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What are the effects of ICT on structural transformation in sub-Saharan Africa?

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Abstract

This paper evaluate the effects of ICT on the structural transformation of sub-Saharan economies. Data generated by the Varieties of Democracy, the WDI and Mensah and Szirmai (2018) allowed us to verify our findings on a panel of 18 SSA economies using VAR modelling. The main findings show that the number of internet users has no effect on structural change or intra-industry productivity in the short term, and this delay can be attributed to the time required to learn and master new ICT tools. However, the impacts of the shock in the number of Internet users on structural change persist over time. This implies that the more Internet connectivity there is, the more resources are transferred to the most productive sectors of SSA economies. a shock to GDP has an immediate and negative effect on structural change in SSA, but a favorable effect on the number of mobile phone subscribers. However, the shock's negative influence on structural change decreases in the first year, then reverses and returns to equilibrium by the third year. The outcome can be explained when the shock to economic growth is not structural, but rather results from new exploitation of natural resources or new debt, which can move resources to less productive sectors. The results suggest a growing adoption of the internet in private and public administrations and enterprises to promote structural transformation of economies.

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Introduction

ICTs are nowadays considered as knowledge and knowledge codification processes (Foray, 2018). As knowledge is inherent in all human activities, it is quite logical to present ICTs as factors of economic efficiency. Thus, ICTs have the potential to affect the structural transformation of developing economies, particularly those in sub-Saharan Africa (SSA), and to promote their long-term development (Cadot et al., 2016; Cadot and Melo, 2016). Structural transformation means a reallocation of resources in the economy from low productivity sectors to high productivity sectors. McMillan et al (2014, 2017) understand it in terms of its two components, intra-industry and structural change. The intra-industry component shows the capacity of each sector to generate internal productivity while structural change expresses the diffusion of productivity to the whole economy. For Lin (2012), the structure of an economy is endogenous to the structure of its factor endowments and sustainable economic development is determined by changes in factor endowments and continuous technological innovation. These changes are multidimensional and include the production matrix, social structure, institutional framework and relationship with the natural environment (Nissanke, 2019; Armah and Baek, 2019). According to Nissanke (2019), structural transformation is an evolutionary process that is not limited to the transformation of economic structures, but also to social transformation, by proceeding to share opportunities ex ante among the entire population, including the poorest segments, irrespective of gender, ethnicity, religion or any other divisive criteria. Structural transformation is therefore a necessity for developing countries, particularly those in sub-Saharan Africa (SSA), to generate sufficient employment, reduce poverty and inequality, and sustain growth (African Development Bank Group [AfDB], 2020; Economic Commission for Africa [ECA], 2016). Structural transformation is therefore a necessity for developing countries, particularly those in sub-Saharan Africa (SSA), as it can generate sufficient productive and decent jobs, reduce poverty and inequality, sustain economic growth and thus promote development (AfDB, 2020; ECA, 2016).

Neoclassical economics, with its assumptions of pure and perfect competition, gives the market the main role in wealth accumulation and the development process. These highly restrictive competition assumptions thus relegate the role of innovations and technical progress in the accumulation of wealth and the development process to the background. Although Adam Smith recognised the importance of know-how and experience in improving labour productivity, the neoclassical analysis leaves only a very marginal place for the process of innovation. It was Schumpeter (1911) who pioneered the recognition of innovation as a fundamental element in generating economic development and guaranteeing the survival of the economy in the long term. As a process, innovation integrates management activities and decision making at the individual and organisational levels. The ability of individuals to carry out their daily tasks, to face risks and to invest time and money in organisations determines how the results of innovation appear (Porter, 1986). Today, it is almost universally recognised that innovation is essential for economic and social success in today's highly globalised business world (Ferreira et al., 2015). Thus, ICT, which is one of the most diffused innovations in the world today, cannot be without effects on the economic efficiency of individual countries and consequently on the structural transformation of developing economies.

ICTs are essential elements of economic systems that have undergone changes over the past decade that have increased value added in all economic sectors, including lowering production costs, increasing output, boosting competitiveness, improving public sector management and enhancing productive capacity (Chadwick, 2005). ICTs have also driven innovation, information exchange and knowledge management, all of which are important for public and private sector performance (Oliva et al., 2019). However, Africa's peripheral markets have greater potential for ICT growth than the frontier economies of the Organisation for Economic Co-operation and Development (OECD) and Asia, which are experiencing saturation levels of ICT penetration (Penard et al., 2012).

The analysis of the effects of ICT on economic performance has generated a considerable body of work at micro, sectoral and macro levels. This work can be grouped into two broad classes, namely the sceptics and the optimists. The first class of authors, described as sceptics, is pioneered by Solow (1987) with his famous "productivity paradox". Indeed, Solow declared in 1987 "I see computers everywhere except in the productivity data". He thus pointed out the absence or nullity of the effects of ICT on productivity in the United States of America (USA). To counteract this famous productivity paradox, the class of authors described as optimistic put forward at least three reasons: the weakness of statistical data due to the fact that the effects of ICT on productivity were poorly measured, the need for time for companies to adapt in order to change their organisation and implement efficient processes and, finally, the emergence of the idea of a technological bias, since it could be that the companies that adopt ICT are already the ones that are productive (Cette et al, 2004; Triplett, 1999; Oliner and Sichel, 1994; Brynjolfsson, 1991). Nevertheless, it is worth recalling that van Ark (2016) reminds us that the productivity paradox seems to be ever present in the new digital economy because ICT is a set of tools that is constantly being renewed and/or improved. Each renewal is likely to reproduce the 'productivity paradox'.

The literature on the evaluation of the effects of ICT on structural transformation is almost non-existent. It generally includes work that assesses the effects of ICT on correcting market failures and firm productivity (Aker and Blumenstock, 2015; Cardona et al., 2013), on economic growth and the global value chain, and on countries' trade performance (Adejumo et al., 2020; Albiman and Sulong, 2017; Rodrik, 2018). While all of these aspects are essential for economic development, they cannot be equated with or replace structural transformation. Indeed, recent work shows that economic growth and other macroeconomic indicators are not necessarily conducive to structural transformation. This is particularly true of economic growth, foreign direct investment and the increase in foreign trade that

SSA has experienced for more than two decades, which do not bring about structural transformation (AfDB, 2020; Cadot et al., 2016; Cadot and Melo, 2016). Thus, taking structural effects into account when assessing the effects of ICT on the economic performance of developing countries is becoming a necessity.

The relationship between ICTs and structural transformation is an extension of that between ICTs and economic growth. From this perspective, at least four schools of thought underpin the relationship between ICTs and structural transformation. In the first school, the authors argue that ICTs are a source of firm heterogeneity, traditionally hidden by neoclassical theory through its assumptions of pure and perfect competition. Indeed, this first school asserts that ICT-intensive sectors can be more productive than other sectors and, subsequently, lead to a shift in the resources of the economy (Seymen, 2017). However, ICTs may also affect productive activities differently between rural and urban areas. This implies a digital divide between urban and rural areas, in which case firms in the industrial sector that use ICT more are more productive than those in the traditional sector. This thinking was already affirmed by Triplett (1999) and Oliner and Sichel (1994). The second school develops the idea that human capital can be increased via the use of ICT (Duţă and Martínez-Rivera, 2015). Indeed, ICT can improve the quality of teaching through innovative methods, motivation, interest and engagement of learners through the ease of communication of information exchange. Furthermore, with the emergence of ICT, companies are becoming increasingly demanding about the level of qualification of the workforce (Caroli and van Reenen, 2001). This implies that individuals who invest more in their human capital are likely to acquire a high level of qualification and thus be recruited by the more productive companies that demand these high levels of qualification, thus boosting the overall productivity of the economy.

