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ICT Use, Innovation, and Productivity

Evidence from Sub-Saharan Africa

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Abstract

This paper examines empirically the links between adoption of information and communications technology (ICT), defined as usage by firms, innovation, and productivity using firm-level data for a sample of six Sub-Saharan African countries: the Democratic Republic of Congo (DRC), Ghana, Kenya, Tanzania, Uganda, and Zambia. Although adoption of information and communications technology in these countries is still lagging behind OECD countries, there is significant heterogeneity on adoption rates across the countries. Kenya has the largest adoption rate of computer, software, and Internet usage. The Democratic Republic of Congo and Tanzania experience lower adoption rates. The degree of internationalization of the firm, use of technology, and extent of competition are important factors explaining firm-level use of ICT. The results of the estimates suggest that ICT use is an important and robust enabler of product, process, and organization innovation across all six countries. However, the final impact on productivity depends on the degree of novelty of the innovation introduced by the firm.

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ICT Use, Innovation, and Productivity: Evidence from Sub-Saharan Africa

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1. Introduction

Low productivity growth is one of the main factors hindering economic growth in many developing economies, especially in Sub-Saharan African. One potential enabler of productivity growth is the adoption and use of information, communication and technology (ICT). ICT can facilitate productivity growth by making use of production factors more efficiently and facilitating the adoption of other technologies. The potential for ICT as a productivity enabler is even larger in those regions farthest away from the technological frontier, such as Sub-Saharan Africa, which until now tended to have lower ICT adoption rates and underdeveloped ICT infrastructure.

The extent of the contribution of ICT towards economic growth is still under debate; even when this issue is investigated using data from the developed world. The early empirical literature in the 1970s and 1980s measuring whether the significant implementation of ICT as a new technological revolution had an impact on productivity growth found inconclusive evidence; coined as the "productivity paradox" or "Solow Paradox".[2] Pilat (2004) suggested several factors that contributed to the "productivity paradox" including the limited capability of aggregate data (at country and/or sector level) to measure properly the impact of ICT on productivity growth.[3] This debate still continues today and it remains an open question about the extent to which ICT can boost productivity growth.[4]

Despite the existing caveats, some literature reviews such as Pilat (2004), Draca et al (2006) and Litan and Rivlin (2001) suggest a positive effect of ICT on productivity growth; although there is some evidence of publication bias in the literature that could overemphasize this positive impact of ICT on productivity. According to Polak (2014), the average estimated ICT elasticity is positive but very small, 0.3%. One possible explanation for this small impact could be the fact that ICT is embedded in many capital and production technologies, which makes it difficult to separate the sole impact of ICT related investments from the impact of production factors.

The objective of this paper is twofold. First, it aims to contribute to the existing empirical literature on the impact of ICT on productivity. Our approach focuses on one specific channel through which ICT can impact productivity: *ICT as an innovation enabler*. Second, and more importantly, our objective is to shed light on the role of ICT in firm level productivity for a sample of African countries. The current low productivity levels in African firms suggest that the enhancing effect of ICT could be potentially large. However,

[2] Solow (1987) has remarked that "computers were everywhere but in the productivity statistics".
[3] Other factors are: some of the benefits of ICT were not picked up in the productivity statistics; benefits of ICT use took a considerable time to emerge, as some other key technologies, such as electricity; small samples of firms drawn from private sources.
[4] This has been pointed out by a recent article from The Economist (2014).

although the impact of ICT on productivity growth could be greatest when firms are far away from the technological frontier, lack of adequate complementary factors such as skilled workers and late ICT adoption could constrain the extent to which ICT impacts firm productivity. While there is a plethora of anecdotal evidence regarding the ICT sector in Africa, there is very little evidence on the impact of ICT in other productive sectors of the economy more broadly; which is where most of the potential gains for poverty reduction and shared prosperity are concentrated.

To explore these questions empirically, we use firm-level data for six African countries - DRC, Ghana, Kenya, Uganda, Tanzania and Zambia, from the enterprise survey 2013 and the companion 2014 innovation module. The survey has an ICT module that measures computer, software and internet use; and it is comparable across the six African countries.

Overall, the findings of the paper suggest that larger, younger, more internationalized –foreign owned, importers, certified and with foreign technology license firms that are financially unconstrained and operate under higher degrees of competition are more likely on average to adopt ICT practices. The results also suggest a positive and significant impact of ICT on innovation; measured along the dimensions of the firm's products, processes and organizational practices. Consequently, we find that ICT acts as an important enabler of innovation. The impact of these innovations on productivity are, however, only significant when more "radical" definitions of innovation are adopted. The results for the country by country regressions are more heterogeneous and show a more complex picture, but the positive impact of ICT on innovation is robust across countries and types of ICT.

The paper is structured as follows. The next section summarizes the existing evidence on the impact of ICT on productivity, mainly in OECD countries. Section 3 briefly defines ICT and section 4 describes the methodology used. Section 5 provides a description of ICT use in these six African countries. Section 6 assesses whether ICT firms are more productive, as well as measuring the impact of ICT on productivity. The last section concludes.

2. The Impact of ICT use on productivity: A brief literature review

The literature analyzing the impact of ICT on productivity is summarized in Table A.1 in the Appendix. In this section we provide a short summary of the main results of this literature.

The adoption of ICT has been increasing steadily and rapidly over the years. Although ICT includes a diverse range of applications, internet adoption is an illustrative example of how ICT has been spreading rapidly across firms. Loundes (2002) showed that the percentage of businesses using internet in Australia more than doubled in three years. In 1998, 29% of Australian businesses used internet, while it increased to 69% in 2001. Recent data show that internet penetration is reaching nearly all enterprises in the developed world; 97.9% of businesses with ten or more employees in OECD countries have internet connection (OECD 2012). Even developing countries have a high percentage of firms using ICT. For instance, the percentage of Turkish and Mexican firms using internet is over 90%, according to OECD (2012). However, adoption of ICT is not evenly distributed across all types of firms. Walczuck et al. (2000) have pointed out that small firms in the Netherlands are not adopting internet at the same speed as their larger counterparts.

Rapid ICT adoption raises important questions about what the ensuing effects might be on firm operations. For instance, Bloom et al. (2009) investigate how ICT affects worker autonomy, distinguishing between reduction of costs in communication and information. According to their findings, worker autonomy shrinks for the former while in the later, decisions are decentralized and worker autonomy increases. Their findings, however, are silent regarding how workers' autonomy affects productivity.

Several papers have analyzed empirically the link between ICT and productivity. At the sector level, Basu et al. (2003)[5] examine how the adoption of ICT could explain differences in US and UK productivity performance. Their focus is on the impact via the reduction of ICT prices. According to the authors, cheap ICT capital is likely to create major changes only if firms can deploy their other inputs in radically different and productivity-enhancing ways. By comparing UK and US performance, the authors reached the conclusion that unmeasured investments in intangible organization capital associated with the role of ICT can explain the divergent productivity patterns of these two countries after 1995.

Similar arguments are used in papers using plant level data, such as in Bartel et al (2005) and Bartel et al. (2009). These papers suggest that the reduction of ICT costs induces ICT investments, which eventually diminish the cost of setup time and raise production of customized products. As a result, firms require more skilled labor leading to productivity growth. Bartel et al (2005) corroborate these channels using valves manufacturing plant level data from the US; and Bartel et al (2009) show that the effect of increased labor skills requirements complementary to ICT are stronger in the UK than the US, also using plant level data for the same valves manufacturing sector.

Using firm-level data, Bresnahan et al (2002) also suggest that the reduction of ICT prices increases investments in work organization and product and service innovations, which raise the demand for skilled workers enhancing productivity growth. Their research, using US firm level data from 1987 to 1994, found evidence of complementarities among all three types of innovations (IT, complementary workplace reorganization and new products and services). In other words, firms adopting innovations tend to use more skilled labor, and the effects of ICT on labor demand are greater when ICT is combined with organizational investments. In sum, they highlight the importance of ICT as an enabler of organizational change, which leads to productivity growth. Using the same firm level data, Brynjolfsson and Hitt (2003) specifically investigate the effect of computerization on productivity and output growth. According to the authors, ICT affects productivity because firms change their production processes and engender complementary innovations within and across firms. Their main conclusion is that the estimated contributions of computerization to output growth steadily increase in the long run. In the short run, measured output contributions of computerization are approximately similar to computer capital costs, but in the long run their contribution is significantly greater than their costs.

Therefore, one strand of this literature argues that productivity gains are reinforced by ICT investments if complementary investments in organization capital are conducted jointly, as found in Crespi et al. (2006) and Commander et al (2011). Crespi et al. (2006) investigate this issue using UK firm-level data from 1998 and 2000. The authors reached similar conclusions as in the previous literature, such as the fact that ICT and organizational change interact in their effect on productivity growth. In addition, the authors find that organizational change is affected by competition, which leads to more innovation as found in Kretschmer et al. (2012). Commander et al. (2011) evaluate this linkage by utilizing firm-level data from two large

[5] Another example of sector level analysis is Fernald (2014).

developing countries: Brazil and India. Their results suggest that firms which have undertaken complementary organizational investments have a higher elasticity between ICT investments and productivity. Moreover, poorer infrastructure quality and pro-worker labor regulation are both associated with lower levels of ICT capital intensity and with lower returns to ICT capital investment.

Another set of papers assume computers are direct inputs into the production function as a specific form of capital; see for example Atrostic et al (2004). The authors investigate this issue using firm-level data from three countries (US, Japan and Denmark). Their main finding is that computers are used to organize or streamline the underlying business processes.

Among all types of ICT investments impacting productivity, internet adoption is the main application investigated by the literature. Sánchez et al. (2006) assess the internet impact on productivity using Spanish firm-level data. According to the authors, there are three channels through which internet may impact productivity: (i) by significantly reducing the cost of many transactions necessary to produce and distribute goods and services; (ii) by increasing management efficiency, especially by enabling firms to manage their supply chains more effectively and to communicate more easily both within the firm and with customers and partners, and; (iii) by increasing competition, making prices more transparent, and broadening markets for buyers and sellers, which puts pressure on suppliers to adopt techniques that translate into cost savings. Their main conclusion of the paper suggests a positive impact of internet adoption on productivity yet at a decreasing rate after a certain level of usage has been reached.[6]

Closer to the spirit of this paper, Polder et al. (2010) investigate the impact of ICT on productivity using data for more than 5,000 Dutch firms from 2002 to 2006. The authors include ICT investments as innovation inputs similar to the treatment of R&D investments in the framework proposed by Crepon et al (1998). The authors' main hypothesis is that the channel through which ICT impacts productivity is through the innovation processes. Thus, ICT is an input to the innovation process, like other knowledge inputs such as R&D, for both technological innovations in the firm's products and processes and non-technological innovations through the firm's organizational practices. In other words, ICT enables higher productivity levels through innovation processes since it is an input raising innovation outputs and eventually leading to higher firm performance. The authors' findings suggest that ICT investments and usage are important drivers of innovation outputs in manufacturing and services. Moreover, they find that the strongest productivity effects are via organizational innovation.

In summary, the literature describes four main channels through which ICT can enhance firm level productivity:

- Improving the autonomy of workers and potentially increasing their labor productivity
- Enhancing the quality of production inputs
- Enhancing organizational and management quality
- Facilitating technological and non-technological innovation

[6] Measured at 83.5% of effective work hours using the internet.

The literature also emphasizes the importance of complementarities in the impact of ICT on productivity; mainly the role of skilled labor in enhancing ICT and the importance of implementing organizational changes.

In this paper and given the availability of data, we focus on the role of ICT as an innovation enabler, which can result in any of the four channels impacting productivity described above.

3. Defining ICT

Information and communication technology (ICT) is defined as the use of computers and other electronic equipment and systems to collect, store, use, and send data electronically. Therefore, ICT is an umbrella term that includes any communication device or application, such as cellular phones, computer and network hardware and software, as well as various services and applications associated with them, such as internet and videoconferencing.

4. Methodology

In order to estimate the impact of ICT on performance, and following the literature, we adopt and expand the framework developed by the Crepon-Douguet-Mairesse (CDM) model (Crepon et al., 1998). The framework is grounded on the idea that firms invest in knowledge inputs, including ICT, which can be transformed into innovation outputs according to the efficiency of their innovation function. Subsequently, these innovation outputs impact productivity contingent on the capacity of firms to transform innovation outputs into improvements in product quality and efficiency. As a result, the CDM model requires the estimation of three stages: determinants of innovation inputs, the knowledge or innovation production function and a productivity equation.

4.1 Determinants of innovation inputs

4.1.1 R&D and knowledge investments

In the traditional CDM model, investments in R&D are the main innovation inputs. In the literature, Polder et al (2010) is one example of distinguishing innovation inputs into two categories: R&D expenditures and ICT investments. In terms of R&D expenditures, both data on internal and external R&D expenditures are available at the firm level, and these are added together in order to construct our measure of R&D expenditure. However, R&D in developing countries tend to be low and not the main knowledge investment. As a result, we also include knowledge expenditures from two other knowledge investments - acquisition of equipment for innovation and training of workers for innovation activities.[7] Thus, our knowledge intensity is as a sum of R&D expenditures, training and equipment deflated by the number of firm's employees and converted to constant US dollars for ease of comparison across countries.

[7] One problem with this variable is that it is censored not only by those not investing but also by firms not reporting or underestimating R&D, since some of it might be performed informally by workers. As a result, one way for adjusting for this potential problem is by using predicted values in the second stage.

Table 1 Variable description

Variables	Description
Knowledge intensity	
Computer Index	Index constructed using standard normalized variables of computer use
Internet Index	Index constructed using standard normalized variables of internet use
ICT Index	Index constructed averaging computer and internet index
R&D+ intensity (RD+/L)	Intramural and extramural R&D expenditure plus training and equipment expenditure per worker
Innovation outputs	
Product innovation	Dummy with value 1 if any new or significantly improved product or service introduced by this establishment.
Process innovation	Dummy with value 1 if any new or significantly improved process introduced by this establishment.
Organization innovation	Dummy with value 1 if establishment make any changes in its organizational structure by creating, dissolving or merging any units of departments
Productivity	
Sales per worker (sales/L)	Logarithm of sales per worker
Firms' Market Condition and Access to Finance	
Access to Finance Obstacles	How much of an obstacle is access to finance. Index 0 not an obstacle to 4 severe obstacle
	This is the principal component of two indices how much of an obstacle is transport and customs and trade regimes. Index 0 not an obstacle to 4 very severe obstacle.
Market Share Change	Market share growth in terms of employment in the last three years
External Market	Export and Import dummies
Informal Sector Competition	How much practices of informal sector is an obstacle. Index 0 not an obstacle to 4 severe obstacle.
Demand Increasing	Dummy indicating whether firm's demand has increased by evaluating revenue or employment growth.
Technology Push Factors	
Certification	Dummy whether a firm has an international recognized quality certification
Foreign Technology	Dummy whether a firm use technology licensed from a foreign-owned company
New Capital in Previous Year	Dummy whether a firm has purchased any new fixed asset in the last fiscal year
Firm characteristics	
Log (K/L)	Capital intensity defined as the log of the ratio of capital to labor in the firm
Educational Obstacles	Dummy created for those which inadequately educated workforce presents major or severe obstacles
Foreign Status	Whether the firm is at least 25% foreign owned
Age	Log of firms' age
Log(L) – Size	Log of employment
Percentage of High School	Percentage of workers with high school degree
Sector Dummy	Dummy based on SIC classification
Country Dummy	Dummy for each country

The determinants of knowledge input intensity can be characterized by three sets of factors that are commonly found in the literature (in the Schumpeterian tradition) (Crepon et al., 1999): 1) firm characteristics, 2) the firm's market conditions (including demand pull and technology push factors), and 3) the investment climate.[8]

Table 1 summarizes the main variables used in the analysis. Firm characteristics include size, age or foreign capital ownership. We also include measures of the degree of the firm's acquired complementary capabilities proxied by the share of skilled employees with formal education.

