which presents the correlation matrix between the endogenous variable ICT-capital intensity and exogenous instruments chosen, we can notice that each instrument is significantly correlated to the ICT-capital intensity variable. This information is important because Hahn and Hausman (2002) noted that the consequence of the use of the excluded instruments that are not correlated with the explanatory variable which is endogenous is to increase the bias in the estimated coefficients by the IV method.

To verify that our model is correctly identified, we implemented the under-identification test through the Anderson canonical correlation statistic. The null hypothesis of this test requires that the model is not identified against the alternative that the matrix of instruments is full rank and the model is identified. As a result, the p-value is 0.0085, and therefore the null hypothesis of non-identification of the model is rejected at the 1% significance level, meaning that the selected instruments are relevant.

Although the correlation between ICT-capital intensity and excluded instruments is significant, it should not be weak because the weakness of instruments drives the bias of IV method that is more severe than bias of OLS method. To check this, we conducted a test of the weakness of instruments proposed by Stock and Yogo (2005) which is the F-statistic form of the Cragg and Donald (1993) statistic. The null hypothesis is that a given group of instruments is weak against the alternative that is strong. The Cragg-Donald Wald F statistic is 24.532, and is greater than 17.62 which is 10% maximal IV relative bias; therefore, the null hypothesis of weakness of instruments is rejected in favour of the hypothesis of strong instruments.

To check whether the instruments chosen were valid, we performed the over-identification test of validity of all instruments proposed by Sargan (1958) and Hansen (1982). The null hypothesis for this test indicates that the instruments are valid and are not correlated with the error term. Upon completion of this test, the Hansen J statistic is 2.644, and the p-value is 0.667, which confirms the fact that our instruments are valid.

6. Conclusion and recommendations

There is extensive literature in the industrialized countries both on the determinants of the adoption of ICT-capital and on the impact of ICT-capital intensity on labour productivity. By contrast, in developing countries, and in SSA countries particularly, very few studies have focused on these issues. This study had set a goal to contribute to the literature and to fill this gap. To be more precise, the main idea of this paper was structured around two main objectives. The first research question conducted on our analysis was to identify and analyse the major determinants of the ICT-capital adoption in SSA countries. Our second concern was to estimate the impact of ICT-capital intensity on firms' labour productivity in SSA countries.

To answer these research questions, we postulated three hypotheses as follow. Firstly, the likelihood of ICT-capital adoption increases with the firm's income; secondly, the labour productivity of adopters increase with investments in ICT-capital intensity; and finally an increase in ICT-capital intensity is associated with an increase in labour productivity when OC is present.

The necessary data to this analysis were collected and harmonized by UNIDO in the AIS (2010), carried out in Africa over the period 2010-2011. The descriptive analysis of the data has revealed several information and among other things that, on average, ICT-capital investment varies according to firms' size while labour productivity vary according to the firms' age and that Southern African firms, on average, adopt and use ICT-capital more intensively than other Africans countries. Several lessons can be learned from this situation. In this regard, public authorities and development partners in this sub-region must work together to firstly strengthen connectivity by focusing on cost reduction of regional and national Internet backbones and secondly promote access to the Internet and make the bandwidth available while integrating ICT in the delivery of public services and sectorial projects to facilitate the application of ICT.

In order to carry out these investigations, the research methodology was inspired, on the one hand, by the Tobit model to correct the existing censoring problem in the available data and, on the other hand, by IV method required to address the endogeneity problem of ICT-capital intensity in the model. On completion of the various analyses of sensitivity and robustness checks, it is noted that the results obtained are very insensitive to sample subdivisions. Also, it emerges that the model is identified and that, the selected instruments are not weak and are valid.

Furthermore, it appears from this study that income, wages and firms' size are significant determinants of the ICT-capital adoption.