In the third school, ICTs are tools for cooperation, collaboration at work, information systems, exchange platforms and data sharing that lead to managerial reorganisations and improve productivity (Martin-Juchat, 2016). Finally, the fourth school emphasises the externalities of technological innovation (endogenous innovations) of countries as the main driver of economic development (Romer, 1990). Indeed, endogenous growth theories consider that innovation can generate both static gains and dynamic gains (a faster rate of innovation) in the long run (Appiah-Otoo and Song, 2021). Endogenous growth models can be divided into two main groups. On the one hand, there are models closer to the neoclassical view, such as Barro (1991), Barro and Sala-I-Martin (1995) and Lucas (1988), which emphasise the accumulation of human capital, and on the other hand, there are models based on the development of human capital, there are models based on Schumpeter's idea of creative destruction such as Aghion and Howitt (2006), Coe and Helpman (1995), Grossman and Helpman (1991) and Romer (1990) which focus on the endogenous development of knowledge and R&D. For the latter class of authors, ICTs should be considered as a factor of production in the same way as the traditional factors of production, namely capital and labour. ICT is important for the economic prosperity of a country because it increases the productive capacity in various economic sectors (Hong, 2016). In addition, ICT connects a country's production activities to global value chains, which increases competitiveness, reduces poverty and improves transparency and efficiency of government management (Sassi and Goaied, 2013). An evolving stream of development literature that focuses on how information technology can be harnessed for positive macroeconomic externalities in Africa also supports the importance of ICT in fostering economic prosperity (Tchamyou, 2019; Abor et al., 2018). The merit of ICT in driving comparative development in SSA compared to other regions of the world is that there is still significant scope for ICT penetration in SSA compared to other regions of the world that have reached saturation levels in ICT penetration (Asongu and Odhiambo, 2019).

In another way, the relationship between ICTs and structural change also lies in the heterogeneity between firms. For labour to be reallocated between existing firms, it is necessary that they differ in their productivity performance. Heterogeneity has traditionally been obscured by neoclassical theory through its five assumptions (atomicity, product and factor homogeneity, fluidity, perfect and free information, and free market entry and exit). The different heterogeneities are access to information, market imperfection and innovation. These three points correspond by analogy to the different conceptions of ICTs as factors of production (Brynjolfsson, 1991), as a new technological paradigm (Bakos and Nault, 1997) and finally as knowledge and the process of knowledge production and codification (Foray, 2018; Nonaka and al., 2014). As factors of production, ICTs are both a production good (for user firms) and a product (for producer firms) that are sources of heterogeneity in terms of their costs (Krugman and al., 2006) and their uses (Matambalya and Wolf, 2006). Geography and human capital, for example, can justify this situation. Taking into account instead the informational, communicational and cognitive-enhancing characteristics of firms, the heterogeneity due to ICTs remains very diverse. Thus, considering a causal link between ICTs and structural change is justified since ICTs is the basis of firm heterogeneity. However, few studies to our knowledge have assessed the effects of ICTs on structural change. Structural change reflects the flow of workers from one sector to another. Indeed, many jobs are created in high-productivity sectors and many jobs are lost in low-productivity sectors, freeing up labour for high-productivity sectors.

The contribution of this paper lies particularly in highlighting the effects of ICTs on structural transformation, an aspect that remains poorly understood in the literature. The specificity of structural transformation is that it accounts for an economy's capacity to generate and spread productivity across all its sectors through supply and demand mechanisms (Sen, 2023). At the same time, it integrates productive, social and environmental efficiency (Nissanke, 2019; Armah and Baek, 2019) following the supply and demand approaches. The demand approach operates according to the Keynesian logic of effective demand, the main determinant of the development or rapid collapse of industry. ICTs can affect demand behaviour (tastes, costs, mimicry, culture, etc.) and therefore determine the direction of structural change. This is why new goods are introduced during the economic growth process in order to maintain growth (Sen, 2023). On the supply side, productivity improvements resulting from innovation and technological progress are considered to be one of the main drivers of structural change (Ngai and Pissarides, 2007; Acemoglu and Guerrieri, 2008). Similarly, Hamermesh et al (1996) point out that the vast majority of worker flows come from jobs created by existing firms which increase their market share compared to jobs created by new firms. Thus, taking structural transformation into account makes it possible to account for the realities of the supply and demand structures of SSA economies.

The objective of this paper is thus to investigate the effects of ICT on structural transformation in SSA. This paper has a triple interest; firstly, it reaffirms the place of ICTs at the heart of development policies. Indeed, postulating a non-zero effect of ICTs on the transformation of economic structures in SSA requires that they be taken into account in development policies. Secondly, this paper fills the gap in the empirical literature on the role of ICTs as a determinant of structural transformation, an aspect still unexplored in the literature. Indeed, this paper enriches the literature on the sources of structural transformation; sources which include ICT. Finally, it supports the idea that structural transformation, which is essential for the economic development of sub-Saharan economies, can be achieved through the increasing adoption of ICT.

The remainder of this article is presented as follows: Section 2 outlines the evolution of ICT adoption and structural transformation in sub-Saharan Africa, Section 3 specifies the methodology adopted, Section 4 presents and discusses the results obtained and Section 5 concludes.

2. Evolution of ICT adoption and structural transformation in sub-Saharan Africa (SSA)

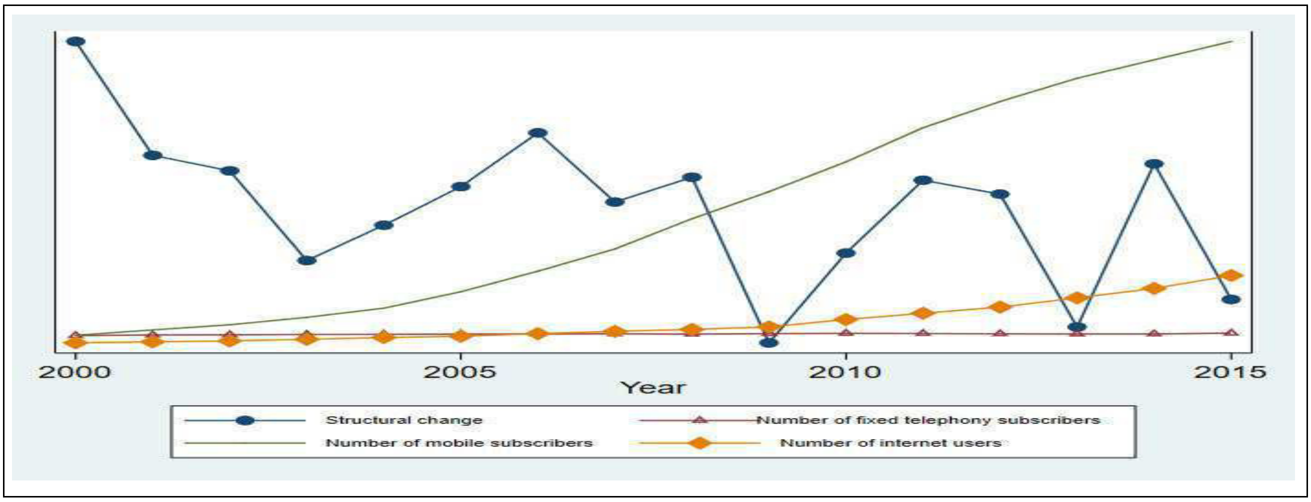
This section presents the characteristics of our sample and reports on the status and evolution of telephony and internet adoption in SSA in relation to the dynamics of structural transformation. To measure the two components of structural transformation, intra-industry productivity and structural change, we use data from the Africa Sector Database (ASD) by Mensah and Szirmai (2018). The ASD presents historical or time series data on employment and value added for 11 sectors in 18 SSA countries. Using the Fabricant (1942) decomposition method, we finally calculate each of these components. The application of Fabricant's method is as follows :