Firm's market conditions, especially the degree of competition, can be important for incentivizing investments in innovation inputs. Demand pull factors are captured by changes in the firm's market share over the past three years, the degree of integration in international markets such as whether the firm exports or imports, and the extent to which informal firms pose a major obstacle to the firm's competitiveness.

Technology push factors can also be important to generate these investments. We use whether the firm has obtained certification, whether it has licensed any foreign technology and whether a firm has acquired any new capital in the last year.

Finally, lack of finance can be an important deterrent to knowledge investments. As a result we also add to the specification an index variable 1-4 to measure the extent to which the firm reports lack of finance as an obstacle.

4.1.2 The ICT equation

One important gap in the data is that we do not have information on how much firms invest in ICT. This implies that we cannot look at the direct impact of ICT capital on productivity. However, information on different uses of ICT enable us to construct an index of ICT use at the firm-level. Information of ICT use in the questionnaire can be divided into computer and internet use, which are:

1) Computer Use
    - Percentage of workers' using a computer regularly;
    - Whether a firm has purchased or developed any software in house;
    - Whether a firm has IT staff;
    - Total cost spent on hiring an external computer or software consultant;
2) Internet Use
    - Communication: whether a firms uses internet for internal communication among its employees or with clients and suppliers;
    - E-commerce: whether a firm uses internet for online purchases or sales;
    - Information: whether a firm uses internet for managing inventory; marketing products; or researching of developing ideas on new products and services.

Therefore, the data allow us to divide ICT use into two separate ICT sub-components: computer use (including software) and internet use. Computer and software use capture potential improvements in productivity more related to the production process, while internet use can generate productivity improvements via reducing information costs, enabling e-commerce and facilitating communication.

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[8] See Cohen and Levin (1989).

Given the lack of ex ante information on what specific sub-dimensions of each ICT use are more important, we calculate a synthetic index for each ICT use using the average of the normalized sub-components in each country. For computer use, we use four variables; two indicator variables and two continuous variables (percentage of workers' using a computer regularly and total cost spent on ICT consultants). Given the potential for large sector differences in these continuous variables, we re-scale the values as the ratio to the sector mean and then we normalize them by subtracting the sample mean and divide them by the standard deviation.

Regarding internet use, there are nine indicators which are standard normalized. Then, the internet use index is created by averaging all standard normalized variables. Finally, an aggregate ICT total index is created by averaging the computer and internet indexes.

Regarding the determinants of ICT, we consider ICT adoption as another investment in knowledge and tangible and intangible assets, and adopt the same specifications as with knowledge investments. In addition to controlling for firm characteristics such as size, age or foreign capital ownership, we focus on identifying the impact of demand and technological factors on adopting ICT practices. In particular, one area that has received some attention in the literature is the impact of increased competition on the adoption of ICT practices. Kretschmer, Miravete, & Pernías (2012) examine the impact of the liberalization of the European automobile distribution system in 2002 and how competitive pressures positively impacted the adoption of software that allowed expanding the sales. In our specifications we focus on the impact of increased competition via changes in market share and also whether firms perceive competition from the informal sectors as significant.

4.1.3 Estimation method

Our knowledge investment intensity variable presents a substantial number of zero values and missing observations, which requires the use of a particular econometric technique to estimate their determinants. The OLS log linear model will exclude a large number of firms with zero investments. In this regard, a Poisson estimator is a good alternative because as Santos-Silva and Tenreyro (2006) show in the context of the trade gravity equation, this estimator provides consistent estimates of the underlying data, even if it does not follow a Poisson distribution.

Regarding our ICT indexes, these are constructed by standard normalizing them which presents a distribution similar to a normal distribution. Therefore, we estimate its determinants by Gaussian approach. Despite their differences, their measures denoted by E_{it} from a firm i in time t are related to another latent variable E^*_{it} such that

$$E_{it} = E^*_{it} = \beta'_2 x_{2it} + \varepsilon_{2it} \text{ when } \beta'_2 x_{2it} + \varepsilon_{2it} > 0 \text{ and zero otherwise} \quad (1)$$

In any particular year t, x_{2t} corresponds to the exogenous explanatory variables that determine knowledge inputs. Disturbances for equations (1) for each input innovation measures are assumed to be *iid* normally distributed. As suggested above we follow Crepon et al. (1998) and focus in the groups of variables suggested above- firm characteristics, demand and competitiveness factors, technological factors and access to finance.

4.2 Innovation function: Product, process and organization

Innovation inputs generate innovation outputs and outcomes. The World Bank Enterprise survey contains information about whether firms implemented technological innovation outcomes (product & process innovations) and non-technological innovation outputs (organizational innovations).[9] For product and process innovation, firms are asked whether they introduced any new or improved product or service, or any innovative new process. For these technological innovation outcomes, there is also information on the degree of innovation in terms of what is defined by "new"; specifically, whether the innovation was new to the firm, local market, national market or international market, respectively.

Organizational innovations are another dimension of innovation that rely less on technological progress but can nonetheless bring about significant improvements in firm performance. We measure organizational innovation through a series of questions that capture whether a firm has undertaken any new organizational method in its business practices, workplace organization or external relations. Specifically, we consider a firm as having introduced an organizational innovation if it engaged in any of the following: 1) outsourced tasks, made changes to external relations, 2) made changes in its management structures, integrated departments/units, or 3) acquired management systems for information and knowledge (proxied by whether it made any changes to its hiring practices of employees or managers). Organizational innovations can improve firm performance such as its productivity by lowering costs, improving the workplace environment, and acquiring knowledge from external sources.

Questions on organizational innovation, however, were only implemented to medium and large size firms, which reduces the estimation sample by more than half. Therefore, our preferred model includes only product and process innovations.

Specifically, the three innovation outputs can be defined as:

$$PD_{it} = \beta_3' X_{3it} + \varepsilon_{3it} \qquad (2)$$

$$PCS_{it} = \beta_4' X_{4it} + \varepsilon_{4it} \qquad (3)$$

$$ORG_{it} = \beta_5' X_{5it} + \varepsilon_{5it} \qquad (4)$$

Where X_3 to X_5 include innovation input variables from equation (1). As with some of the ICT inputs, levels of generated knowledge are latent, or unobserved. In this case, we only observe whether a firm had a certain type of innovation or not. Therefore, we define L(.) as an indicator function which takes the value 1 if the condition is true and zero otherwise. Formally:

$$PD_t = L(PD^*_t > 0) = L(\beta_3' X_{3t} > \varepsilon_{3t}), \qquad (5)$$

$$PCS_t = L(\beta_4' X_{4t} > \varepsilon_{4t}), \qquad (6)$$

$$ORG_t = L(\beta_5' X_{5t} > \varepsilon_{5t}) \qquad (7)$$

One important element in the decision to innovate is that firms decide simultaneously what innovation outputs to produce based on existing knowledge capital investments. As a result, one should expect some

[9] The survey also has information on marketing innovation, as well as other innovation outputs such as whether the firm has applied for a patent or a trademark.

correlation between the decisions to carry out product and process innovations, and perhaps organizational innovations. In other words, it implies that:

$$\varepsilon_t = (\varepsilon_{3t}, \varepsilon_{4t}, \varepsilon_{5t})' \sim N(0, \Sigma) \quad (8)$$

In terms of defining the set of explanatory variables used, we follow the literature on the determinants of innovation outcomes. Firms' size and age are used as controls. For skilled labor, this is proxied by whether inadequately educated workforce is a major or severe obstacle for their development. For competition, we use whether practices of competitors in informal sector presents major or severe obstacles for them as well as whether firms revenue or employment has increased in the last three years. Whether a firm has an internationally-recognized certification is also used to capture firms' innovation quality. Degree of integration in international markets is measured by firms' export status. Finally, sector and country dummies are included.

4.3 Productivity equation

The final stage to estimate the impact of innovation on firm performance is to derive the productivity equation. We approximate productivity using a Cobb-Douglas function where sales (Y) are a function of capital (K), labor (L) and innovation outputs (H), equation (9) below:

$$Y_{it} = f(H_{it}, K_{it}, L_{it}) \quad (9)$$

$$Y_{it} = H_{it}^{\delta} K_{it}^{\alpha} L_{it}^{\beta} \quad (10)$$

$$(Y_{it} / L_{it}) = (H_{it}^{\delta} K_{it}^{\alpha} L_{it}^{\beta} / L_{it}) (L_{it}^{\alpha} / L_{it}^{\alpha})$$

Transforming equation 6 in logarithm form and adding sector controls (Z_{it}), we have

$$\log (Y_{it} / L_{it}) = \delta_0 + \delta \log (H_{it}) + \alpha \log (K_{it} / L_{it}) + (\beta+\alpha-1) \log(L_{it}) + \theta Z_{it} + \varepsilon_{it} \quad (11)$$

Equation (11) is estimated by OLS, yet there is a potential simultaneity between innovation outputs and performance. In order to tackle this issue, we use predicted values of innovation outcomes as instruments. Eventually, our equation to be estimated turns to:

$$\log (Y_{it} / L_{it}) = \delta_0 + \delta_1 \log (\hat{H}^{prod}{}_{it}) + \delta_2 \log (\hat{H}^{proc}{}_{it}) + \ + \delta_3 \log (K_{it} / L_{it}) + \delta_4 \log(L_{it}) + \theta X_{it} + \varepsilon_{it} \quad (12)$$

Equation (12) is estimated by OLS. For controls, we have used sector dummies in all estimation and country dummies when estimating all countries jointly. We also estimate equation (12) adding organizational innovation, although there is a significant number of observations lost when doing so.

4.4 Solving the model

Estimating the model presents several challenges. The first challenge is the potential reverse causality between knowledge inputs and innovation outcomes - i.e. more innovation can trigger more knowledge investments and ICT - and between knowledge outcomes and performance – i.e. the most productive firms are more successful in innovation. Solving each model separately raises endogeneity issues and would otherwise lead to biased coefficients, and consequently over or underestimate the true effects of innovation on productivity. For example, unobserved factors that make a firm more likely to invest in R&D might be correlated with firm's higher levels of productivity (selection). Alternatively, unexpected shocks that lead to higher chances that innovation outcomes are successful in the second equation may also (positively) affect productivity outcomes in the third equation (simultaneity).

There have been two main approaches in the literature on how to solve the model. Crepon et al. (1998) suggest solving the model simultaneously using Asymptotic Least Squares.[10] Meanwhile, Griffith et al. (2006) assume that there are no feedback effects and solve the model sequentially, instrumenting knowledge activities in the innovation equation, and innovation outputs in the productivity equation, to avoid endogeneity.

In the original CDM model, the authors solved the model simultaneously using Asymptotic Least Squares (ALS), a minimum distance estimator.[11] This approach is advantageous when the joint distribution of observed variables does not have a closed form and when numerical integration techniques are computationally burdensome. Consistent estimates are first obtained in each equation via maximum likelihood, and then the structural parameters are obtained by minimizing their distance to the reduced form estimates using the empirical covariance matrix weighting function.

Most subsequent papers have followed a sequential approach, where predicted values of one endogenous variable are entered in the estimations of the other equations, correcting for standard errors by bootstrapping methods and using IV in each stage to account for endogeneity, see Griffith, Huergo, Mairesse, and Peters (2006). One benefit to this approach lies in its ability to take into account measurement issues arising in the nature of survey data. For example, firms that do not report undertaking R&D may in fact still possess knowledge outputs. However, one drawback from this approach is that it does not allow to correlation across the different stages that are captured using a structural methodology. Furthermore, standard errors may be underestimated in the model's last stage.

Recent advances in numerical simulation techniques have made possible solving of the model by full information maximum likelihood with given distributions for the random part of the model. This approach is able to fully exploit the complex interactions in the data without relying on approximations to functional forms. Mohnen and Hall (2013) discuss the tradeoffs between efficiency and robustness to misspecification. Hall, Lotti, and Mairesse (2009) find similar results comparing estimation, although larger standard errors using simultaneous maximum likelihood of all three stages than the sequential method. One extension they do not consider is to allow correlation between disturbances in the SEM model. The approach we follow is, therefore, to estimate the model simultaneously using the SEM estimator in STATA. For robustness, we also estimate the model sequentially using instruments of innovation inputs and outcomes as in Griffith et al. (2006) and compare the results with the SEM estimates.

5. ICT use in a sample of African countries

5.1 The data

We use data collected by the Enterprise Surveys innovation modules. The survey was implemented mainly in 2014 and has one section regarding ICT use that complements the section on innovation. Overall, the

[10] This implies solving the knowledge function, innovation equation, and productivity equation simultaneously by maximum likelihood using as initial values the estimates of solving the model sequentially in the first place.

[11] Alternatively, the model could be solved by GMM but it has been shown to be less efficient in large samples.

data set has around 3,000 observations equally distributed between the manufacturing sector and other sectors excluding agriculture (see Table 2); manly services and within services wholesale and retail. The survey targeted formal firms only and excluded micro firms, although a few firms on the survey are de facto micro when surveyed and have less than 5 employees.

Table 2 Number of Firms according to their size, sector and country

	Manufacturing			**Services and others**			
	small(<20)	**Medium (20-99)**	**Large (100 and over)**	**small(<20)**	**Medium (20-99)**	**Large (100 and over)**	***Total***
Ghana	193	66	18	164	84	14	***539***
DRC	108	48	14	140	39	6	***355***
Tanzania	163	68	35	170	80	12	***528***
Uganda	129	50	25	168	55	11	***438***
Zambia	131	109	21	200	51	21	***533***
Kenya	104	100	76	153	81	31	***545***
Total	***828***	***441***	***189***	***995***	***390***	***95***	***2938***

Source: Author's own elaboration from enterprise surveys

The ICT section provides information on computer and software use and different types of internet use.[12] In the next sub-sections, we provide a detailed overview of computer and internet use for the six African countries of our sample.