In view of the results obtained, we can see that the companies which have a high income and paying high wages have a high propensity to adopt ICT. Also, large and medium-sized enterprises as well as companies that export adopt ICT much more. However, at the policy level, government and policy makers must provide support through programmes designed to facilitate the adoption of ICT by all firms in general, but particularly small business unable to export their goods and services and firms paying low wages.

Compared to the Cobb-Douglas production function, the Translog production function has been tested to be more adequate with our data set. Moreover, using the Translog model, the study reveals that the impact of ICT-capital intensity on labour productivity in SSA countries is positive and significant in the presence of OC. This means that firms investing in ICTs significantly improve their productivity and hence their performance. This would allow these firms to become more competitive, more offensive and, ultimately, this could logically allow them to increase their market share.

Also, the estimated coefficient of ordinary-capital squared, firms' size and firms' age are positive and significant, after correction the endogeneity problem in the model using IV method.

The share of women is negative and significant at 5% level of significance. This suggests several ideas related to gender issues. It highlights the need for adequate training of women directed towards firms; it also shows women's unequal access to have jobs in the firms.

The OC and the interaction term between OC and ICT-capital are non-significant. This result is remarkable and requires more advanced investigations in future work. Maybe there could be a study on the impact of OC, but not for all types of firms, that deserves special attention in a future paper.

It's therefore important, not only to improve access to ICTs by government and public authorities, but also to generate the policies necessary to advancing the ICT skills, knowledge and capacities of workers at the firm level. Also, firms' owners must put their hands in the dough to develop skills and training of employees and managers in the firm so that they can effectively use available and existing resources and infrastructure.

Given that some firms cannot afford to pay for training for their workers, policy actions such as developing a flexible design for ICT training, electronical learning courses and exchange mechanisms for ICT skills training resources, as well as fostering ICT education at all levels should be followed more intensively. This will lead to more adequately trained ICT practitioners and users to meet the growing needs of firms.

Firms' managers should be encouraged to implement OC within their firms, because OC are very complementary investments in ICT-capital, and this could allow firms to significantly increase their productivity.

In addition, policy makers and development community interested in promoting ICT as tools for improving business could use the results of this study to better develop their strategies. Finally, we expect that through dissemination activities, African firms will be sensitized and informed on the ways they can use the most of ICT-capital to improve their productivity.

Notes

1 Software includes acquisition of pre-packaged software, customized software and software developed in-house.
2 See, Jorgenson and Stiroh (1999), Baldwin and Sabourin (2002), Jorgenson and Vu (2007) and Van Reenen et al. (2010).
3 OC here refers to managerial practices carried out within the company such as innovation, decentralization of management levels, restructuring of business processes, and others.
4 Asongu and Nwachukwu, (2018) argues that, Africa generally has the lowest ICT penetration rate in the world.
5 Firstly, technological context refers to adopter perceptions of technological attributes. Secondly, organizational context includes descriptive characteristics of the organization. Thirdly, environmental context refers to the organization's industry, government, competitors and its dealings with trading partners.
6 The constraints faced by enterprises in developing countries are, among others, related to high costs of Internet service provision, inadequate regulatory environment and poor infrastructure; while in developed countries this is not the case.
7 This is particularly in the improvement of the quality of output and labour input, the variety of products, quality customer service and reducing delays.
8 Agriculture in this survey represents all the companies that deal with: fertilizers and pesticides, farm implements and inputs, and agricultural machinery.
9 Size groups (Small-Medium-Large), has been measured in terms of number of full-time employees, output and fixed assets. In the surveys notes, UNIDO has mentioned that, size groups in terms of output and number of full-time employees depends on the country. However, assets have kept the same measure in all countries of the database.
10 OECD in 2008 recommended the 10% threshold to define the ownership. The AIS (2010) survey follows the OECD definition of ownership which considers all Foreign Direct Investment (FDI) that gives the foreign investor ownership of 10% or more of the shares of a firm as FDI.
11 A full description of the design and implementation of the survey is available in UNIDO (2011).
12 The distribution by sub-region is presented as follows. Southern Africa: Lesotho, Madagascar, Malawi, Mozambique and Zambia; Central Africa: Cameroon; East Africa: Burundi, Ethiopia, Kenya, Uganda, Tanzania and

Rwanda; West Africa: Burkina Faso, Cape Verde, Ghana, Mali, Niger, Nigeria and Senegal.