$$\Delta \mathbf{Q} = \sum_j (q_j^1 - q_j^0)\, s_j^0 + \sum_j (s_j^1 - s_j^0)\, q_j^1 \quad (1)$$

Where $\Delta \mathbf{Q}$ is the change in total productivity between two periods, q_j^t and s_j^t represent the value added and employment rate in industry $\mathbf{j}$ in period $\mathbf{t}$ respectively. The first term refers to the intra-industry productivity that McMillan et al. (2017) refer to as the *"fundamentals"* of the economy. The second term, which captures the reallocation of workers across industries, is the structural change.

The ICT indicators come from the World Bank's World Development Indicators (WDI) database. These include the number of fixed-line subscribers as a percentage of the population, the number of mobile phone subscribers as a percentage of the population and the number of internet users as a percentage of the population. Figure 1 below presents the relationship between the ICT variables and the second component of structural change, namely structural change. To construct this figure, we calculated the averages of each variable by year for all countries in our sample. The ICT variables used are: the number of internet users as a percentage of the population, the number of fixed-line subscribers as a percentage of the population and the number of mobile subscribers as a percentage of the population.

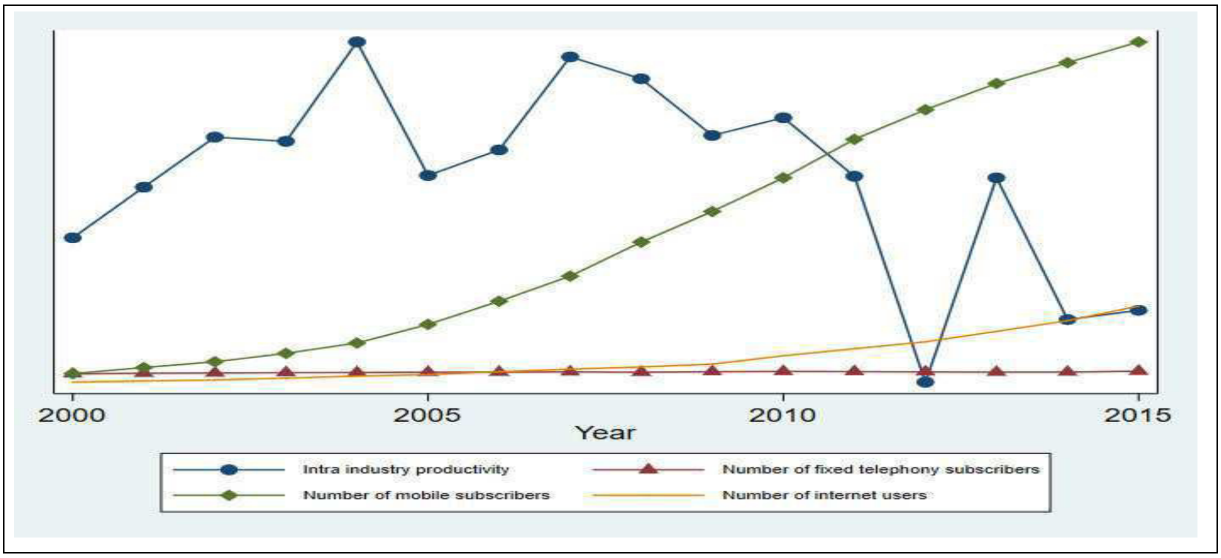
Figure 1: Trends in internet users, fixed line subscribers, mobile subscribers and structural change in SSA.



Sources: authors with data from WDI and ASD

Figure 1 shows that ICT adoption becomes effective around the year 2000. However, the adoption of internet and mobile telephony is at a positive and increasing rate while that of fixed telephony is at a negative rate. This can be explained by the continued decline in the price of mobile phones and internet access (Alzouma, 2008; Tamokwe, 2013), but also by the ease of travel that mobile phones offer. However, SSA is overwhelmingly adopting mobile phones over the internet. Overall, there is an upward trend in internet and mobile phone adoption. In contrast to what we have just seen for internet and mobile phone adoption, structural change has an up and down pattern. Indeed, structural change decreases sharply between 2001 and 2003, increases between 2003 and 2008 before falling sharply again in 2009. Thus, the structural change decreases immediately after the considerable adoption of ICT in 2000 before increasing again three years later. One likely explanation is the adaptation time needed for organisations, households and administrations to learn and master the new tools adopted. Similarly, the succession of jagged trends after 2005 can be explained by the succession of adaptation times created by the repetitive innovations in ICT. Figure 2 below repeats the elements of Figure 1, replacing structural change by intra-industry productivity, the first component of structural transformation.

Figure 2: Evolution of the number of internet users, the number of fixed-line subscribers, the number of mobile subscribers and intra-industry productivity in SSA.



Sources: authors with data from WDI and ASD

Figure 2 shows that, in contrast to structural change, intra-industry productivity has a positive slope until 2007, then declines until 2012 before rising again. However, the evolution of intra-industry productivity in each phase is not uniform. The argument that there is an adjustment time is not appropriate in this case as intra-industry productivity increases just after the considerable adoption of mobile phones and the internet. The most plausible explanation in this case would be that in the short run only those individuals, organisations and administrations that are already productive or skilled adopt ICT. In this case, ICT would have an effect on intra-industry productivity in the short run and on structural change in the long run. As McMillan and Rodrik (2011) point out, at the beginning of the structural transformation process there is first an improvement in intra-industry productivity. It is following this improvement that the mechanism of reallocation of labour from low to high productivity sectors occurs. These two graphs show that the relationship between intra-industry productivity, structural change and ICT remains ambiguous and depends on several other factors. This requires the mobilisation of a rigorous analysis using appropriate tools that would allow us to be better informed on the subject.

3. Methodology

The methodology focuses on two points: first, the data sources and the justification for the choice of variables, and second, the specification of the econometric model.

3.1. Data sources and variables

The data come from two different sources: intra-industry productivity and structural change are calculated from data in the Africa Sector Database (ASD) by Mensah and Szirmai (2018) using the Fabricant (1942) decomposition method. The ASD presents historical or time series data on employment and value added for 11 sectors in 18 SSA countries. The rest of the variables come from the World Development Indicators (WDI) and the Varieties of Democracy (V-Dem) Project (Ziblatt et al., 2021). The study period is 2000-2015 as this range allows for easy synchronisation of the two data sources, while the 18 countries selected for the study are the only SSA countries available in the DSA.