5.2 Computer use

On average, around 2/3 of African firms have at least one employee using a computer regularly. Table 3 shows the percentage of firms in these six countries which has at least one person using a computer regularly. On average, 62.9% of African firms in these countries has a regular computer user in 2013, percentage comparable to Australian firms in 1997/98, according to Loundes (2002). However, differences are substantial across countries, since it is only 40.9% in Tanzania yet it reaches to nearly 90% in Kenya. Recent data from the European Union (EU) shows that 97% of firms located in this region has a computer. Therefore, we may infer that Kenya is more similar to European countries than to other parts of Africa.

*This percentage is greater in services in most of the countries, yet differences are small on average. A*frican countries show similar pattern as EU countries: Services having a higher percentage of firms with computer than manufacturing. Zambia is the only country showing a percentage in manufacturing higher than in services. Across sectors, the manufacturing sector shows more variance than services. While the minimum in services is over 60% (Hotel and Restaurants, 60.1%), in manufacturing the minimum use reaches 36.9% in Garments.

[12] The survey also provides information on mobile phone use.

Table 3 Firms Using Computer Regularly by Country (Percentage in terms of All Firms)

Sectors	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	68.8	53.7	40.4	56.3	69.1	88.2	62.7
Main Sectors							
Manufacturing	66.8	46.0	41.4	42.5	76.8	86.1	60.0
Services	70.8	56.3	40.0	60.8	67.0	89.1	64.0
Sectors							
Food	72.4	76.5	57.0	56.7	85.9	77.6	71.0
Textiles	35.4	0.0	19.3	61.4	88.6	84.9	48.3
Garments	37.0	6.6	61.8	40.8	38.2	-	36.9
Wood	24.0	40.6	51.1	19.5	40.9	81.2	42.9
Publishing, printing, and Recorded media	91.9	90.2	81.0	100.0	100.0	100.0	93.9
Chemicals	95.3	79.1	63.9	100.0	100.0	98.5	89.5
Plastics & rubber	96.0	100.0	100.0	57.5	79.5	100.0	88.8
Non metallic mineral products	77.3	69.7	26.3	94.4	64.4	100.0	72.0
Fabricated metal products	45.1	34.9	35.5	17.0	89.5	100.0	53.7
Machinery and equipment	-	10.6	0.0	27.0	86.7	100.0	44.9
Furniture	48.5	26.4	20.6	31.0	48.6	100.0	45.9
Other Manufacturing	87.4	59.3	26.8	97.3	91.2	98.6	76.8
Construction	88.1	87.8	26.4	18.7	100.0	100.0	70.2
Services of motor vehicles	53.6	77.8	41.0	55.5	90.5	95.4	69.0
Wholesale	78.4	78.0	37.8	69.5	57.1	77.8	66.4
Retail	59.8	54.4	47.6	57.9	70.4	87.3	62.9
Hotel and restaurants	71.2	40.7	34.3	67.4	54.9	91.9	60.1
Transport Section	97.7	62.4	52.8	61.9	69.2	100.0	74.0
IT	91.1	92.2	-	90.9	100.0	100.0	94.9

Source: Author's own elaboration from enterprise surveys

Larger, younger and medium-aged, international traders and foreign owned firms are more likely to use computers. As Table 4 suggests, larger and medium sized firms are more likely to use computers. Medium aged firms are also more likely to use computers on average, although in Kenya young firms show high computer use and in Tanzania young firms show little computer use. Also, as expected more internationalized firms, via trading or foreign ownership, have larger prevalence of computer use. Firms that are only importers show a higher percentage of computer use than only exporters (see Table 4); although two-way traders are the firms with more computer use in most countries. Overall computer use appears to be quite high among all kinds of Kenyan firms, while computer use is low among Tanzania and DRC firms.

Table 4 Firms Using Computer Regularly by Categories at Country Level (Percentage in terms of All Firms)

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Size							
Small	57.3	48.8	34.3	60.0	67.4	81.5	58.2
Medium	89.7	74.4	59.6	35.3	67.5	96.8	70.5
Large	98.6	94.1	68.9	89.6	100.0	100.0	91.9
Age							
age<5	68.6	51.7	16.9	58.4	70.5	91.8	59.6
age 5-9	69.2	46.8	33.4	53.7	64.1	98.3	60.9
age 10-14	67.3	51.6	50.3	73.0	79.6	95.2	69.5
age 15-19	71.3	57.6	38.6	73.0	88.3	81.2	68.3
age 20-24	70.7	64.1	53.7	53.3	63.6	90.6	66.0
age 25-29	78.7	78.9	39.3	51.5	67.7	74.0	65.0
age 30-34	62.4	88.7	64.0	32.6	72.5	90.1	68.4
age>34	60.7	75.6	41.5	38.7	38.0	81.7	56.0
Trade							
No Trader	63.5	51.4	39.9	50.8	67.5	86.5	59.9
Importer	93.7	66.6	68.6	100.0	96.6	99.1	87.4
Exporter	78.2	65.6	35.5	81.4	67.0	89.1	69.5
Two-way	90.8	100.0	55.7	100.0	100.0	89.3	89.3
Foreign Status							
Domestic	64.1	50.0	42.3	58.0	64.9	88.0	61.2
Foreign	97.0	72.5	26.2	42.8	84.9	88.7	68.7

Source: Author's own elaboration from enterprise surveys

On average, only 20% of African firms have developed or purchased any software recently. Across countries, Kenya and DRC show the highest percentage of firms that have purchased or developed software (over 30%), while only 10% in Tanzania (see Table 5). On average, firms in the services sector tend to invest more in software than those from the manufacturing sector. As expected, the percentage of firms purchasing or developing software increases with firms' size.

Table 5 Firms which have developed/purchased any Software by Categories at Country Level (% All Firms)

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	11.2	30.5	10.0	14.3	24.4	30.3	20.2
Main Sectors							
Manufacturing	9.4	23.5	8.2	12.9	22.8	31.3	18.1
Service	12.9	32.8	10.7	14.8	24.9	29.9	21.1
Size							
Small	7.0	28.2	7.9	14.0	22.1	22.2	17.1
Medium	17.9	37.8	16.6	14.2	24.2	39.7	25.4
Large	25.6	61.1	22.0	21.0	58.5	46.1	38.4

Source: Author's own elaboration from enterprise surveys

Table 6 Computer and Software Index by Country, Sector and Size

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	86.07	104.93	74.47	80.07	107.98	119.52	100.00
Main Sectors							
Manufacturing	87.79	95.28	82.74	85.19	109.94	118.88	99.84
Services	84.29	108.12	71.39	78.40	107.44	119.80	100.15
Size							
Small	74.56	98.00	70.49	81.13	103.21	100.71	83.12
Medium	100.44	131.10	84.28	71.86	104.30	140.55	117.25
Large	145.55	179.08	116.21	101.83	190.28	160.90	157.23

Source: Author's own elaboration from enterprise surveys

Table 7 Firms with Internet Connection by Country (Percentage in terms of Firms Using Computer)

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	57.7	27.6	21.9	23.0	49.5	72.7	42.1
Main Sectors							
Manufacturing	56.1	33.3	21.9	17.8	64.5	73.5	44.5
Services	59.5	25.7	21.9	24.7	45.2	72.4	41.6
Sectors							
Food	60.7	65.3	38.2	22.7	71.6	59.6	53.0
Textiles	35.4	0.0	13.2	32.9	65.9	80.3	37.9
Garments	37.0	5.6	6.8	1.6	22.1	-	14.6
Wood	18.7	23.2	31.6	14.2	40.9	81.2	35.0
Publishing, printing, and Recorded media	77.9	79.3	74.6	94.1	100.0	67.6	82.3
Chemicals	100.0	63.5	38.7	100.0	83.5	98.5	80.7
Plastics & rubber	80.9	100.0	69.7	0.0	68.7	100.0	69.9
Non metallic mineral products	50.8	36.3	22.5	78.3	49.6	100.0	56.2
Fabricated metal products	38.0	17.4	16.6	6.4	71.6	100.0	41.7
Machinery and equipment	-	9.7	0.0	27.0	78.9	97.1	42.5
Furniture	27.2	9.5	12.8	0.8	30.1	100.0	30.1
Other Manufacturing	74.0	69.6	9.6	34.9	83.2	91.1	60.4
Construction	82.6	87.8	26.4	6.5	86.6	100.0	65.0
Services of motor vehicles	45.8	26.1	24.4	28.5	59.8	77.3	43.7
Wholesale	72.9	55.3	29.5	24.6	29.6	62.1	45.7
Retail	43.7	16.6	24.0	24.9	43.6	74.8	37.9
Hotel and restaurants	52.9	16.4	16.4	28.5	35.7	60.2	35.0
Transport Section	90.0	52.9	46.2	25.4	59.4	93.4	61.2
IT	91.1	78.6	0.0	3.0	96.9	79.1	58.1

Source: Author's own elaboration from enterprise surveys

5.3 Internet use

Internet use varies significantly across African countries. Among those firms using a computer regularly, the percentage of them which has an internet connection is less than 50% (see Table 5); which is below other developing countries like Mexico and Turkey.[13] In this regard, Kenya shows the highest percentage (72.7%) and differences across sectors are low compared to other countries. Less than a quarter of firms using a computer in Tanzania and Uganda have internet access. Manufacturing tends to have a higher proportion of firms with internet, especially in DRC and Zambia.

Table 8 Firms with Internet Connection by Categories at Country Level (Percentage in terms of Firms Using Computer)

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Size							
Small	43.8	20.9	18.0	21.3	44.2	64.4	35.5
Medium	83.0	58.7	34.2	19.3	56.4	83.1	55.8
Large	95.5	63.7	42.9	80.4	93.3	87.6	77.2
Age							
age<5	58.4	20.6	16.9	26.4	43.2	66.8	38.7
age 5-9	59.8	33.0	15.2	23.4	42.6	81.9	42.6
age 10-14	57.2	14.6	18.9	31.1	60.3	69.6	41.9
age 15-19	55.9	41.5	29.5	16.5	62.0	69.1	45.7
age 20-24	66.1	31.7	33.9	22.5	53.4	83.9	48.6
age 25-29	45.6	34.2	23.1	36.6	54.2	59.4	42.2
age 30-34	51.0	49.1	38.4	9.1	58.7	78.9	47.5
age>34	55.2	45.8	22.2	13.6	27.8	69.9	39.1
Trade							
No Trader	51.2	24.8	21.7	21.2	45.2	70.8	39.1
Importer	84.1	55.8	16.7	93.7	83.2	95.2	71.4
Exporter	74.9	37.3	25.8	27.3	55.8	70.4	48.6
Two-way	72.3	100.0	46.6	74.6	100.0	89.3	80.5
Foreign Status							
Domestic	52.6	21.4	23.3	23.2	44.3	72.3	39.5
Foreign	88.3	60.7	16.1	20.9	67.7	76.9	55.1

Source: Author's own elaboration from enterprise surveys

Younger firms are not more connected to the internet compared to older firms. Regarding firm characteristics, internet use and computer use are highly correlated: larger and more internationalized firms are more likely to adopt internet. One small difference is that middle-aged firms tend to adopt more internet use. In general, we expect that there is a propensity for younger firms to adopt more often new technologies such as internet; however, this pattern is not observed in these African countries. One possible explanation might be the higher cost of internet access. Even for more developed countries like OECD members, costs remain an important barrier for internet adoption as reported in OECD (2004). When looking at firms' size,

[13] More than 90% of Mexican (2008) and Turkish (2010) businesses with over 10 employees has access to internet, according to OECD (2012).

the figures corroborate this suggested explanation, because the percentage of firms having internet connection increases substantially with firms' size (see Table 6). While in OECD countries differences are less than 5% (small is 95% on average and large, 99.6%), large firms in Africa show a percentage that is more than the double than small firms. Foreign, importers and two-way traders exhibit higher shares compared to other firms.

On average, more than 50% of firms with internet connection purchase or sell online. Huge differences emerge comparing countries regarding e-commerce. For instance, the percentage of firms doing e-commerce in Ghana is half of what is observed in Kenya. Manufacturing firms not only purchase online more than firms in the service sector but also sell more online, yet the difference is small (less than 5%). The percentage of firms selling online is higher than those purchasing online in all different firm sizes.

Table 9 Firms doing E-commerce (Percentage in terms of Firms with Internet Connection)

Type	Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Purchasing Online	**Aggregate**	31.0	47.7	55.6	70.0	51.5	60.1	52.7
	Main Sectors							
	Manufacturing	33.8	36.0	79.8	75.9	50.4	55.9	55.3
	Service	28.1	53.0	46.5	68.6	51.9	62.1	51.7
	Size							
	Small	25.4	46.5	48.8	66.0	49.1	57.7	48.9
	Medium	35.8	48.1	68.9	70.2	51.7	58.7	55.6
	Large	39.7	56.5	59.0	93.4	66.3	72.7	64.6
Selling Online	**Aggregate**	29.9	39.8	68.4	65.8	53.4	61.2	53.1
	Main Sectors							
	Manufacturing	32.3	37.5	79.6	79.3	51.0	56.6	56.0
	Service	27.6	40.8	64.2	62.5	54.4	63.3	52.1
	Size							
	Small	23.7	34.9	65.1	59.5	52.4	58.6	49.0
	Medium	29.8	44.5	75.7	75.4	48.6	61.8	55.9
	Large	60.6	63.6	65.8	90.3	72.8	69.8	70.5

Source: Author's own elaboration from enterprise surveys

Table 10 Firms Managing Inventory on the Internet (Percentage in terms of Firms with Internet Connection)

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	30.6	54.3	89.2	77.5	50.4	63.2	60.9
Main Sectors							
Manufacturing	37.1	53.0	93.4	81.5	53.6	65.3	64.0
Service	24.1	54.9	87.5	76.7	49.2	62.2	59.1
Size							
Small	23.1	50.4	85.2	72.7	53.4	62.2	57.8
Medium	36.6	52.9	97.4	86.2	42.2	63.1	63.0
Large	46.1	84.0	85.1	94.0	53.4	66.8	71.6

Source: Author's own elaboration from enterprise surveys

Nearly 90% of Tanzanian firms with internet connection manage inventory on the internet. On average, 60% of African firms use internet to manage their inventory, Tanzania and Uganda showing the highest percentage (see Table 10). Manufacturing firms tend to use more the internet for managing inventory compared to service firms. The percentage of small and medium firms managing their inventory is very close to the average.

More than 70% of firms with internet connection in Uganda, Zambia and Kenya do marketing on the internet. Table 11 shows the percentage of firms with internet connection that do marketing on the internet. While manufacturing firms tend to use more internet for this purpose, it is not standard for all countries. Manufacturing firms in Kenya and Zambia, for instance, tend to do less marking online compared to firms in the service sector.