13 We are referring to the age of the firm and not to the age of the employees.

14 This report is the first of a series of five Regional Integration Strategy Papers (RISP) for North Africa, West Africa, Central Africa, East Africa and Southern Africa, that the AfDB has launched.

15 The OC is not available for all firms in our sample, but was asked from all of them. So, this is one possible explanation for the low number of observations for this variable. To define OC, we use the survey question: "During the last three financial years, has this company introduced any new or significantly improved production processes including methods of supplying services and ways of delivering products? If yes, please specify the process."

16 The theoretical model and the estimation method were inspired by Cameron and Trivedi (2010).

17 This approach has been used in the literature when there are zero observations in order not to lose observations (see, for example, Mahmut et al. [2011]; Paul et al. [2000]).

18 See, for example, Bresnahan (1999), Brynjolfsson and Hitt (2000) and Dedrick et al. (2003).

19 See, Bresnahan (1999), Brynjolfsson and Hitt (2000) and Commander et al. (2011), among so many others.

20 Brynjolfsson et al. (2000) show that when OC is included in the model, it increases market valuation and decreases the amount attributable to ICT. They also reveal that market valuation effects are greatest for firms that have high levels of investment in both ICT and OC; these underlines, once again, the complementarity of the two factors. This complementarity has also recently been mentioned by commander et al. (2011) by introducing into their model an interaction term between ICT-capital and OC to understand how ICT has an impact on performance.

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Appendix

Table A1: Correlation matrix between ICT-capital intensity and excluded instruments

	ict	av_oict	Skillra
ict	1.0000		
av_oict	0.1471***	1.0000	
Skillra	0.1251***	0.1536***	1.0000

Notes: Authors' computations using AIS 2010, UNIDO. *** denote significance at the 1% level.

Table A2: Construction and definition of all variables used in empirical models

Variables	Description
LP: Labour Productivity	Value added per worker.
ICT: ICT-capital	Sum of intellectual and ICT assets at the end of last financial year in USD.
ICT/L: ICT-capital intensity	Sum of intellectual and ICT assets at the end of last financial year in USD over full-time employee.
K: Ordinary-capital	(Total value of current assets at the end of last financial year in USD - Sum of intellectual and ICT assets at the end of last financial year in USD).
K/L: Ordinary-capital intensity	(Total value of current assets at the end of last financial year in USD - Sum of intellectual and ICT assets at the end of last financial year in USD) over full-time employee.
Train: Training intensity	Total training expenditures (external plus internal training), in USD over full-time employee.
OC: Organizational Changes	Company has introduced new or significantly improved products/services into the market during last three financial years (Yes/No). 1 if Yes and 0 if No.
age: age of the company in the regression and selection equations	Age of the company in years.
age: age of firm when determining the impact of ict-capital on productivity	Age of company, categorical variable (1: <5 years, 2: 5-10 years, 3: 11-20 years, 4: >20 years).

Adopt: Adoption	1 if firm has invested in ICT assets (ICT assets > 0); 0 if firm has not invested in ICT assets.
expshare: Exportation Share	Total exports over sales (%).
femshare: Female Share	Share of female full-time employment in total full-time employment (%).
income: Income of firms	Total sales in USD.
market orientation: Market orientation of firms	Local market seeking (exports <10%); Regional market seeking (exports >10%, SSA exports>50%); Global market seeking (exports >10%, rest exports>50%).
own: Ownership structure	Domestic (foreign ownership < 10%); Foreign (10%>=foreign ownership =<100%).
Skillra: Skill ratio	Skill ratio classification of the manufacturing sector (based on quartiles of mean manufacturing skill ratio).
wages: firms' wages	Total wages and salaries, in USD.
L: Workers	Total number of full-time employees.