As for the other variables mobilised, their selection is based on empirical work including McMillan et al. (2014), Lectard and Rougier (2018), Moussir and Chatri (2019) and others. We select as ICT indicators the number of mobile phone subscribers as a percentage of the population and the number of internet users per 100 people as these two indicators remain the most widely used ICT indicators in SSA to date (Kiyindou, 2009; Tamokwe, 2013). Since there is a strong correlation between the number of mobile phone subscribers and the number of internet users as mobile phone subscription is generally used as a channel to access the internet, we build a model for each of these variables. However, while it is possible to use fixed telephony as an internet access channel, the fact that the number of fixed telephony subscribers has fallen sharply allows us to neglect the latter.

Of course, intra-industry productivity and structural change depend on the quality of countries' governance, human capital, trade openness and the level of economic development (measured by the growth rate of GDP per capita) (Moussir and Chatri, 2020). The quality of governance is measured by the public sector corruption index while human capital is measured by the education inequality index. Both variables are derived from the V-Dem. The public sector corruption index ranges from 0 to 1 and a value close to 1 means that the public sector is highly corrupt. Public sector can affect transformation by limiting the mobility of resources through regulations, business licences, services to individuals and the flouting of consumer rights. The education inequality index captures the level of human capital in each country. Indeed, several authors agree that human capital is an indispensable factor for structural transformation (Moussir and Chatri, 2020; Lectard and Rougier, 2018) and high educational inequality can have adverse effects on the structural transformation of developing countries. This variable reflects the distribution of access to education in a given country. High inequality means that a large proportion of the population (the demand) is without education. This index, which lies between -3 and 3, has been rescaled by us so that it now lies between 0 and 1. Thus, a value close to 1 indicates very high educational inequality. Finally, to account for the specificity of SSA countries that rely heavily on natural resource exports (Fosu, 2010), we also include in the model the per capita value of natural resources as a percentage of GDP per capita. This variable, which does not exist in V-Dem, was generated by dividing the value of natural resources per capita by GDP per capita and multiplying by

100. It allows us to test the existence of a resource curse in SSA. Similarly, structural transformation involves trade with the outside world (Moussir and Chatri, 2020). The level of trade is taken into account in our model by the ratio of the sum of exports and imports as a percentage of the GDP of the countries concerned. The opening up of trade affects both the supply and demand approaches to structural change. Companies face greater competition and have more market opportunities, while consumer behaviour may change as a result of imported goods. In summary, our data covers 18 SSA countries over the period 2000 - 2015. Intra-industry productivity and structural change are the two dependent variables. The number of mobile phone subscribers and the number of internet users as a percentage of the population are our variables of interest. The public sector corruption index, the education inequality index, trade openness, the growth rate of GDP per capita and the value of natural resources as a percentage of GDP per capita are the control variables.

3.2. Econometric model specification

Our modelling is based on that of Moussir and Chatri (2019) which is based on the framework of endogenous growth theory. This framework defends the idea that technical progress depends on several factors that can sustain growth in the long run. According to this framework, ICTs are likely to create a redistribution of productivity gains within an economy through the waves of innovation they stimulate (Koutroumpis et al., 2020). Moreover, the literature is unanimous on the fact that structural transformation, which is a dynamic phenomenon, must be assessed by a dynamic model (Lectard, 2016). In order to highlight the direct and indirect effects of ICT on structural transformation in SSA, it is necessary to use a model that allows for both long-term and short-term effects. Indeed, ICT affects intra-industry productivity and structural change differently in the short run than in the long run. From this perspective, a panel data vector autoregression (VAR) model is used to assess the effects of ICT on structural change in SSA. The use of the panel data VAR model is justified by the fact that it does not impose a priori restrictions on the exogeneity and endogeneity of variables (Gossé and Guillaumin, 2014). Also, it allows to capture both static and dynamic interdependencies. In addition, the VAR model can capture the dynamic relationships between several time series simultaneously, making it easier to forecast multivariate time series. The VAR model can also be used to analyse shocks and impulse responses, helping to understand how shocks affect variables over time (Im et al., 2003). Most importantly, the VAR model does not require strict theory-based specifications and allows greater flexibility in data analysis.

The specification of the VAR model is as follows:

$$\boldsymbol{Y_{it} = A_0 + A_1 Y_{it-1} + A_2 Y_{it-2} + \cdots + A_P Y_{it-P} + v_{it}} \quad \mathbf{(2)}$$

Where, $\boldsymbol{Y_{it}}$ is the vector of dependent variables (this is all the variables presented in the first point of the methodology), $\boldsymbol{Y_{it-1}, \ldots, Y_{it-p}}$ are vectors of the lagged variables of $\boldsymbol{Y_{it}}$ at periods $\boldsymbol{t-1}$,… $\boldsymbol{t-}$

$\boldsymbol{p}$. $\boldsymbol{A_0}$ is the vector of constant parameters, $\boldsymbol{A_{j\neq 0}}$ is the vector of parameters associated with the lagged variables, $\boldsymbol{i}$ represents the country, $\boldsymbol{t}$ the period and $\boldsymbol{v_{it}}$ the error term. Moreover, the vector auto regression (VAR) model on panel data allows for the estimation of parameters that are consistent and robust to problems of variable omission, simultaneity and endogeneity (Anderson and Hsiao, 1981).

The parameters of the VAR process can only be estimated on stationary series. Thus, we first examine the stationarity of the different variables. The current literature is developing around the idea that dependencies between individuals in the panel should be explicitly taken into account. This is why we first perform the Pesaran (2015) test to check the dependencies between individuals in the panel for each variable. The rejection of the null hypothesis of this test allows us to conclude that there is independence between the individuals of the panel. Table 1 below shows the results of the Pesaran (2015) tests for our different variables.

Table 1: Dependency tests of individuals in the panel

Variables	Probability	Conclusion
Structural change	0.000	Independent
Intra industry productivity	0.000	Independent
Internet users	0.002	Independent
Mobile phone subscribers	0.000	Independent
GDP per capita growth rate	0.018	Independent
Public sector corruption index	0.007	Independent
Educational inequality	0.000	Independent
Value of natural resources	0.033	Independent
Trade openness	0.000	Independent

Sources: Author with data from ASD, V-Dem and WDI

The results of the Pesaran (2015) tests show that all individuals in the panel are independent for our variables over the selected study period. This means that we can in the following use first generation unit root tests without compromising the results. First generation unit root tests are those that rely on the assumption of inter-individual independence of the residuals, an assumption that allows us to establish very simply the statistical test distributions and to obtain generally asymptotic or semi-asymptotic normal distributions (Mignon and Hurlin, 2005). In this work, we apply the Im, Pesaran and Shin (IPS) test (Im et al., 2003). The IPS test poses the null hypothesis that all panels contain a unit root and the alternative hypothesis that some panels are stationary (Mignon and Hurlin, 2005). Moreover, this test is adapted to the case corresponding to this study where the number of individuals in the panel and the number of time units are small and almost equal (StataCorp LP, 2009). The results of the unit root tests are presented in Table 2 below. The test results are performed at the 5% significant level.