Table 11 Firms Doing Marketing on the Internet (Percentage in terms of Firms with Internet Connection)

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	39.8	40.8	64.4	72.7	72.9	70.6	60.2
Main Sectors							
Manufacturing	45.6	59.2	69.7	76.4	70.3	64.5	64.3
Service	34.0	31.6	62.2	71.9	73.9	73.5	57.8
Size							
Small	37.0	30.4	62.4	68.5	66.2	59.9	54.1
Medium	41.4	49.2	70.1	81.7	84.3	81.6	68.1
Large	47.8	80.4	54.1	85.5	84.0	81.0	72.1

Source: Author's own elaboration from enterprise surveys

Kenya is by far the country with larger internet intensity use from the six African countries. Looking at the internet index described above for all African countries, Kenya's internet intensity is higher than other African countries (see Table 12). At the sector level, manufacturing firms uses more internet than firms in the service sector. Moreover, huge differences emerge while looking at the firms' size. On average, the internet index is nearly three times higher in large firms than small firms.

Table 12 Internet Index by Country, Sector and Size

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	91.26	62.33	59.78	66.04	105.45	152.08	100.00
Main Sectors							
Manufacturing	94.07	70.50	63.69	59.66	138.19	149.85	104.63
Service	88.33	59.64	58.32	68.13	96.37	153.07	95.44
Size							
Small	66.96	49.92	50.82	60.04	93.79	127.72	69.15
Medium	131.40	109.98	88.33	61.97	118.59	179.86	137.33
Large	173.20	190.94	98.35	218.55	211.61	204.18	187.76

Source: Author's own elaboration from enterprise surveys

5.4 Overall ICT intensity

The overall ICT index is a combination of the internet index and the computer and software index. Table 13 shows the ICT index by country, sector and firm size. Kenya shows the highest index followed by Zambia, Ghana, Uganda and Tanzania. Although the manufacturing sector shows a higher index, the difference is not substantial. On the other hand, larger firms have ICT index values that more than double those of small firms.

Overall, the descriptive analysis suggests the following three findings: (i) firms in Kenya are those with larger ICT use; (ii) the differences in ICT use between manufacturing and services are not significant; and (iii) larger firms show significantly larger levels of ICT use than small firms.

Table 13 ICT Index by Country, Sector and Size

Categories	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya	Average
Aggregate	88.77	82.78	66.83	72.78	106.67	136.45	100.00
Main Sectors							
Manufacturing	91.05	82.39	72.84	71.92	124.63	134.99	102.33
Service	86.39	82.91	64.59	73.06	101.68	137.10	97.70
Size							
Small	70.61	73.00	60.26	70.17	98.31	114.76	75.85
Medium	116.54	120.12	86.39	66.72	111.73	160.99	127.69
Large	159.93	185.25	106.92	162.53	201.37	183.41	173.10

Source: Author's own elaboration from enterprise surveys

6. ICT use, innovation and productivity

6.1 Are ICT adopters more productive?

A critical challenge when examining the relationship between ICT adoption, innovation and productivity, is reverse causality; while ICT use can increase productivity, it is also possible that only more productive firms adopt ICT. In what follows, we start exploring this question by looking at basic distribution plots between labor and multifactor productivity and ICT adoption. Specifically, we focus in two categories of ICT adoption: computer users and internet users. We use the relative distribution of productivity between adopters and non-adopters as a first approximation for stochastically dominance, which provides a better measure of productivity differences between these groups than evaluating it by simple averages.

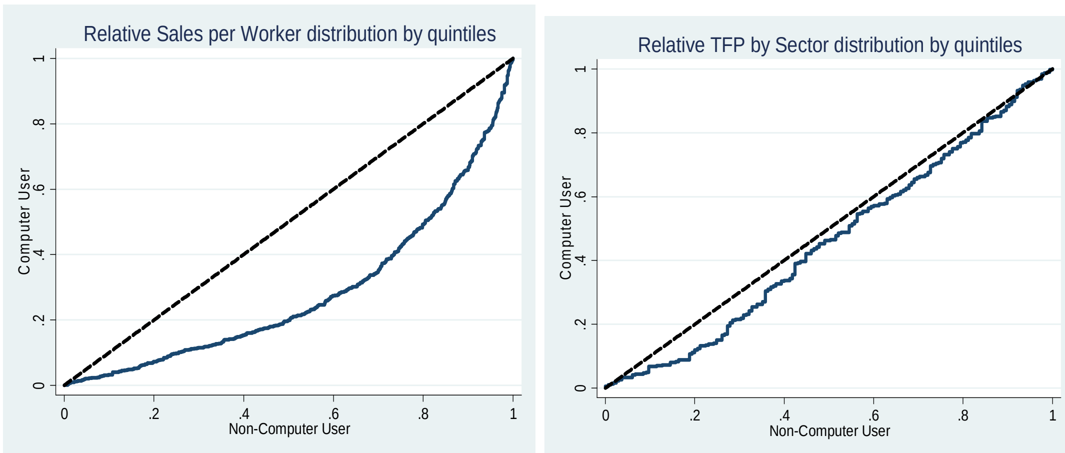
Computer users are more productive than non-users. Figure 1 shows the relative distribution of labor productivity for all firms in all countries pooled together, measured by sales per worker, and of total factor productivity (TFP) estimated at the sector level.[14] As observed, differences between computer users and non-computer users are wider in labor productivity compared to TFP. Computer users show higher productivity level throughout the whole relative distribution of labor productivity. Looking at their averages, computer users are four times more productive than non-users. Regarding TFP, productivity differences between computer users and non-users are larger for low productivity firms than for most productive firms. Evaluating at their mean, computer users are 26.2% more productive than non-users in terms of TFP.

Internet users are also more productive than non-users. Observing the distribution of internet users versus non-users (Figure 2) shows similar results as for computer use; internet users tend to be more productive than non-internet users regarding labor productivity. For TFP, there are no productivity differences for very

[14] Figures using value added per employee as labor productivity and TFP measures using sector as a dummy are available in the Appendix.

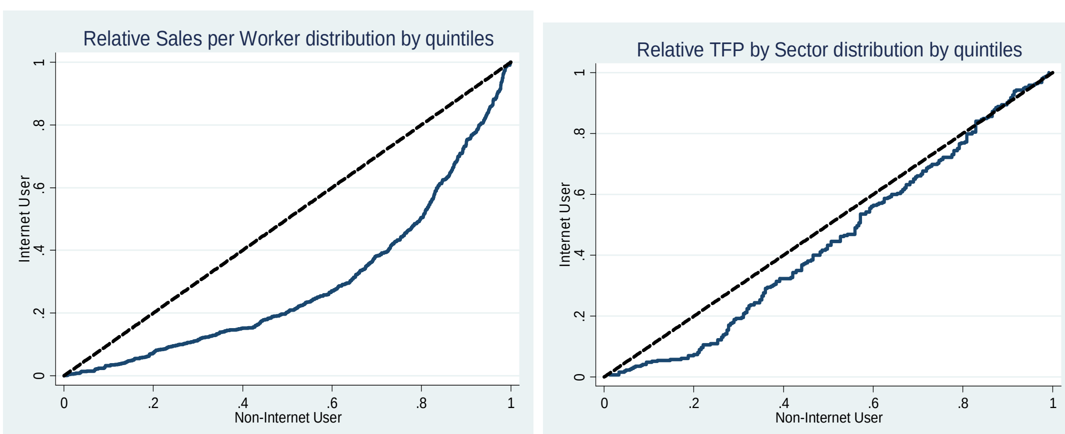
low and high productivity firms. Looking at their averages, internet users are 3.7 more productive than non-users in terms of labor productivity and 34.7%, in terms of TFP.

Figure 1 Computer Users versus Non-Computer Users



Source: Author's own elaboration from enterprise surveys

Figure 2: Internet Users versus Non-Internet Users



Source: Author's own elaboration from enterprise surveys

Therefore, the graphs above suggest that while ICT adopters tend to be more productive than non-adopters, there is no statistical dominance, at least for TFP. This implies that although it is likely that there is some self-selection of more productive firms into ICT adoption, there could also be some impact of ICT on productivity. This issue is explored in detail in the next section.

6.2 ICT as an innovation enabler

In this section we implement the methodology developed in section 4. As described earlier our main hypothesis is that ICT acts as an enabler to innovation, which in turns affects productivity. As a result, we adopt the CDM framework and integrate an ICT adoption equation in the model and also use ICT as an additional input for innovation.

As described above, we estimate the model simultaneously using the SEM estimator by maximum likelihood. The model is estimated on the full sample and also on individual countries (Tables 14 to 19). We report the baseline model for all individual countries, but discuss additional robustness based on the pooled regressions. One important added value of our methodology is that we can also allow for correlation in the innovation equations and estimate the model with unrestricted variance and covariance matrix. In this case, the innovation equations are based on a linear probability model, rather than a Probit. All equations control for sector effects using 2-digit ISIC dummies. The pooled results also have country dummies.

6.2.1 The determinants of ICT adoption

Column (5) in tables 14 to 21 show the determinants of ICT adoption. In Table 15 we differentiate between the internet index (column (5)) and the computer and software index (column (6)). Starting with the determinants of overall ICT adoption in Table 14, the estimates suggest that larger, younger and more internationalized – via ownership or via importing (not exporting) - firms are more likely to adopt ICT. Technological factors also play an important role inducing adoption since ISO certified, firms with new capital stock, with a technology license are more likely to adopt ICT. Also, firms with adequate complementary factors such as more skilled labor and that face lower problems of financial access are more likely to adopt ICT. Finally, our results also highlight the importance of increased competition via reduction in market share as an important element inducing ICT adoption.

In Table 15, we report similar estimates but differentiating between ICT internet and ICT computer and software. The results are very similar to those reported in Table 15 for the overall index with two differences. The impact of competition inducing ICT adoption is only significant via the Internet index and not computer and software. Second, technological factors such as the use of technological license from a foreign company is also significant mainly for the internet index.

Tables 16 to 21 display the results at the country level. The sample is reduced significantly and for some of the countries we estimate the model with less than 300 observations. For the individual estimates there is more heterogeneity in the results and mainly size and the level of skilled labor are robustly determinants of ICT adoption in most countries.

While the computer and software index reflect mainly whether firms use computers and have developed purchased software, the internet index is significantly more complex. This is because it goes beyond internet adoption and implies the use of internet for different organizational and management practices. Tables A3.1 to A3.3 show individual estimates of specific types of internet use; internet for management inventory, internet for marketing and e-commerce. Columns (1) and (2) of the tables estimate the model for the pooled sample. In column (2) we estimate the model using a mixed model nested in sectors and then countries.

The results for inventory and marketing are very similar to the ones discussed above for the synthetic indices. Explaining the determinants of e-commerce is, however, harder, especially after controlling sector effects. In the case of e-commerce larger firms, with new capital, ISO certification, more skilled labor and lower access to finance constraints are more likely to introduce internet trading. As a result, technology and complementary factors appear to be key drivers for e-commerce.

One interesting element of the disaggregated ICT uses is the impact of competition. The competition variable seems to be important inducing marketing and inventory management, but it is not a significant determinant of e-commerce. This suggests that competition induces organizational and management changes in the use of internet, although not in the case of e-commerce. In general, the impact of competition from informal firms is not significant, suggesting that either ICT adoption is not an option to compete against these firms, or given the significant impact of size, that ICT adopters are not the firms that face the strongest competition from informal firms.

Table 14 Base model estimations - Pooled sample

Pooled sample	**(1) Log(sales/l)**	**(2) Product innovation**	**(3) Process innovation**	**(4) R&D+ per worker**	**(5) ICT total index**
Log(K/L)	0.1869***				
	(0.028)				
Log(L)	0.3014***	0.0121	0.0229**	0.1152	0.2006***
	(0.054)	(0.010)	(0.010)	(0.088)	(0.016)
Product Innovation	-0.0214				
	(0.121)				
Process Innovation	0.0811				
	(0.122)				
ICT Index		0.0922***	0.1057***		
		(0.015)	(0.015)		
RD+/L		0.0076*	0.0166***		
		(0.004)	(0.004)		
Log(age)		-0.0133	0.0097	0.1893	-0.0522**
		(0.015)	(0.015)	(0.120)	(0.022)
Informal sector competition		-0.0151	0.0550***	-0.0950	-0.0064
		(0.020)	(0.021)	(0.077)	(0.011)
Education obstacle		0.0213	-0.0169		
		(0.024)	(0.024)		
Exporter		0.0124	-0.0178	0.1197	-0.0426
		(0.025)	(0.025)	(0.249)	(0.036)
Demand increasing		0.0348*	0.0298		
		(0.020)	(0.021)		
Certification		-0.0182	0.0287	-0.0839	0.1914***
		(0.026)	(0.026)	(0.246)	(0.043)
Market share change				-0.0519	-0.0705**
				(0.171)	(0.032)
Foreign Status > 25% ownership				0.7003***	0.0755*
				(0.261)	(0.044)
Importer				0.7358***	0.1614***
				(0.281)	(0.054)
New Capital in Previous Year				0.8290***	0.0877***
				(0.185)	(0.027)
Percentage of High School				0.0081*	0.0028***
				(0.004)	(0.000)
Access to Finance obstacle				-0.1588**	-0.0279**
				(0.076)	(0.011)
Foreign Technology				-0.2687	0.1074**
				(0.287)	(0.053)
Cov(product-process)		0.0043			
		(0.004)			
Constant	6.4948***	0.1799***	0.1590***	-1.6098***	-0.8723***
	(0.359)	(0.060)	(0.060)	(0.543)	(0.089)
Sector fixed effects	YES	YES	YES	YES	YES
Country fixed effects	YES	YES	YES	YES	YES

Observations	2,345	2,345	2,345	2,345	2,345

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 15 Base model – ICT internet and ICT computer and Software