Note: Authors' construction using UNIDO's AIS 2010-2011.

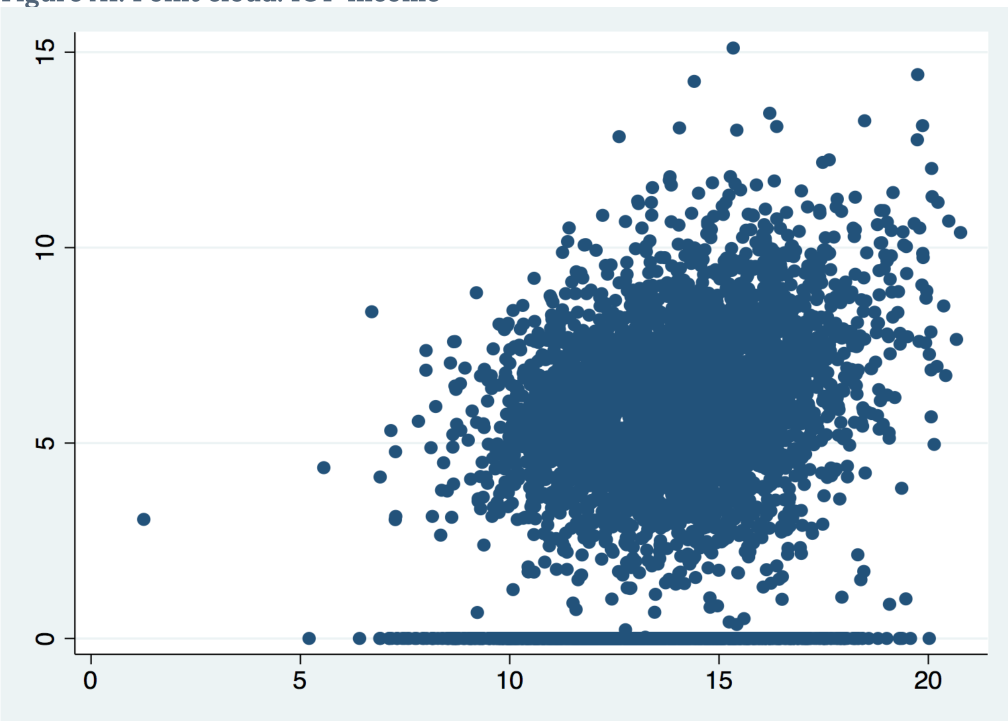
Table A3: Estimation of basic OLS model

Variables	**Basic model (OLS)**	
	ict all (1)	**ict >0 (2)**
income	0.180*** (0.027)	-0.0001 (0.021)
wages	0.441*** (0.040)	0.502*** (0.032)
age	-0.002 (0.003)	0.0002 (0.002)
size **Medium**	0.769*** (0.110)	0.507*** (0.077)
Large	1.257*** (0.144)	1.275*** (0.107)
own	0.155* (0.091)	0.116* (0.062)
expshare	0.004*** (0.001)	0.004*** (0.0009)
cons	-2.765*** (0.368)	0.686** (0.283)
Country dummy	Yes	Yes
Industry dummy	Yes	Yes

Obs.	4907	3606
R-squared	0.139	0.206
Log likelihood	-	-
Pseudo R-squared	-	-
Left-Censored Obs. at ict<=0	-	-
Uncensored Obs.	-	-

Notes: Authors' estimations using AIS 2010, UNIDO. Standard errors reported in parentheses are robust to heteroscedasticity. *, ** and *** denote significance at 10%, 5% and 1% levels, respectively.

Figure A1: Point cloud: ICT-income



Source: AIS 2010, UNIDO.

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