Table 2: Unit root testing

Variables	Probability	Conclusion
Structural change	0.000	I (0)
Intra industry productivity	0.000	I (0)

Internet users	0.0077	I (0)
Mobile phone subscribers	0.0485	I (0)
GDP per capita growth rate	0.000	I (0)
Public sector corruption index	0.000	I (0)
Educational inequality	0.000	I (0)
Value of natural resources	0.000	I (0)
Trade openness	0.0003	I (0)

Sources: Author with data from ASD, V-Dem and WDI

Table 2 shows that all variables are stationary in level. This eliminates the need for Co-integration tests, which is why we use a simple VAR model. However, before estimation, it is necessary to determine the optimal lags. We determine the optimal lag by regressing our model at several orders of lag to retain the one that minimizes the Akaike information criterion appropriate for prediction models. The results of the estimations lead us to retain a lag of order 1. Moreover, before commenting on the results, the stability test of the VAR model carried out confirms the stability of our model (appendix 1).

4. Results and discussion

This section has two subsections. The first sub-section presents the descriptive statistics and the econometric results, while the second subsection tests the robustness of our econometric analysis.

4.1. Descriptive statistics and the econometric results

Table 3 shows the means and standard deviations of the different variables over the study period.

Table 3: Descriptive statistics

Variables	Means	Standard deviations
Structural change	34.974	105.605
Intra industry productivity	6.098	14.212
Internet users	7.12	9.47
Mobile phone subscribers	40.03	39.44
GDP per capita growth rate	3.142	2.755
Public sector corruption index	0.553	0.223
Educational inequality	0.014	0.909
Value of natural resources	78.732	138.968
Trade openness	0.774	0.327

Sources: Authors with data from ASD, V-Dem and WDI

It can be seen from the table above that the average structural change is equal to 34.974 but with a very high standard deviation equal to 105.605. This shows a very large disparity in structural change between SSA countries. There is also a disparity but this time less than the previous one between SSA economies in terms of intra-industry productivity. Indeed, intra-industry productivity is on average equal to 6.098 while its standard deviation is only 14.212. With regard to ICT indicators, there is homogeneity between countries in the number of internet users and the number of mobile phone subscribers since the standard deviations are roughly equal to the averages. It can be seen that only

7.12% of the population use the internet in SSA while about 40% have a mobile phone subscription. Given that mobile telephony is the most widely used ICT indicator in SSA, it can be argued that the vast majority of the population that is still excluded from using the internet in SSA is excluded in particular because of the costs involved, as mobile phone subscriptions are a channel for accessing the internet. However, as shown in Figure 1 and Figure 2, the continuing shift away from fixed-line telephony that appears to be common to all SSA countries has prompted us to leave this ICT indicator.

Table 3 also provides other important results. It can be seen that SSA economies have on average a corrupt public sector and that this phenomenon is common to these countries as the mean of this variable equal to 0.553 is closer to 1 than to 0 while its small deviation (0.223) indicates homogeneity. Public sector corruption is therefore a major concern of sub-Saharan economies. On the other hand, SSA has a very low inequality in education with an average of 0.014, even if this result hides a very high heterogeneity between the different countries of the region. With regard to natural resource management, its contribution to GDP is on average equal to 78.732 with also a heterogeneity between the different countries. Finally, Table 3 shows that the SSA countries, on average, import more than they export, since the average of this last variable is less than one. However, it is still very early to conclude that the structural transformation of SSA countries must involve increasing ICT integration. Such a conclusion requires an analysis based on rigorous econometric tools such as panel VAR modelling, the results of which are presented in Table 4.

Table 4 : Panel VAR model estimations

X \ Y	A	B	C	D	E	F	G	H	I
A (t-1)	**0.242****	0.037	0.005*	0.000	-0.007	0.039	-0.02	-0.002**	0.31*
	(0.05)	(0.298)	(0.08)	(0.655)	(0.202)	(0.665)	(0.359)	(0.041)	(0.065)
B (t-1)	-3.15*	**0.674****	0.086	0.006	-0.000	0.000	-0.031	-0.000	0.041
	(0.054)	(0.031)	(0.219)	(0.344)	(0.461)	(0.541)	(0.612)	(0.856)	(0.281)
C (t-1)	0.041*	0.011**	**0.452*****	0.001	0.027	-0.000	0.000	-0.000	0.104
	(0.071)	(0.043)	(0.000)	(0.4)	(0.210)	(0.328)	(0.234)	(0.978)	(0.215)
D (t-1)	0.004	0.001	-1.658	**1.023****	0.002	-0.013	0.043	1.004	1.085
	(0.624)	(0.399)	(0.663)	(0.006)	(0.615)	(0.531)	(0.673)	(0.761)	(0.397)
E (t-1)	**-0.98***	0.057	0.283	0.019*	**0.619*****	-0.009	0.004	-0.000	0.005**
	(0.088)	(0.568)	(0.406)	(0.069)	(0.000)	(0.513)	(0.216)	(0.268)	(0.06)
F (t-1)	-2.079	-4.463	0.25	0.067	0.265	**0.97*****	0.641	-0.000	-2.6
	(0.140)	(0.2)	(0.889)	(0.899)	(0.193)	(0.000)	(0.588)	(0.529)	(0.410)
G (t-1)	1.158	0.092	-13.85	0.49	1.29	**0.011***	**1.231****	-1.003	-0.087
	(0.307)	(0.416)	(0.449)	(0.121)	(0.377)	(0.056)	(0.038)	(0.283)	(0.701)
H (t-1)	-0.028***	-1.07*	-0.007	0.000	0.219*	0.068	0.000	**3.606*****	0.835*
	(0.000)	(0.098)	(0.582)	(0.581)	(0.088)	(0.285)	(0.782)	(0.000)	(0.087)
I (t-1)	3.187	10.30**	0.043**	0.604	1.12***	-0.000	-0.001	-1.956	**0.633****
	(0.231)	(0.012)	(0.047)	(0.113)	(0.000)	(0.119)	(0.701)	(0.738)	(0.016)

A	Structural change	**D**	Mobile phone subscribers	**G**	Educational inequality
B	Intra industry productivity	**E**	GDP per capita growth rate	**H**	Value of natural resources
C	Internet users	**F**	Public sector corruption index	**I**	Trade openness

NB: The values in brackets are the probability tests. ** P< 10% ** P< 5% *** P< 1%*