Pooled sample	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) R&D+ per worker	(5) Internet index	(6) Computer index
Log(K/L)	0.1826***					
	(0.027)					
Log(L)	0.3129***	0.0136	0.0194*	0.0888	0.2451***	0.1594***
	(0.053)	(0.010)	(0.010)	(0.088)	(0.020)	(0.016)
Product Innovation	-0.0377					
	(0.123)					
Process Innovation	0.1026					
	(0.124)					
Internet Index		0.0611***	0.0443***			
		(0.013)	(0.013)			
Computer Index		0.0235	0.0685***			
		(0.018)	(0.018)			
RD+/L		0.0077*	0.0170***			
		(0.004)	(0.004)			
Log(age)		-0.0090	0.0126	0.2076*	-0.0597**	-0.0417*
		(0.015)	(0.015)	(0.116)	(0.028)	(0.021)
Informal sector competition		-0.0114	0.0581***	-0.0851	-0.0098	-0.0021
		(0.020)	(0.020)	(0.075)	(0.015)	(0.011)
Education obstacle		0.0148	-0.0164			
		(0.024)	(0.024)			
Exporter		0.0244	-0.0175	0.0768	-0.0602	-0.0191
		(0.025)	(0.024)	(0.242)	(0.048)	(0.037)
Demand increasing		0.0388*	0.0276			
		(0.020)	(0.021)			
Certification		-0.0154	0.0287	-0.0019	0.1869***	0.1870***
		(0.026)	(0.026)	(0.230)	(0.054)	(0.043)
Market share change				-0.0281	-0.0962**	-0.0441
				(0.176)	(0.041)	(0.033)
Foreign Status > 25% ownership				0.6477**	0.0867	0.0746*
				(0.281)	(0.057)	(0.045)
Importer				0.6875***	0.2434***	0.1124**
				(0.241)	(0.071)	(0.055)
New Capital in Previous Year				0.8341***	0.0945***	0.0868***
				(0.186)	(0.036)	(0.027)
Percentage of High School				0.0091**	0.0034***	0.0022***
				(0.004)	(0.001)	(0.000)
Access to Finance obstacle				-0.1513**	-0.0294**	-0.0265**
				(0.074)	(0.015)	(0.011)
Foreign Technology				-0.2575	0.2348***	0.0011
				(0.285)	(0.070)	(0.055)
Cov(product-process)		0.0047				
		(0.004)				
Constant	6.3519***	0.1710***	0.1889***	-1.9746***	-1.0424***	-0.7314***
	(0.296)	(0.049)	(0.051)	(0.631)	(0.122)	(0.090)
Sector fixed effects	YES	YES	YES	YES	YES	YES
Observations	2,345	2,345	2,345	2,345	2,345	2,345

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 16 Base model estimations - Ghana

	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) R&D+ per worker	(5) ICT total index
Log(K/L)	0.1658**				
	(0.076)				
Log(L)	0.4836***	-0.0511**	0.0306	0.0171	0.2592***
	(0.101)	(0.025)	(0.029)	(0.225)	(0.034)
Product Innovation	0.1525				
	(0.301)				
Process Innovation	-0.2757				
	(0.279)				
ICT Index		0.1101***	0.0880**		
		(0.038)	(0.043)		
RD+/L		0.0090	0.0327***		
		(0.009)	(0.007)		
Log(age)		0.0783**	0.0381	0.0296	-0.0373
		(0.033)	(0.037)	(0.268)	(0.049)
Informal sector competition		-0.0140	0.0259	-0.2712**	-0.0493**
		(0.043)	(0.047)	(0.116)	(0.020)
Education obstacle		0.1072	0.0264		
		(0.066)	(0.070)		
Exporter		0.0326	-0.0758	-0.4527	-0.0690
		(0.057)	(0.060)	(0.482)	(0.075)
Demand increasing		0.1092**	0.1023**		
		(0.045)	(0.050)		
Certification		0.0246	0.0946	-0.7830	0.1799
		(0.072)	(0.085)	(0.604)	(0.117)
Market share change				-0.4455	-0.1240**
				(0.335)	(0.063)
Foreign Status > 25% ownership				1.5620***	-0.0472
				(0.518)	(0.084)
Importer				0.3109	0.1418
				(0.481)	(0.098)
New Capital in Previous Year				1.1690***	0.0757
				(0.341)	(0.053)
Percentage of High School				0.0094	0.0028***
				(0.007)	(0.001)
Access to Finance obstacle				-0.1229	-0.0198
				(0.101)	(0.021)
Foreign Technology				-0.2645	0.0169
				(0.508)	(0.097)
Cov(product-process)		0.0045			
		(0.008)			
Constant	6.0216***	0.0543	-0.0284	-1.0292	-0.7790***
	(0.685)	(0.109)	(0.134)	(0.940)	(0.174)
Sector fixed effects	YES	YES	YES	YES	YES
Observations	449	449	449	449	449

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 17 baseline model - DRC

	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) R&D+ per worker	(5) ICT total index
Log(K/L)	0.3739*** (0.072)				
Log(L)	0.2746* (0.153)	0.0495 (0.032)	-0.0182 (0.033)	-0.1259 (0.145)	0.2226*** (0.045)
Product Innovation	-0.1173 (0.346)				
Process Innovation	0.8266*** (0.316)				
ICT Index		0.0450 (0.040)	0.0855** (0.043)		
RD+/L		-0.0109 (0.030)	0.0892** (0.038)		
Log(age)		-0.0235 (0.045)	0.0710* (0.041)	0.3368 (0.306)	0.0369 (0.066)
Informal sector competition		-0.0124 (0.059)	0.0791 (0.061)	0.0848 (0.138)	0.0309 (0.030)
Education obstacle		0.0670 (0.067)	-0.0551 (0.067)		
Exporter		0.0797 (0.116)	-0.0447 (0.109)	0.8681** (0.427)	0.3595** (0.166)
Demand increasing		0.0056 (0.068)	0.0343 (0.064)		
Certification		-0.0927 (0.078)	-0.0567 (0.083)	-0.0596 (0.425)	0.0682 (0.139)
Market share change				0.3049 (0.514)	0.0869 (0.133)
Foreign Status > 25% ownership				0.9150** (0.445)	0.0325 (0.134)
Importer				-0.9496 (0.658)	0.0702 (0.159)
New Capital in Previous Year				-0.0800 (0.323)	-0.0143 (0.073)
Percentage of High School				0.0172*** (0.005)	0.0037*** (0.001)
Access to Finance obstacle				0.2253 (0.169)	-0.0078 (0.028)
Foreign Technology				1.0976 (0.668)	0.0269 (0.240)
Cov(product-process)		0.0493*** (0.013)			
Constant	4.8021*** (0.625)	0.1538 (0.180)	0.1682 (0.120)	-3.1482*** (0.960)	-0.9618*** (0.274)
Sector fixed effects	YES	YES	YES	YES	YES
Observations	300	300	300	300	300

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 18 Baseline model - Tanzania

	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) R&D+ per worker	(5) ICT total index
Log(K/L)	0.2783***				
	(0.070)				
Log(L)	0.5150***	-0.0065	0.0235	-0.7739***	0.0913**
	(0.161)	(0.020)	(0.022)	(0.160)	(0.038)
Product Innovation	0.7429*				
	(0.380)				
Process Innovation	0.2695				
	(0.359)				
ICT Index		0.0333	0.0901**		
		(0.039)	(0.044)		
RD+/L		0.0477*	0.0518		
		(0.028)	(0.037)		
Log(age)		-0.0531	0.0678*	0.3902	-0.0726
		(0.039)	(0.040)	(0.241)	(0.072)
Informal sector competition		0.0162	0.1506***	-0.3872**	-0.0203
		(0.053)	(0.054)	(0.151)	(0.026)
Education obstacle		0.0472	0.0578		
		(0.057)	(0.060)		
Exporter		-0.0058	0.0428	-0.3552	-0.1774**
		(0.051)	(0.055)	(0.466)	(0.084)
Demand increasing		-0.0216	0.0433		
		(0.043)	(0.048)		
Certification		0.0186	-0.1160	1.5049***	0.5977***
		(0.062)	(0.073)	(0.482)	(0.136)
Market share change				-0.0273	-0.0352
				(0.179)	(0.060)
Foreign Status > 25% ownership				0.2402	-0.1827
				(0.479)	(0.140)
Importer				0.7695	0.3118
				(0.532)	(0.206)
New Capital in Previous Year				0.3670	0.0359
				(0.337)	(0.069)
Percentage of High School				0.0071	0.0006
				(0.005)	(0.001)
Access to Finance obstacle				-0.0898	-0.0831**
				(0.218)	(0.037)
Foreign Technology				1.0587	0.5429*
				(0.986)	(0.325)
Cov(product-process)		-0.0285***			
		(0.007)			
Constant	4.8153***	0.2456**	-0.0930	-1.4539	-0.3074
	(0.673)	(0.121)	(0.107)	(1.179)	(0.250)
Sector fixed effects	YES	YES	YES	YES	YES
Observations	312	312	312	312	312

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 19 Baseline model Uganda

	(1)	(2)	(3)	(4)	(5)
	Log(sales/l)	**Product innovation**	**Process innovation**	**R&D+ per worker**	**ICT total index**
Log(K/L)	0.0899				
	(0.083)				
Log(L)	0.4730***	-0.0389	0.0611**	0.0591	0.1971***
	(0.140)	(0.030)	(0.027)	(0.129)	(0.041)
Product Innovation	-0.1201				
	(0.375)				
Process Innovation	-1.0602**				
	(0.457)				
ICT Index		0.1976***	0.0398		
		(0.046)	(0.044)		
RD+/L		-0.0236**	0.0156		
		(0.010)	(0.013)		
Log(age)		-0.0375	0.0694*	0.5790*	-0.0076
		(0.041)	(0.042)	(0.323)	(0.050)
Informal sector competition		-0.0815	0.0949	0.3367***	0.0116
		(0.057)	(0.058)	(0.107)	(0.040)
Education obstacle		0.0482	-0.1491**		
		(0.065)	(0.063)		
Exporter		0.1985***	0.0149	-1.8627**	-0.1061
		(0.075)	(0.071)	(0.767)	(0.087)
Demand increasing		-0.0524	0.0045		
		(0.054)	(0.054)		
Certification		-0.0716	0.0862	-0.1620	0.0558
		(0.078)	(0.072)	(0.352)	(0.095)
Market share change				0.0410	0.0665
				(0.299)	(0.093)
Foreign Status > 25% ownership				-0.8805	0.2062
				(0.600)	(0.128)
Importer				1.6628**	0.3270*
				(0.670)	(0.172)
New Capital in Previous Year				-0.1644	0.0910
				(0.381)	(0.079)
Percentage of High School				0.0007	0.0018*
				(0.005)	(0.001)
Access to Finance obstacle				-0.0049	-0.0459
				(0.174)	(0.031)
Foreign Technology				1.6588***	0.0402
				(0.423)	(0.102)
Cov(product-process)		0.3229***			
		(0.035)			
Constant	7.0441***	0.6300***	0.1243	-4.2919***	-0.7420***
	(0.965)	(0.154)	(0.147)	(1.403)	(0.185)
Sector fixed effects	YES	YES	YES	YES	YES
Observations	329	329	329	329	329

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 20 Baseline model - Zambia

	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) R&D+ per worker	(5) ICT total index
Log(K/L)	0.0616**				
	(0.027)				
Log(L)	0.4455***	0.0369	0.0477**	-0.1389	0.2589***
	(0.096)	(0.027)	(0.023)	(0.141)	(0.036)
Product Innovation	-0.2337				
	(0.175)				
Process Innovation	0.2630				
	(0.227)				
ICT Index		0.1089***	0.0750**		
		(0.036)	(0.032)		
RD+/L		0.0045	0.0164***		
		(0.011)	(0.006)		
Log(age)		-0.0038	-0.0136	0.0614	-0.0814
		(0.036)	(0.033)	(0.239)	(0.053)
Informal sector competition		0.0556	-0.0263	-0.3429**	0.0088
		(0.045)	(0.044)	(0.148)	(0.025)
Education obstacle		0.0244	-0.1695***		
		(0.064)	(0.062)		
Exporter		-0.0312	-0.0089	1.4119***	0.0110
		(0.060)	(0.055)	(0.470)	(0.079)
Demand increasing		0.1811***	0.0322		
		(0.052)	(0.051)		
Certification		0.0503	0.1422***	0.2275	0.3269***
		(0.063)	(0.051)	(0.434)	(0.096)
Market share change				-0.6154**	-0.1672
				(0.304)	(0.105)
Foreign Status > 25% ownership				0.8676*	0.1381*
				(0.467)	(0.074)
Importer				0.4716	0.1174
				(0.564)	(0.097)
New Capital in Previous Year				0.4886	0.1353**
				(0.527)	(0.067)
Percentage of High School				-0.0084	0.0027***
				(0.007)	(0.001)
Access to Finance obstacle				0.0655	-0.0194
				(0.189)	(0.025)
Foreign Technology				-0.3702	0.2136*
				(0.718)	(0.125)
Cov(product-process)		0.0278***			
		(0.010)			
Constant	7.2531***	0.1831	0.5534***	-0.6814	-0.7014***
	(0.308)	(0.115)	(0.114)	(0.775)	(0.199)
Sector fixed effects	YES	YES	YES	YES	YES
Observations	465	465	465	465	465

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 21 baseline model - Kenya

	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) R&D+ per worker	(5) ICT total index
Log(K/L)	0.1283**				
	(0.063)				
Log(L)	0.1063	0.0622***	0.0107	0.1051	0.1382***
	(0.093)	(0.019)	(0.019)	(0.127)	(0.031)
Product Innovation	0.1141				
	(0.236)				
Process Innovation	-0.0014				
	(0.219)				
ICT Index		0.0722**	0.1590***		
		(0.029)	(0.029)		
RD+/L		0.0110**	0.0081		
		(0.005)	(0.005)		
Log(age)		-0.0249	-0.0320	0.2538*	-0.0872**
		(0.028)	(0.029)	(0.154)	(0.044)
Informal sector competition		-0.0596	0.0232	0.0408	0.0141
		(0.044)	(0.047)	(0.149)	(0.026)
Education obstacle		-0.0737	0.0171		
		(0.045)	(0.051)		
Exporter		0.0110	-0.0121	0.3583	-0.0139
		(0.046)	(0.048)	(0.279)	(0.072)
Demand increasing		0.0305	0.0062		
		(0.040)	(0.040)		
Certification		-0.0618	-0.0049	0.0568	0.0149
		(0.048)	(0.049)	(0.300)	(0.072)
Market share change				-0.1870	0.0269
				(0.385)	(0.077)
Foreign Status > 25% ownership				0.4161	0.0306
				(0.353)	(0.111)
Importer				0.8074**	0.0709
				(0.408)	(0.086)
New Capital in Previous Year				1.0189***	0.1600**
				(0.296)	(0.066)
Percentage of High School				0.0372***	0.0049***
				(0.007)	(0.001)
Access to Finance obstacle				-0.3858***	-0.0281
				(0.136)	(0.027)
Foreign Technology				1.0189***	0.1600**
				(0.296)	(0.066)
Cov(product-process)		-0.0113			
		(0.009)			
Constant	8.6555***	0.1414	0.3111***	-5.4243***	-0.1484
	(0.646)	(0.089)	(0.093)	(1.063)	(0.195)
Sector fixed effects	YES	YES	YES	YES	YES
Observations	490	490	490	490	490

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

6.2.2 The determinants of innovation and the role of ICT

The knowledge function - R&D+ adoption

Before discussing the results of the impact of ICT on innovation, we briefly focus on the knowledge function results. As one of the main inputs of innovation, column (4) in Tables 14 to 21show the estimates of the intensity of investments in knowledge per worker; this includes R&D, equipment and training for innovation (R&D+). Based on the literature - Crepon et al. (1999) or Griffith et al. (2006) - firm characteristics, complementary factors facilitating these investments, technology factors and market demand conditions form the set of explanatory variables.