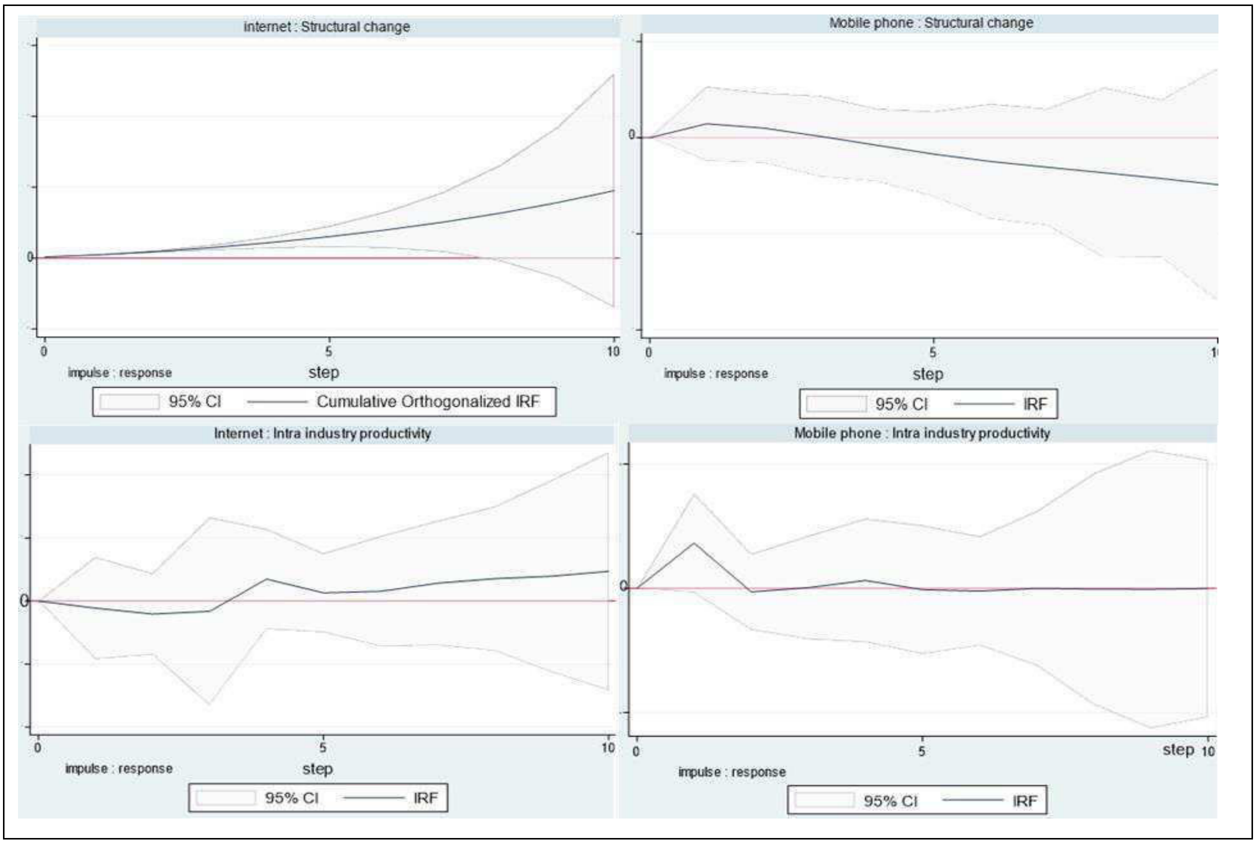
Sources: Authors with data from ASD, V-Dem and WDI

The results show that the number of Internet users positively affects intra-industry productivity and structural change in the current period in sub-Saharan Africa. Thus, 1% more Internet users significantly increases structural change by 4.1% and intra-industry productivity by 1.1%. These results can be explained by the fact that the internet offers a wide range of services and a wave of new-generation innovations that even integrate telephony into many applications (Appiah-Otoo and Song, 2021). Another explanation may be that the Internet directly affects structural change and intra-industry productivity but that there is an indirect effect of the Internet on structural change via the intra-industry productivity channel. This may explain to some extent the fact that the effects of the internet on structural change are higher in intensity than the effects of the internet on intra-industry productivity.

Table 4 also presents several other important results. One of these is that structural change also has a positive and significant impact on the number of Internet users. Thus, the more factors migrate to high-productivity sectors, the greater the number of Internet users. This last result can be interpreted as the existence of a technological bias, as it is possible that the best-performing companies are those that adopt ICTs. Thus, resources that migrate to the most productive sectors may adopt the Internet on a massive scale in order to increase or maintain their level of productivity. Similarly, trade openness increases intra-industry productivity, internet users and GDP per capita growth rate. The latter result can be explained by the fact that ICTs allow the extension of markets (Filali, 2018), increase externalities and promote economies of scale (Kante et al., 2019).

Furthermore, in terms of the social impact of ICT, the results show that ICT promotes educational inequality in SSA but reduces corruption in the public sector of these economies. In this case, ICTs can be a tool to fight corruption; but measures must be taken to avoid the exclusion of a segment of the population, which is likely to increase educational inequalities. Indeed, recent literature shows that ICTs increase wealth inequalities (Njangang et al., 2021) and therefore certainly increase educational inequalities. However, an advantage of the VAR model specification is that it allows for impulse analyses to better understand the reactions of structural change and intra-industry productivity to shocks on the number of internet users and mobile phone subscribers. Figure 3 below presents the response functions of structural change and intra-industry productivity for SSA countries to shocks that are likely to increase the number of internet users and mobile phone subscribers respectively. These shocks can be the construction of infrastructure that improves and promotes the use of ICTs, the adoption of new tax exemption laws on mobile phones (preferably smartphones) and the promotion of mass training of the population on the various uses of ICTs so as to increase the profitability of these tools.

Figure 3: Impulse responses of structural change and intra-industry productivity to shocks on ICT variables