The estimates suggest that it is more difficult to predict the intensity of R&D+ investments in African countries, than ICT adoption, once one controls for sector specific elements. One potential explanation is that both R&D and R&D+ are extremely concentrated in a few firms of very different characteristics. Based on the pooled specification, we find four main determinants of R&D+ intensity: (i) the degree of internationalization of the firm – via ownership and importing; (ii) whether the firm uses new capital; (iii) use of more skilled labor, and; (iv) whether the firm appears less constrained by access to finance.

The innovation equation

Before analyzing the determinants of innovation is important to point out that innovation rates arising from the survey are unusually high for these countries. As a result, we take advantage of the fact that the product and process innovations are described by the managers and clean the data when there are confusion on the type of innovation. Appendix E describes the methodology used. Based on the description of the product and process innovations, innovations are re-classified in order to clean errors in their attribution. In some cases there was not enough information to attribute an innovation, and in other cases there was confusion between product and process innovations, or between process and marketing innovations. The outcome of this exercise is that innovation rates are significantly adjusted, but are more in line with the rates that one should be expecting in these countries.

The main objective of the paper is to understand the role of ICT adoption as an enabler for innovation and productivity growth. Columns (2) and (3) show the results from estimating a multivariate linear probability model for the decisions to introduce product and process innovation allowing for correlation in the residuals and estimated within the system of equations.[15] This framework controls for potential simultaneity in the decision to introduce these types of innovations and also the potential endogeneity of both the R&D intensity and the ICT index.

The pooled sample results suggest that larger firms are more likely to adopt process innovation. In addition, firms experiencing a demand increase are more likely to introduce product innovations. Also, as expected, investments in R&D and knowledge for innovation are significant inputs for both product and process innovation.

Regarding the main issue investigated in the paper, the impact of ICT use on innovation, *the results show a very robust positive effect, which is consistent across countries and across the two types of ICT considered – computer and software and internet modes. ICT is, therefore, an important enabler of innovation.* An

[15] In this section, organizational innovation is omitted due to a significant loss of observations since this question was only asked to medium and large size firms.

increase of 1 unit in the ICT index[16] will increase process innovation by 0.11 units and product innovation by 0.09 units. The coefficients are large and significant in Ghana and Kenya; while only significant for product innovation in Tanzania and process innovation in Uganda.

The table in Appendix C displays the results including organizational innovation. The sample is, however, significantly reduced given the fact the organizational section of the survey was only implemented to medium and large firms. In any case, the results confirm previous findings where ICT acts as an innovation enabler taking into account the effects from organizational innovation.

6.2.3 Innovation and productivity

The final stage of the structural model is to estimate the impact of product and process innovation on productivity, proxied by sales per worker. Column (1) in the tables show the results of estimating the pooled and country by country regressions of the productivity equation. The coefficients for the ratio of capital to labor and on labor are significant in most specifications and with the expected signs.

The results for the innovation variables are, however, not statistically significant. Only in the cases of DRC, Tanzania, Uganda and Zambia; we find that product or process innovation are significant, and in some cases the coefficients show a puzzling negative sign.

One important element when looking at the relationship between ICT, innovation and productivity relates to the definition of innovation. So far, the paper has used the standard definition of innovation followed in most innovation surveys that relates to whether the innovation is new to the firm. In addition to the subjective nature of the question about "the introduction of significant changes" to measure innovation, the fact that only new to the firm counts as innovation is translated into very large innovation rates in these countries. Even considering that firms further away from the technological frontier may find it easier to implement incremental innovations, the actual measured rates are unreasonable high as compared to OECD and emerging market rates, and question the degree of "innovativeness" of such innovations and the potential presence of some noise in the data.

As a result, in Appendix D we reproduce the estimations for product and process innovation when using two alternative definitions for innovation: innovation new to the national market and innovation new to the international market. The objective is, therefore, to understand how the results change when we use a more restrictive measures of "innovativeness".

Table D.1 shows the results for the new to the national market definition, while Table D.2 shows the results for the new to the international market definition. All the main coefficients of interest for these models are summarized in Table 22.

Two strong results emerge from the estimates. *First, ICT continues to be a very important enabler of more radical innovations, both product and process. Second, narrowing the definition to more radical innovations increases the significance of product innovation. In other words, ICT is an enabler of innovation, which increases productivity when innovations are more "radical" or "innovative".* Our interpretation of this result is the fact that product innovation impacts positively innovation depending on the "quality' or degree of "innovativeness" of the innovations introduced. In the case of new to the international market, or radical innovators, the degree of "innovativeness" is substantial and, therefore, we

[16] The index ranges between -0.4 to 2.4, with an average close to zero.

find a positive link to productivity. In the case of process innovation, however, we cannot find this link, but this is consistent with the international evidence that suggests more heterogeneity of results in relation to the impact of process innovation on productivity (Hall, 2011).

Table 22 Summary results

Productivity Equation	Pooled	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya
New to the firm							
Product Innovation	-0.0214	0.1525	-0.1173	0.7429*	-0.1201	-0.2337	0.1141
Process Innovation	0.0811	-0.2757	0.8266***	0.2695	-1.0602**	0.2630	-0.0014
New to national market							
Product Innovation	0.2728	0.7210*	-0.8738	1.8213*	-0.4706	-1.0580	0.3293
Process Innovation	0.0901	-0.3351	-0.4725	0.5022	0.0479	1.2553**	0.1065
New to international market							
Product Innovation	0.7203***						
Process Innovation	-0.2845						
Product Innovation Equation							
New to the firm							
RD+_per_emp	0.0076*	0.0090	-0.0109	0.0477*	-0.0236**	0.0045	0.0110**
ICT Index	0.0922***	0.1101***	0.0450	0.0333	0.1976***	0.1089***	0.0722**
New to national market							
RD+_per_emp	0.0069**	-0.0018	-0.0053	0.0059	-0.1256**	0.0023	0.0136***
ICT Index	0.0646***	0.0792***	0.0253*	0.0517*	0.7531***	0.0483**	0.0551***
New to international market							
RD+_per_emp	0.0011						
ICT Index	0.0192***						
Process Innovation Equation							
New to the firm							
RD+_per_emp	0.0166***	0.0327***	0.0892**	0.0518	0.0156	0.0164***	0.0081
ICT Index	0.1057***	0.0880**	0.0855**	0.0901**	0.0398	0.0750**	0.1590***
New to national market							
RD+_per_emp	0.0078**	-0.0022	-0.0051	0.0071	-0.0832**	0.0049	0.0149***
ICT Index	0.0520***	0.0606**	0.0477**	0.0035	0.4268***	0.0443**	0.0567***
New to international market							
RD+_per_emp	0.0037						
ICT Index	0.0098*						

*** p<0.01, ** p<0.05, * p<0.1

6.2.4 Robustness

In line with the literature and following Griffith et al. (2006) we also estimate the model sequentially. In order to control for the potential endogeneity of both the R&D intensity and the ICT index, we instrument both variables with the predicted valued from the first stage regressions and correct the standard errors by bootstrapping them.

The most important result of these additional estimations[17] is that as found above, *ICT adoption increases the probability to introduce both types of innovation in the pooled regressions.* So on average, ICT acts as an enabler of innovation. Again, when looking at the productivity equation the coefficients on product and process innovation remain with no statistically significance in the pooled regressions with the exception for new to international market innovation where the product innovation coefficient is positive and statistically significant.[18]

A final robustness test that we produce is to estimate alternative specifications of the productivity equation based using as dependent variable, value added per worker, which is a better measure of productivity. The problem in doing this is that we lose more than half the number of observations and almost the entire services sector given the lack of information on inputs used. The results for this reduced sample, however, confirm the main findings of previous estimates, ICT is an important enabler of innovation, both product and process, but firm innovations does not appear to impact productivity when measured as value added per worker.

In conclusion, the paper finds a very robust result, ICT appears to be an enabler of innovation, but the final impact on productivity depends of the degree of innovativeness of such innovation.

7. Conclusion

In the last decade there has been a significant boom in the ICT sector in some countries in Africa. While the impact of some of these new "tech" ventures is potentially large, this effect is likely to be insignificant compared to the potential effect on employment and productivity growth from broad based ICT adoption by the African productive sector. The potential for ICT as a productivity enabler is large in those regions furthest away from the technological frontier such as Sub-Saharan Africa, which until now tended to have lower ICT adoption rates and underdeveloped ICT infrastructure.

This paper has analyzed empirically firm level ICT adoption in six African countries using freshly collected data from the Enterprise Surveys innovation modules. The data suggest that most African firms are still lagging behind ICT adoption rates as compared with firms in developed countries. However, when looking at specific countries in the sample, the data show a very heterogeneous picture; some countries, such as Kenya, show high ICT adoption rates and others, such as DRC and Tanzania, have low ICT adoption, which is in line with their income per capita level.

Given this ICT adoption heterogeneity, it is important to measure what impact this is having on firms' innovation capabilities and productivity. ICT can act as an enabler for the introduction of new processes or new products, which in turn can have a positive impact on productivity. Thus, in the second part of the paper, we have measured empirically the impact of ICT on innovation outcomes and productivity.

Regarding ICT use, the findings of the paper suggest that larger, younger, more internationalized –foreign owned, importers, certified and with foreign technology license – firms, which are financially unconstrained and operate under higher degrees of competition, are more likely on average to use ICT. This suggests the

[17] These estimates are available upon request.
[18] As only few firms have introduced a new product or process to the international market in these six countries as a whole, it is not feasible to estimate at the country level.

importance of competition and trade and investment policies as a vehicle to facilitate ICT use via increased competition and foreign exposure/links.

More importantly, we find a positive and robustly significant impact of ICT on innovation, measured along the dimensions of the firm's products, processes and organizational practices. Consequently, we find that ICT acts as an important enabler of innovation outcomes. This is important for policy, given the significant bias in policies to support R&D as the main innovation input.

The link to productivity, however, is less clear and depends on how innovation is measured. The impact of product innovation on productivity is only significant when more novel forms of innovation – new to the national or international market- are adopted. Therefore, ICT has an indirect positive impact on productivity when it is an input for more novel innovations. This can underline lack of complementary factors for increasing the quality of innovations or significant risk when introducing these innovations.

The findings of the paper suggest three main policy implications. First, providing ICT infrastructure is critical, but firms also need to have economic incentives to adopt these new ICT practices. In this regard when incentivizing ICT adoption three sets of elements appear to be important; firm internationalization, adequate educational skills and adequate access to finance. Therefore, it is important when designing ICT adoption incentives that governments consider that financially constrained firms are unlikely to use ICT and also that access to skilled labor is an important complementary factor.

Second, and related to the previous point, competition appears also as an important factor inducing ICT adoption, especially regarding internet practices for the organization of the firm. Competitive pressure is important in explaining ICT use, and as result, ICT and competition policy to ensure a competitive environment in different sectors should go hand in hand.

The third main policy implication is the fact that the one the channel through which ICT affects productivity is via innovation. However, this impact depends on the "quality" and "novelty" of these innovations. Therefore, maximizing the contribution of ICT on productivity requires supporting firm innovation capabilities. Programs such as extension services can be important to overcome coordination and information market failures and enhance the quality of innovation capabilities in order to maximize the contribution of ICT adoption.

Finally, it is important to stress that innovation is not the only channel through which ICT can impact productivity. ICT can increase the effectiveness of the use of capital and labor, and in some sectors is an important factor of production. ICT can also have an impact on firms' organization and increase labor productivity significantly. As a result, more work is needed to understand the empirical importance of these channels, especially in those poorer countries where the needs for productivity growth matter the most.

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Appendix A. Summary of the literature

Selected Literature Review

Table I: Papers Using Firm-Level data

Papers	Countries / Period / Data Type	Channels through which the impact productivity	Method	Main Conclusions
Aral, Brynjolfsson and Van Alstyne (2007)	US / Individual Level Data / 2002	It is an investigation on whether ICT intensity (measured by emails, for example) raises workers' productivity (workers are headhunters)	FGLS and FE (daily level data) and OLS (for 2002 year)	✓ IT use is positively correlated with non-linear drivers of productivity; ✓ Structure and size of workers' communication networks are highly correlated with performance; ✓ An inverted U-shaped relationship exists between multitasking and productivity such that, beyond an optimum, more multitasking is associated with declining project completion rates and revenue generation ✓ Asynchronous information seeking such as email and database use promotes multitasking while synchronous information seeking over the phone shows a negative correlation.
Atostic, Boegh-Nielsen, Motohashi and Nguyen (2004)	US, Japan and Denmark / Firm Level Data / 1990s	✓ Computers may be used directly as inputs to the production process, as a specific form of capital; ✓ Computers may be used to organize or streamline the underlying business processes.	OLS	✓ Intra firm and inter firm network is positively correlated with TFP level.
Bartel, Ichniowski and Shaw (2005)	US in Valve Manufacturing / 1997 and 2002 / Plant Level (212 plants)	✓ Improve production process efficiency by reducing cost of setup time ✓ Increase production of customized goods (product innovation) ✓ More competition in customized products. ✓ Require new labor skills	OLS for the first difference	✓ Alters business strategies, moving firms away from commodity production towards customized production ✓ Improves efficiency of all stages of the production process by reducing setup times ✓ Increases skill requirements of workers while promoting the adoption of new human resources practices

Bartel, Ichniowski, Shaw and Correa (2009)	UK and US / 1997 and 2002 / Plant Level	Same as above	OLS for the first difference	Same as above. Differences across countries are: ✓ US firms adopted ICT earlier, but in 2002 they were very similar. ✓ Effect of increase of labor skills requirements was stronger in the UK
Basu, Fernald, Oulton, & Srinivasan (2003)	US and UK / Sector Level Data / US staring 1977 and UK 1979 till 2000	✓ Cheap ICT capital is likely to affect truly major changes only if firms can deploy their other inputs in radically different and productivity-enhancing ways.	Traditional Growth Accounting	✓ Unmeasured investments in intangible organization capital, associated with the role of ICT, can explain the divergent US and UK TFP performance after 1995.
Bloom, Garicano, Sadun and Van Reenen (2009)	US, France, Germany, Italy, Poland, Portugal, Sweden and UK / 2002 to 2004 / Firm Level	How different types of ICT affect worker's autonomy. In terms of ICT, they classify them into two distinct components: communication; information. Improvements in information (ERP and CAD/CAM) lead to decentralization while in communication (Data Networks) leads to centralization.	Simple OLS (when outcome variable permits) or a Probit (in the case of autonomy of the worker)	✓ Increase in ERP and CAD/CAM (reduction of information costs) leads to decentralization. ✓ Increase in NETWORK (reduction of communication costs) leads to centralization. Further Research: They affirm of examining the effect of differential type of IT adoption on other outcomes such as productivity and wage inequality. Found those two, yet it seems that they do not distinguish ICT into info and communication: http://cep.lse.ac.uk/textonly/_new/staff/vanreenen/pdf/aer102(1).pdf http://cep.lse.ac.uk/pubs/download/occasional/op028.pdf
Bresnahan, Brynjolfsson and Hitt (2002)	US / 1987 – 1994 / Firm Level	Decline in IT prices increases investments in work organization and product and service innovations, which increase demand for skill workers and therefore increase productivity	Panel and Cross Section with interactions in order to address complementarities. OLS and IV (instruments are IT lagged in time)	They found evidence of complementarities among all three innovations (IT, complementary workplace reorganization and new products and services) in factor demand and productivity regressions. Firms that adopt these innovations tend to use more skilled labor. The effects of IT on labor demand are greater when IT is combined with the particular organizational investments they identify, highlighting the importance of IT-enabled organizational change.
Brynjolfsson and Hitt (2003)	US / 1987-1994 / Firm Level (527 firms)	ICT affects productivity because firms change their production processes and engender complementary innovations within and among firms (combining computers with other innovations to change their production processes).	First estimate TFP using capital and labor (Value Added) or including Material (Output). Then, estimate the impact of computer investment on TFP. OLS and IV are used (instruments are fraction of PCs	✓ measured output contributions of computerization in the short run are approximately equal to computer capital costs; ✓ measured long-run contributions of computerization are significantly above computer capital costs (a factor of 5 or more in point estimates); ✓ estimated contributions steadily increase as we move from short to long differences.