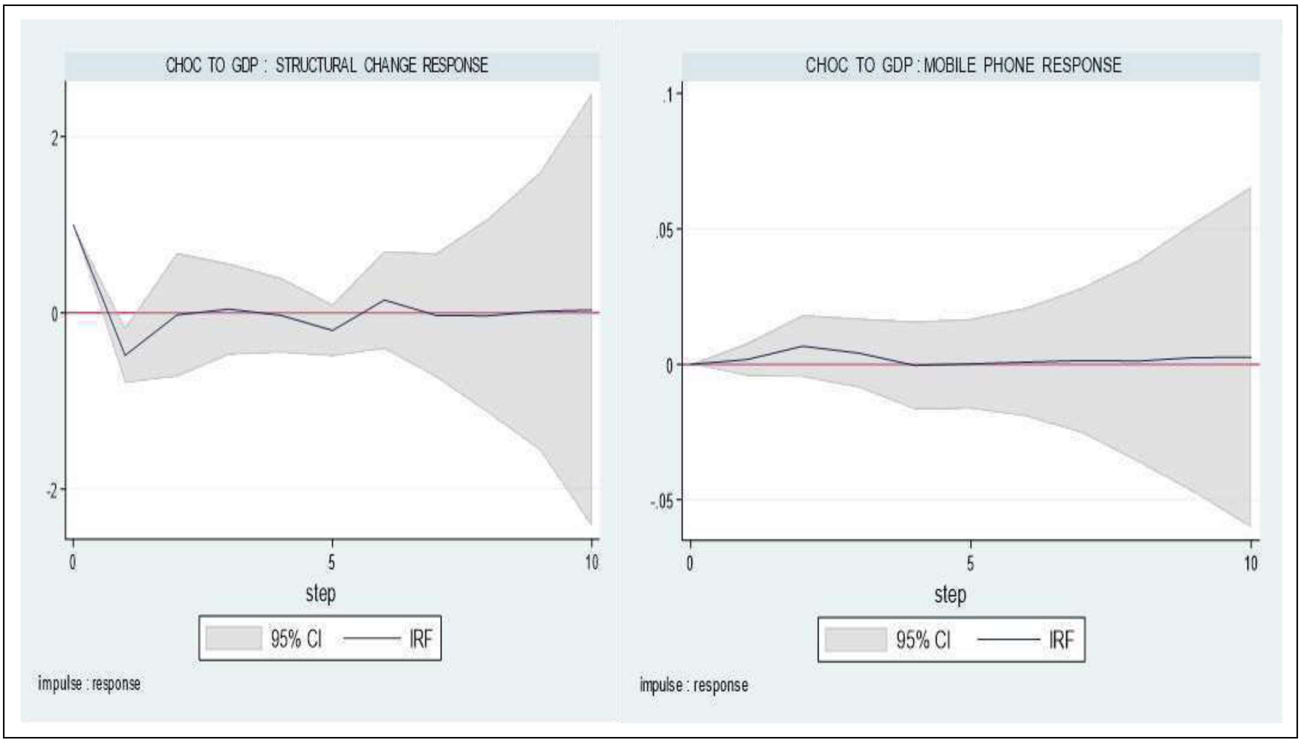


Sources: Authors with data from ASD, V-Dem and WDI

Figure 3 shows that a shock to the number of Internet users has no effect on structural change and intra-industry productivity in the short term. It can be seen that a shock at period 0 only begins to have an effect after around 3.5 years. This delay can be explained by the adaptation time needed to learn and master the new ICT tools, but also by the restructuring of organisations and institutions (Jorgenson and Griliches, 1967). However, we note that the effects of the shock in the number of Internet users on structural change remain continuous over time, albeit with a weak slope, whereas the effects of the shock in the number of Internet users on intra-industry productivity are initially negative until around the second year after the shock, before becoming positive for the rest of the period. This last result suggests that an improvement in internet access has immediate and continuously increasing positive effects on the reallocation of resources. This means that the more Internet access there is, the more resources are reallocated to the most productive sectors of SSA economies. We can therefore conclude that the positive impact of ICTs on structural transformation is highly perceptible. Our results confirm Brynjolfsson's (1991) initial idea that ICTs contribute to the economic development of countries. In order to further appreciate the effects of ICT, it is worth examining the behaviour of the other variables in the model following an ICT shock. For telephony, Figure 3 shows that a shock to the number of mobile phone subscribers has positive short-term effects on structural change and intra-industry productivity, although the intensity is higher for intra-industry productivity. These effects weaken after two years and are cancelled out in the case of intra-industry productivity, whereas they become negative in the case of structural change.

In order to highlight other important results, and taking into account the estimates in Table 4 above, the following Figure 4 presents the reaction functions of structural change and the number of mobile phone subscribers following a shock to GDP.

Figure 4: Impulse responses of structural change and mobile phone subscribers to shocks on GDP



Sources: Authors with data from ASD, V-Dem and WDI

Figure 4 shows that a shock to GDP has an immediate and negative effect on structural change in SSA, while it has a positive effect on the number of mobile phone subscribers. However, the negative effect of the shock on structural change fades in the first year, changes direction and returns to equilibrium by the third year. This result can be explained when the shock to economic growth is not structural but comes, for example, from new exploitation of natural resources or new debt, which can direct resources towards less productive sectors. For example, it is common for debt in SSA countries to be used to finance less profitable projects that mobilise sufficient financial, human and material resources and are often subject to corruption and poor governance. As for the positive effects on the number of mobile phone subscribers, this result can be explained by the fact that the fruits of growth resulting from the shock can be used to finance a number of telecommunications infrastructure projects, especially as telecommunications have been part of the development agenda of almost all SSA countries in recent years, in order to boost the African Continental Free Trade Area (AfCFTA).

However, to determine the extent to which the variables interact, i.e. in which direction the shock has the greatest impact, Table 5 presents the variance decomposition for each variable 10 years later.

Table 5: Forecast-error variance decomposition

Response \ Impulsion		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Total
(1)	Structural change	**0.177**	0.230	0.255	0.109	0.078	0.027	0.024	0.033	0.067	1
(2)	Intra industry productivity	0.102	**0.123**	0.214	0.088	0.090	0.101	0.107	0.066	0.109	1
(3)	Internet users	0.002	0.012	**0.440**	0.112	0.119	0.079	0.036	0.069	0.131	1
(4)	Mobile phone subscribers	0.005	0.007	0.131	**0.405**	0.171	0.045	0.021	0.047	0.168	1
(5)	GDP per capita growth rate	0.009	0.005	0.211	0.118	**0.207**	0.073	0.034	0.188	0.155	1
(6)	Public sector corruption index	0.012	0.005	0.096	0.128	0.204	**0.334**	0.094	0.109	0.018	1
(7)	Educational inequality	0.001	0.016	0.231	0.018	0.211	0.067	**0.316**	0.088	0.062	**1**
(8)	Value of natural resources	0.013	0.012	0.005	0.018	0.107	0.073	0.034	**0.532**	0.206	1
(9)	Trade openness	0.002	0.005	0.206	0.120	0.094	0.052	0.044	0.034	**0.443**	1

Sources: authors with data from Limi Kouotou and Epo (2019), ASD and WDI

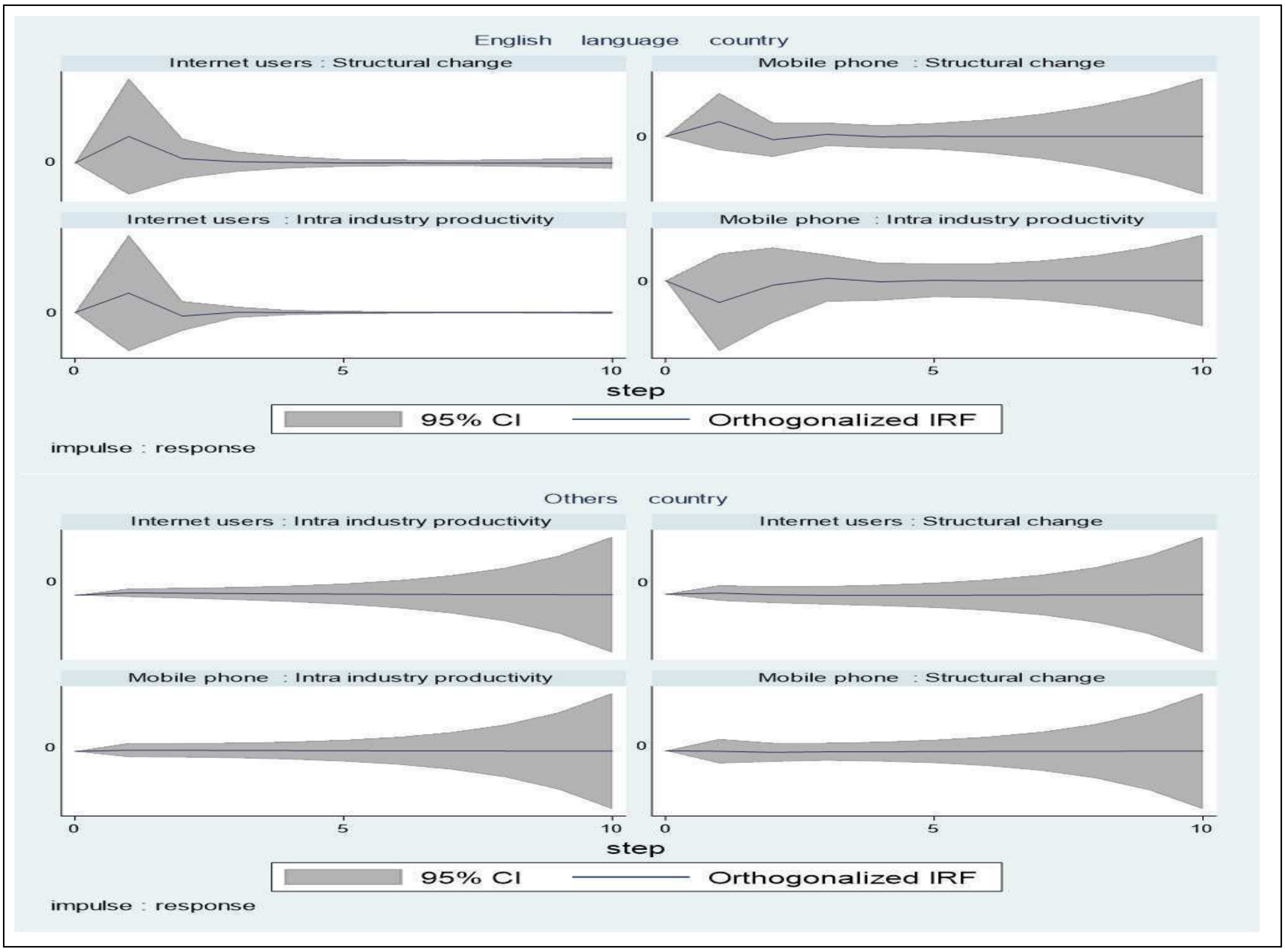
Table 5 shows that 25.5% and 21.4% of the variance in the forecast error of structural change and intra-industry productivity is due to the variance in the number of internet users respectively. Similarly, 10.9% and 8.8% of the variance in the forecast error of structural change and intra-industry productivity is due to the variance in the number of mobile phone subscribers, respectively. These results also reveal that the effects of the internet are stronger than those of mobile telephony in SSA. The fact that the internet offers a wide range of services and a wave of next-generation innovations that even integrate telephony into many applications may explain these results. Thus, these results confirm that ICT is important for structural change and intra-industry productivity in SSA. Furthermore, we observe that 44% of the variance in the prediction error of the number of internet users is due to its own variations and 13% to that of the number of mobile phone subscribers while 42.5% of the variance in the prediction error of the number of mobile phone subscribers is due to its own variations and 11% to that of the number of internet users. These latter results confirm the high use of mobile telephony as an internet access channel in SSA.