			connected to a network, capital age, and others).	
Commander, Harrison and Menezes-Filho (2011)	Brazil and India / Firm Level Data (around 1,000 firms) / 2005	✓ Investment in ICT complemented by other types of investments (such as organization change) lead to higher productivity.	Estimation of production function splitting capital into IT capital and non IT capital. OLS, First-Difference and IV (Levinshon and Petrin method). It does also interact with Organization Change and Electricity Power Outrage.	✓ Strong and positive association between ICT capital and productivity (higher than in developed countries); ✓ High elasticities are concentrated in firms that have undertaken complementary organization investments ✓ Poorer infrastructure quality and pro-worker labor regulation are both associated with lower levels of ICT capital intensity and with lower returns to ICT capital investment.
Crespi, Criscuolo and Haskel (2006)	UK / 1998 and 2000 / Firm Level (around 1,000 firms)	Computer investment requires complementary investment in organization capital to obtain productivity gains and such investment in organization capital requires diverting resources away from current production.	OLS for the first difference and an IV (instruments are variation of market share, size and multinational dummies – explaining factors of Organizational Change)	Consistent with previous literature ✓ IT appears to have high returns in a growth accounting sense when organization change is omitted; ✓ When organization change is included the IT returns are greatly reduced; ✓ IT and organization change interact in their effect on productivity growth; ✓ Non-IT investment and organization change do not interact in their effect on productivity growth New Findings ✓ Organization change is affected by competition; ✓ Strong effects on the probability of introducing organization change from ownership.
Crepon, Duguet and Mairesse (1998)	France / Firm Level Data (4,164 firms) / 1986-1990	✓ Research relation linking to its determinants, the innovation equation relating research to innovation output measures, and the productivity equation relating innovation output to productivity. In other words, determinants => research input (R&D) => research output (patents or innovative sales) => productivity	Two-stage estimation procedure: first stage Method of Moments (M-estimation); second stage method of asymptotic least squares (ALS-estimation). 1) Tobit specification for R&D investment; 2) Heterogenous count data specification for patents;	✓ Probability of engaging in R&D for a firm increases with its size, market share and diversification, and with the demand pull and technology push indicators; ✓ Research effort of a firm engaged in research increases with the same variables, except for size; ✓ Firm innovation output (patent numbers or innovative sales) rises with its research effort and with the demand pull and technology indicators; ✓ Firm productivity correlates positively with a higher innovation output, even after controlling for skill composition of labor force and physical capital intensisty.

			3) Ordered probit specification for innovative sales.	
Fernald (2014)	US / Industry Level Data / 1947:Q2-2014:Q1	✓ None	Multi-sector Growth Model	✓ Labor productivity and TFP growth slowed prior to the Great Recession. Around ¾ of the shortfall of actual output from pre-recession trends reflects a reduction in the level of potential.
Griffith, Huergo, Mairesse & Peters (2006)	France, Germany, UK and Spain / Firm Level Data (around 10,000 obs) / 1998 - 2000	✓ Firm's decision to engage in sufficient effort to result in observable R&D; ✓ Intensity with which the firm undertakes R&D, or R&D investment function; ✓ Innovation or knowledge to take two different forms (process and product innovations); ✓ Output production function, where knowledge is an input.	Following CDM 1st) Probit to explain whether R&D and R&D intensity (OLS); 2nd) OLS for product and process innovation; 3rd) OLS for productivity	✓ Determinants to engage in formal R&D are remarkably similar across countries. For instance, government funding plays an important role in all countries with national funding having the largest impact; ✓ Firms' greater R&D effort per employee makes them more likely to be process or product innovators; ✓ Results for productivity are mixed across these countries. Process innovation is only associated with higher productivity in France and product innovation is associated with higher productivity in France, Spain and the UK.
Kretschmer, Miravete, & Pernías (2012) – not about productivity, but rather innovation	France / Firm Level Data / 2000-04	✓ Liberalization increases inter- and intra-brand competition and affects how competitive the market for dealers is, which in turn may affect the incentive to adopt an innovation	Maximum Likelihood Estimation	✓ Distinguish two types of software: Human Resources Management; Applications Development Software. ✓ Firms view these innovations as substitutes and concentrate their effort in one type of software as they expand their scale of production.
Polder, Van Leeuwen, Mohnen & Raymond (2010)	Netherlands / Firm Level Data (more than 5,000 firms / 2002-06	✓ ICT enables organizational investments (business processes and work practices), which in turn lead to cost reductions and improved output and, hence, productivity gains.	Augmented CDM model by including ICT. 1st) Innovation Input: ML Tobit for R&D and ICT investments (measured by $ per employee); 2nd) Innovation Output: Trivariate probit model to explain product, process and organization innovations;	✓ ICT investment and usage are important drivers of innovation in both manufacturing and services; ✓ Doing more R&D has a positive effect on product innovation in manufacturing; ✓ The strongest productivity effects are derived from organizational innovation; ✓ Positive effects of product and process innovation when combined with an organizational innovation; ✓ There is evidence that organizational innovation is complementary to process innovation.

			3rd) Productivity: OLS and Olley and Pakes	
7) Sánchez, J. I. L., Minguela Rata, B., Rodríguez Duarte, A., & Sandulli, F. D. (2006)	Spain / Firm Level Data (2,286 firms) / Internet	✓ Same from Litan & Rivlin (2001)	IV Estimation in a Cross Section. They evaluate internet usage at work (measured by hours spent on internet) on productivity. Instrument for internet (whether a firm has a website)	✓ They find a positive impact of internet on labor productivity, but after a certain point at decreasing rate. ✓ Further work is on contribution of the various uses of internet to productivity.

Table II Papers with Literature Reviews

Papers	Countries / Period / Data Type	Channels through which the impact productivity	Method	Main Conclusions
Draca, Sadun and Van Reenen (2006)	Developed Countries	✓ N/A	TFP-Based Approaches, GMM and Olley and Pakes	The empirical estimates suggest a much larger impact of ICT on productivity than would be expected from the standard neoclassical model that they focus on.
Litan & Rivlin (2001)	US and Economic Impact of Internet	✓ By significantly reducing the cost of many transactions necessary to produce and distribute goods and services; ✓ by increasing management efficiency, especially by enabling firms to manage their supply chains more effectively and to communicate more easily both within the firm and with customers and partners; ✓ by increasing competition, making prices more transparent, and broadening markets for buyers and sellers, which puts pressure on suppliers to adopt techniques that translate into cost savings.	N/A	✓ Transactions-cost saving from transition to the Internet is especially high in the health-care sector, because it is information-intensive, among others. Other sectors are financial-services industry and government sector; ✓ Efficient Management has a considerable potential especially in manufacturing, which main gains come from manage supply chains more effectively, reduce inventory, and cut customer-service costs. ✓ Making the economic system more competitive by bringing markets closer result in lower profit margins, more efficient production and greater consumer satisfaction.
Pilat (2004)	Literature Survey	✓ ICT investments improve labor productivity because of capital accumulation. ✓ rapid technological progress in the production of ICT goods and services contributes to growth in efficiency of capital and labor, or multifactor productivity (MFP), in the ICT industry. ✓ firms increase their overall efficiency (MFP) after extensively use of ICT throughout the economy	N/A	The studies discussed above demonstrate that the empirical evidence of the economic impacts of ICT is significantly improved from what it was only a few years ago.

Polak (2014)	Literature Review	✓ N/A	Meta-Analysis	The empirical part is based on a collection of more than 800 estimates of IT payoff effects from almost 70 studies written in the last 20 years. The meta-analysis reveals the presence of publication bias and estimates the ICT elasticity to be only 0.3%

Table III: Papers with Stylized Facts

Papers	Countries / Period / Data Type	Facts
Loundes (2002)	Australia	✓ 29% of business use internet in 1998 and 69%, in 2001 ✓ 22% of Australian businesses have a webpage in 2001 ✓ The vast majority of businesses using internet for purchasing and/or selling indicated they have gained some benefit from doing so.
Walczuck, Van Braven & Lundgren (2000)	Netherlands	Small firms are not adopting internet with the same speed their larger counterparts do
OECD (2004)	OECD countries and emerging economies	✓ Recent data from the European Union (EU) shows that 97% of firms located in this region has a computer. ✓ Sector composition in OECD countries: services have much larger computer use intensity rates than manufacturing (% of employees using computer). ✓ More than 90% of Mexican (2008) and Turkish (2010) businesses over 10 employees has access to internet. ✓ Considering all firms, only 10.1% of small firms purchase online which is less than half of what was observed in small firms from the European Union in 2009 (23%). However, large firms in theses African countries are purchasing online even more than their EU counterparts, since percentages are 45.2% for Africa and 39% for EU considering all firms.

Appendix B. Determinants of ICT

Table B.1 Determinants of using internet for inventory

	(1) Pooled	(2) POOLED RE	(5) Ghana	(6) DRC	(7) Tanzania	(8) Uganda	(9) Zambia	(10) Kenya
Log(L)	0.2645***	0.2758***	0.3285***	0.4469***	0.2159**	0.3579***	0.2050**	0.1705***
	(0.033)	(0.032)	(0.101)	(0.123)	(0.087)	(0.098)	(0.080)	(0.060)
Log(age)	-0.1043**	-0.0850*	-0.0270	-0.3175*	-0.3232**	-0.0536	-0.0689	-0.0924
	(0.049)	(0.048)	(0.153)	(0.176)	(0.164)	(0.146)	(0.118)	(0.093)
Market Share Change	-0.1486**	-0.1494**	0.1648	-0.5595	-0.1479	0.3647	-0.6106**	-0.1254
	(0.076)	(0.071)	(0.193)	(0.421)	(0.150)	(0.323)	(0.250)	(0.175)
Foreign Status	0.1232	0.0525	-0.3560	0.1590	-0.4026	0.5406*	0.1790	0.1030
	(0.092)	(0.088)	(0.265)	(0.275)	(0.362)	(0.299)	(0.161)	(0.233)
Importer	0.2604**	0.2563**	0.1407	0.1973	0.4088	1.3609**	0.1692	0.1840
	(0.111)	(0.101)	(0.255)	(0.394)	(0.446)	(0.530)	(0.233)	(0.214)
Exporter	-0.0574	-0.0023	-0.3695	0.7490**	-0.3389	-0.3865	0.5652***	-0.0706
	(0.080)	(0.079)	(0.235)	(0.377)	(0.220)	(0.271)	(0.184)	(0.148)
New Capital in Previous Year	0.0531	0.0535	0.0490	-0.1330	-0.1744	0.3695	0.1026	0.0404
	(0.064)	(0.064)	(0.169)	(0.216)	(0.197)	(0.226)	(0.154)	(0.134)
Percentage of High School	0.0056***	0.0056***	0.0058**	0.0089**	0.0022	0.0070**	0.0046*	0.0094***
	(0.001)	(0.001)	(0.003)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)
Certification	0.1085	0.1452*	0.5059**	0.3078	0.9530***	-0.0656	0.1122	-0.2628*
	(0.083)	(0.079)	(0.249)	(0.328)	(0.247)	(0.245)	(0.190)	(0.150)
Access to Finance Obstacles	-0.0551**	-0.0575**	-0.1282**	0.0610	-0.1579*	-0.2061**	0.0207	-0.0045
	(0.026)	(0.026)	(0.060)	(0.088)	(0.087)	(0.090)	(0.061)	(0.056)
Informal Sector Competition	-0.0325	-0.0356	-0.0846	0.0418	-0.1078	-0.0698	-0.0370	0.0677
	(0.025)	(0.025)	(0.064)	(0.083)	(0.074)	(0.104)	(0.058)	(0.052)
Foreign Technology	0.3941***	0.3856***	0.1247	0.1166	1.8396***	-0.0565	0.5977**	0.4532**
	(0.117)	(0.111)	(0.297)	(0.572)	(0.622)	(0.345)	(0.252)	(0.225)
Constant	-1.7862***	-1.8629***	-1.3885**	-2.2051***	-0.0046	-1.5188**	-1.7105***	-1.3540***
	(0.223)	(0.175)	(0.583)	(0.700)	(0.596)	(0.617)	(0.509)	(0.390)
Observations	2,251	2,251	427	246	295	309	449	477
Country dummies	Yes	Yes						
Sector dummies	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

Coefficients are marginal effects. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table B.2 Determinants of marketing adoption

	(1) Pooled	(2) POOLED RE	(5) Ghana	(6) DRC	(7) Tanzania	(8) Uganda	(9) Zambia	(10) Kenya
Log(L)	0.2744***	0.2683***	0.2077**	0.4795***	0.1711*	0.2280**	0.4811***	0.1778***
	(0.034)	(0.032)	(0.095)	(0.125)	(0.094)	(0.095)	(0.090)	(0.063)
Log(age)	-0.1112**	-0.0666	-0.1649	-0.2348	-0.1000	-0.0359	-0.1496	-0.0632
	(0.048)	(0.048)	(0.136)	(0.184)	(0.181)	(0.136)	(0.116)	(0.089)
Market Share Change	-0.1956***	-0.1541**	-0.1741	0.1130	-0.3728**	0.2691	-0.2426	-0.0309
	(0.076)	(0.073)	(0.190)	(0.418)	(0.163)	(0.293)	(0.245)	(0.175)
Foreign Status	0.1069	0.1176	-0.2422	0.1736	-0.7170	0.6018**	0.2552	0.1145
	(0.092)	(0.088)	(0.256)	(0.298)	(0.444)	(0.279)	(0.161)	(0.257)
Importer	0.2492**	0.2871***	0.0773	0.0539	0.8594*	0.7263	0.3845	0.1906
	(0.111)	(0.103)	(0.244)	(0.402)	(0.449)	(0.454)	(0.250)	(0.221)
Exporter	-0.0051	0.0039	0.0669	0.6379	-0.3613	0.0444	-0.0021	-0.0548
	(0.082)	(0.079)	(0.218)	(0.395)	(0.240)	(0.254)	(0.178)	(0.152)
New Capital in Previous Year	0.1815***	0.1757***	0.3736**	-0.3400	0.0782	0.0574	0.2005	0.3049**
	(0.064)	(0.064)	(0.155)	(0.228)	(0.222)	(0.226)	(0.148)	(0.136)
Percentage of High School	0.0054***	0.0062***	0.0053**	0.0098**	0.0061**	0.0053*	0.0043*	0.0069***
	(0.001)	(0.001)	(0.003)	(0.004)	(0.003)	(0.003)	(0.002)	(0.003)
Certification	0.3441***	0.3202***	0.5431**	0.1242	1.1088***	0.1296	0.3246*	0.1792
	(0.082)	(0.080)	(0.256)	(0.330)	(0.268)	(0.238)	(0.186)	(0.152)
Access to Finance Obstacles	-0.0432	-0.0514**	-0.0799	0.0067	-0.1403	-0.0722	-0.0011	-0.0454
	(0.026)	(0.026)	(0.061)	(0.091)	(0.102)	(0.092)	(0.061)	(0.057)
Informal Sector Competition	-0.0335	-0.0298	-0.1078*	0.1416	-0.0319	-0.0541	0.0011	-0.0289
	(0.025)	(0.025)	(0.059)	(0.094)	(0.085)	(0.108)	(0.060)	(0.055)
Foreign Technology	0.1450	0.1944*	-0.0804	-0.5143	1.4092*	-0.3098	0.1677	0.3346
	(0.120)	(0.114)	(0.290)	(0.574)	(0.743)	(0.373)	(0.274)	(0.232)
Constant	-1.9216***	-1.9778***	-1.0979**	-2.3585***	-1.6029**	-1.7424***	-2.3545***	-1.2738***
	(0.226)	(0.190)	(0.548)	(0.678)	(0.727)	(0.563)	(0.502)	(0.383)
Observations	2,251	2,251	430	221	293	277	435	471
Country dummies	Yes	Yes						
Sector dummies	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

Coefficients are marginal effects. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table B.3 Determinants of e-commerce adoption

	(1) Pooled	(2) POOLED RE	(5) Ghana	(6) DRC	(7) Tanzania	(8) Uganda	(9) Zambia	(10) Kenya
Log(L)	0.2633***	0.2652***	0.6278***	0.3706***	0.3125***	0.2993***	0.4172***	0.1002*
	(0.034)	(0.033)	(0.138)	(0.140)	(0.112)	(0.103)	(0.084)	(0.061)
Log(age)	-0.0499	-0.0344	-0.1675	-0.3188	-0.0742	0.0478	-0.2119*	0.0316
	(0.052)	(0.052)	(0.209)	(0.232)	(0.210)	(0.154)	(0.125)	(0.088)
Market Share Change	-0.0715	-0.0572	-0.0723	0.8922**	-0.2221	0.1602	-0.3567	-0.0607
	(0.081)	(0.080)	(0.270)	(0.371)	(0.172)	(0.352)	(0.276)	(0.180)
Foreign Status	0.0282	0.0223	-0.6432*	-0.0928	-0.6769	0.3634	-0.2195	0.7428***
	(0.097)	(0.095)	(0.340)	(0.307)	(0.492)	(0.302)	(0.174)	(0.246)
Importer	0.1838	0.1761*	0.1950	-0.5191	0.7988*	0.7711	0.0969	0.0252
	(0.120)	(0.106)	(0.303)	(0.524)	(0.457)	(0.489)	(0.251)	(0.213)
Exporter	-0.0291	-0.0039	-0.5373	0.8428**	-0.4145	-0.2023	0.3071	-0.0186
	(0.088)	(0.085)	(0.352)	(0.399)	(0.296)	(0.295)	(0.194)	(0.150)
New Capital in Previous Year	0.1353*	0.1204*	0.0874	-0.1238	0.2276	0.1517	0.2721	0.1538
	(0.071)	(0.071)	(0.195)	(0.249)	(0.268)	(0.241)	(0.166)	(0.136)
Percentage of High School	0.0037***	0.0042***	0.0017	0.0043	0.0067**	0.0067**	0.0041	0.0036
	(0.001)	(0.001)	(0.004)	(0.005)	(0.003)	(0.003)	(0.003)	(0.002)
Certification	0.2516***	0.2692***	0.2007	0.1216	1.0255***	0.0697	0.5254***	0.0188
	(0.087)	(0.084)	(0.363)	(0.341)	(0.317)	(0.264)	(0.194)	(0.154)
Access to Finance Obstacles	-0.0571**	-0.0794***	0.1809**	0.1070	-0.3107***	-0.1180	-0.0493	-0.0932*
	(0.028)	(0.029)	(0.083)	(0.107)	(0.107)	(0.087)	(0.064)	(0.056)
Informal Sector Competition	-0.0417	-0.0450*	-0.1106	0.0665	-0.1520	-0.1338	-0.0612	0.0329
	(0.028)	(0.027)	(0.079)	(0.108)	(0.103)	(0.115)	(0.062)	(0.053)
Foreign Technology	0.2043*	0.2288**	0.1262	1.1708*	1.2315	-0.2443	0.1712	0.3400
	(0.122)	(0.116)	(0.351)	(0.692)	(0.830)	(0.386)	(0.268)	(0.216)
Constant	-2.5754***	-2.2081***	-3.4359***	-2.6287***	-2.4215**	-2.3001***	-2.3325***	-1.4928***
	(0.243)	(0.188)	(0.739)	(1.010)	(0.956)	(0.617)	(0.481)	(0.394)
Observations	2,251	2,251	400	191	278	282	435	477
Country dummies	Yes	Yes						
Sector dummies	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

Coefficients are marginal effects. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix C. Baseline model with organizational innovation

	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) Organizational innovation	(5) R&D+ per worker	(6) ICT total index
Log(K/L)	0.2312***					
	(0.039)					
Log(L)	0.3225***	0.0133	0.0236**	0.0378**	0.1004	0.2023***
	(0.074)	(0.010)	(0.010)	(0.016)	(0.093)	(0.015)
Product Innovation	-0.1965					
	(0.190)					
Process Innovation	-0.0831					
	(0.208)					
Organizational innovation	0.1240					
	(0.191)					
ICT Index		0.0895***	0.1067***	0.1532***		
		(0.015)	(0.015)	(0.023)		
RD+/L		0.0074*	0.0177***	-0.0017		
		(0.004)	(0.004)	(0.005)		
Log(age)		-0.0064	0.0186	-0.0170	0.2352**	-0.0498**
		(0.015)	(0.015)	(0.024)	(0.119)	(0.022)
Informal sector competition		-0.0073	0.0652***	0.0082	-0.0897	-0.0033
		(0.020)	(0.020)	(0.035)	(0.073)	(0.011)
Education obstacle		0.0201	-0.0156	0.0200		
		(0.024)	(0.024)	(0.039)		
Exporter		0.0257	-0.0089	0.0327	0.0922	-0.0416
		(0.025)	(0.024)	(0.036)	(0.248)	(0.036)
Demand increasing		0.0409**	0.0317	0.0577		
		(0.020)	(0.021)	(0.035)		
Certification		-0.0225	0.0260	-0.0104	0.0003	0.1946***
		(0.026)	(0.026)	(0.037)	(0.239)	(0.043)
Market share change					-0.0192	-0.0691**
					(0.180)	(0.032)
Foreign Status > 25% ownership					0.6268**	0.0842*
					(0.282)	(0.044)
Importer					0.8312***	0.1505***
					(0.235)	(0.049)
New Capital in Previous Year					0.8419***	0.0966***
					(0.190)	(0.028)
Percentage of High School					0.0080**	0.0031***
					(0.004)	(0.000)
Access to Finance obstacle					-0.1352*	-0.0328***
					(0.072)	(0.011)
Foreign Technology					-0.1861	0.1184**
					(0.296)	(0.052)
Cov(product-process)		0.0056				
		(0.004)				
Cov(product-organ)		0.0196***				
		(0.007)				
Cov(organ-process)		0.0216***				
		(0.007)				

Constant	6.5595***	0.1667***	0.1290***	0.2103**	-2.1390***	- 0.7583***
	(0.482)	(0.049)	(0.048)	(0.087)	(0.588)	(0.084)
Sector Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes				
Observations	2,288	2,288	2,288	2,288	2,288	2,288

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix D. Baseline model with different definitions of innovation

Table D.1 Baseline model new to the national market

	(1) Log(sales/l)	(2) Product innovation	(3) Process innovation	(4) R&D+ per worker	(5) ICT total index
Log(K/L)	0.1859***				
	(0.028)				
Log(L)	0.2913***	0.0078	0.0106*	0.1134	0.2022***
	(0.054)	(0.006)	(0.006)	(0.087)	(0.015)
Product Innovation	0.2728				
	(0.211)				
Process Innovation	0.0901				
	(0.185)				
ICT Index		0.0646***	0.0520***		
		(0.009)	(0.009)		
RD+/L		0.0069**	0.0078**		
		(0.003)	(0.003)		
Log(age)		-0.0014	-0.0011	0.1989*	-0.0506**
		(0.007)	(0.008)	(0.118)	(0.022)
Informal sector competition		0.0004	-0.0025	-0.0885	-0.0059
		(0.010)	(0.010)	(0.075)	(0.011)
Education obstacle		0.0031	-0.0092		
		(0.012)	(0.013)		
Exporter		0.0319**	0.0167	0.1523	-0.0396
		(0.014)	(0.014)	(0.245)	(0.036)
Demand increasing		0.0068	0.0026		
		(0.010)	(0.010)		
Certification		-0.0086	0.0221	-0.0636	0.1870***
		(0.015)	(0.016)	(0.240)	(0.043)
Market share change				-0.0291	-0.0701**
				(0.170)	(0.032)
Foreign Status > 25% ownership				0.6656**	0.0807*
				(0.263)	(0.044)
Importer				0.7735***	0.1780***
				(0.282)	(0.053)
New Capital in Previous Year				0.8081***	0.0907***
				(0.182)	(0.028)
Percentage of High School				0.0080*	0.0028***
				(0.004)	(0.000)
Access to Finance obstacle				-0.1553**	-0.0279**
				(0.076)	(0.011)
Foreign Technology				-0.2467	0.1178**
				(0.278)	(0.053)
Cov(product-process)		0.0163***			
		(0.002)			
Constant	6.5346***	0.0321	0.0126	-1.6405***	-0.8870***
	(0.359)	(0.030)	(0.032)	(0.530)	(0.090)
Sector Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	2,345	2,345	2,345	2,345	2,345

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table D.2 Baseline model - radical innovators – new to the international market

	(1) Log(sales/l)	(2) Product innovation Intl	(3) Process innovation Intl	(4) R&D+ per worker	(5) ICT total index
Log(K/L)	0.1881***				
	(0.028)				
Log(L)	0.3002***	0.0027	0.0062	0.1134	
	(0.053)	(0.003)	(0.004)	(0.087)	
Product Innovation	0.7203***				
	(0.257)				
Process Innovation	-0.2845				
	(0.297)				
ICT Index		0.0192***	0.0098*		
		(0.005)	(0.005)		
RD+/L		0.0011	0.0037		
		(0.002)	(0.003)		
Log(age)		0.0066*	-0.0019	0.1989*	-0.0390*
		(0.004)	(0.004)	(0.118)	(0.022)
Informal sector competition		0.0054	-0.0022	-0.0885	-0.0039
		(0.006)	(0.006)	(0.075)	(0.011)
Education obstacle		0.0083	0.0061		
		(0.008)	(0.008)		
Exporter		0.0086	0.0039	0.1523	-0.0336
		(0.008)	(0.007)	(0.245)	(0.036)
Demand increasing		0.0122**	0.0085		
		(0.005)	(0.006)		
Certification		-0.0050	-0.0019	-0.0636	0.2071***
		(0.009)	(0.008)	(0.240)	(0.042)
Market share change				-0.0291	-0.0551*
				(0.170)	(0.032)
Foreign Status > 25% ownership				0.6656**	0.0797*
				(0.263)	(0.044)
Importer				0.7735***	0.2020***
				(0.282)	(0.053)
New Capital in Previous Year				0.8081***	0.1067***
				(0.182)	(0.028)
Percentage of High School				0.0080*	0.0029***
				(0.004)	(0.000)
Access to Finance obstacle				-0.1553**	-0.0297***
				(0.076)	(0.011)
Foreign Technology				-0.0291	-0.0551*
				(0.170)	(0.032)
Medium Size					0.3660***
					(0.035)
Large Size					0.6119***
					(0.058)
Cov(product-process)		0.0068***			
		(0.002)			
Constant	6.5035***	-0.0142	-0.0026	-1.6405***	-0.5205***
	(0.357)	(0.017)	(0.020)	(0.530)	(0.088)
Sector Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	2,345	2,345	2,345	2,345	2,345

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix E. Re-classification of innovation

Based on the description of the product and process innovations, these were re-classified in order to clean errors in their attribution. In some cases there was not enough information to attribute an innovation, and in other cases there was confusion between product and process innovations, and between process and marketing innovations. Below are some examples of how the re-classification was implemented.

Delivery

- improved delivery process (additional, superior vehicles) = process innovation
- introduce delivery as new offering (not core business) = product innovation
- introduce delivery -direct sales (same core business) = marketing
- delivery method for service sector (restaurants) = process innovation
- expansion of delivery, such as additional trucks (without specifying improvements) = not innovation
- expansion of delivery to new areas or across country = marketing
- an upgrade in delivery vehicle = process innovation

Distinction between introducing new types of product as product innovation or marketing

- food: new recipe but not necessarily any improvement = marketing
- garments: new line, new design = product innovation (under assumption that there is product differentiation, quality improvements)
- wholesaler starts to offer new product or new range of product = product innovation

Other

- creation of online store = process (services)/marketing (Manufacturing)
- wholesaler opens own retailer store = product innovation
- introduced warranty = marketing
- product innovation same description as main line of business = not innovation
- Process innovation leading to product innovation = classify as both product and process
- New brand, type, design without specifying specific attribute changes = marketing
- Training of employees, improving outcomes = process

Table E.1 below shows the results of the reclassification. In most cases, innovation rates were significantly reduced. Also in a few cases, process innovations were re-classified as organizational innovation.

Table E.1 Re-classification of product and process innovation

	Overall	Ghana	DRC	Tanzania	Uganda	Zambia	Kenya
Product Innovation	40.18%	27.96%	34.42%	17.86%	51.68%	59.99%	39.87%
Product Innovation - clean	29.16%	19.67%	22.34%	21.06%	35.92%	38.12%	26.25%
Process Innovation	44.13%	35.92%	33.02%	36.26%	46.86%	68.58%	38.05%
Process Innovation - clean	31.25%	26.33%	25.88%	18.02%	35.23%	54.73%	27.58%