We also observe that 17.7% of the variance of the forecast error of structural change is due to its own variations and 23% to that of intra-industry productivity, while 12.3% of the variance of the forecast error of intra-industry productivity is due to its own variations and 10.2% to that of structural change. The latter result is consistent with McMillan and Rodrik's (2011) assertion that intra-industry productivity improvement occurs early in the structural transformation process. It is afterwards that the reallocation of factors from low to high productivity sectors takes place. This result also confirms that structural transformation requires, in the first instance, the improvement of the fundamentals of the economy (human capital, innovation, institutions, infrastructure, etc.) that enable each sector to produce efficiently.

4.2. Sensitivity analysis

In order to test the robustness of our analyses, we calculate the reaction functions of structural change and intra-industry productivity to shocks on ICT variables, for countries whose official language is English and for the other countries. This allows us to control for some historical and cultural specificities of the countries.

Figure 6: Impulse responses of structural change and intra-industry productivity to shocks on ICT variables by official language



Sources: Author with data from ASD, V-Dem and WDI

Figure 6 shows that only English-speaking countries really benefit from ICT to boost their structural transformation. While the reaction functions of structural change and intra-industry productivity are almost linear in the other countries, indicating a very weak reaction, the non-linearity of the latter is clearly perceptible in the English-speaking countries. Thus, the Anglo-Saxon countries would be more dynamic in the mobilisation of ICTs in different sectors of activity. However, this result can be qualified by the fact that our sample is largely dominated by English-speaking countries (89%).

5. Conclusion

The purpose of this research is to evaluate the impact of ICT on the structural change of sub-Saharan economies. According to the literature, ICTs have promoted innovation, information interchange, and knowledge management, all of which are critical to public and private sector performance (Oliva et al., 2019). They have also reduced production costs, increased competitiveness, and enhanced public-sector management. Data from the Varieties of Democracy (V-Dem) Project (Ziblatt et al., 2021), the WDI, and Mensah and Szirmai (2018) enabled us to evaluate our assertions on a panel of 18 SSA economies using VAR modeling. The main findings show that the number of internet users has no effect on structural change or intra-industry productivity in the short term, and this delay can be attributed to the time required to learn and master new ICT tools, as well as organizational and institutional restructuring. However, the impacts of the shock in the number of Internet users on structural change persist over time. This conclusion implies that improved internet connection has immediate and rising favorable effects on resource reallocation. This implies that the more Internet connectivity there is, the more resources are transferred to the most productive sectors of SSA economies.

Another key finding is that a shock to GDP has an immediate and negative effect on structural change in SSA, but a favorable effect on the number of mobile phone subscribers. However, the shock's negative influence on structural change decreases in the first year, then reverses and returns to equilibrium by the third year. The outcome can be explained when the shock to economic growth is not structural, but rather results from new exploitation of natural resources or new debt, which can move resources to less productive sectors. Finally, we may infer that the favorable impact of ICT on structural transformation is highly visible. Our results confirm Brynjolfsson's (1991) initial idea that ICTs contribute to the economic development of countries. The paper also recommends that sub-Saharan economies reduce the cost of access to the internet in order to reduce the digital divide. Furthermore, refining the measurement of ICTs (robotics, 3D printing...) to focus on usage can increase the accuracy of results.

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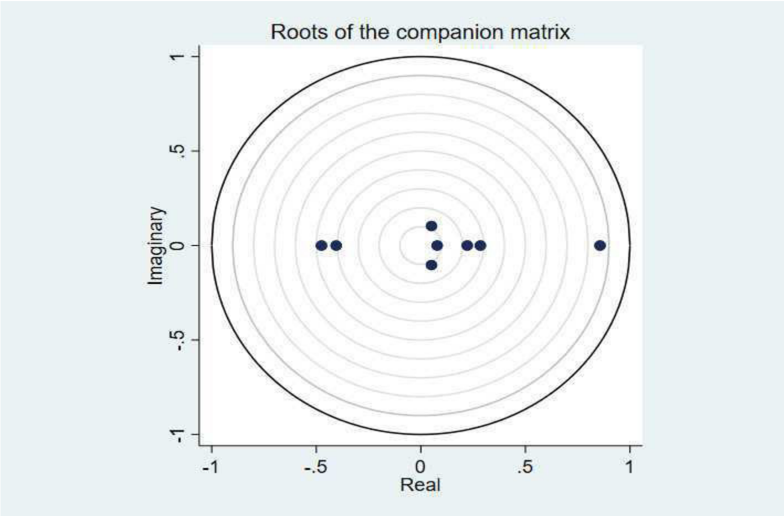
Appendices

Appendix 1: panel VAR stability test

Eigenvalue stability condition		
Real	Imaginary	Modulus
0.856	0.000	0.856
-0.475	0.000	-0.475
-0.404	0.000	-0.404
0.284	0.000	0.284
0.221	0.000	0.221
0.051	-0.103	0.115
0.051	-0.103	0.115
0.078	0.000	0.078

All the eigenvalues lie inside the unit circle.

pVAR satisfies stability condition



Sources: Author with data from ASD, V-Dem and WDI