12 Information and communication technologies' impact on growth and employment in Africa

Evelyn F. Wamboye and Kiril Tochkov

Introduction

Since the mid-1990s, African countries have registered strong output growth that reversed decades of dismal economic performance, and was only temporarily interrupted by the 2008 global financial crises. This process has been primarily driven by a dramatic rise in global demand for commodities that stimulated exports in resource-rich African countries. Growth has also benefited from macroeconomic stability, which was achieved by reducing fiscal imbalances, curtailing inflationary pressures and lessening the external debt burden with the help of debt relief initiatives (Hostland and Giugale, 2013; Wamboye and Tochkov, 2015).

The period of robust growth coincided with a rapid spread of information and communication technologies (ICTs) in Africa. Between 2000 and 2012, mobile cellular subscriptions increased from less than two to more than 60 per 100 people (Figure 12.1), whereas the number of internet users rose from less than one to more than 16 per 100 (Figure 12.2). Moreover, the number of African households owning a computer has more than doubled, and internet access at home has grown fivefold since 2005.[1] Investment in telecommunication with private participation has also grown substantially, with a consistent upward trend since 1995. Particularly, the value increased by 486% from $60.4 million in 1995 to $354 million in 2010 (Figure 12.3). A similar trend is observed in investment in mobile cellular communication, whereby the value more than doubled from $103 million in 2004 to $291 million in 2009 (Figure 12.4).

A large body of literature provides evidence of positive effects of ICTs on growth using micro-level (Brynjolfsson and Hitt, 2003; Jensen, 2007; Brasini and Freo, 2012; Hall, Lotti, and Mairesse, 2013) and aggregate data from developing (Roller and Waverman, 2001; Sridhar and Sridhar, 2007; Kathuria, Uppal, and Mamta, 2009; Hawash and Lang, 2010) and developed (Oliner and Sichel, 2000; Oulton, 2002; Jorgenson, 2003; Jimenez-Rodriguez, 2012) countries and large cross-country samples (Waverman, Meschi, and Fuss, 2005; Jorgenson and Vu, 2007; Papaioannou and Dimelis, 2007; Gruber and Koutroumpis, 2011; Yousefi, 2011). In the case of Africa, fixed-line (Gyimah-Brempong and Karikari, 2010)

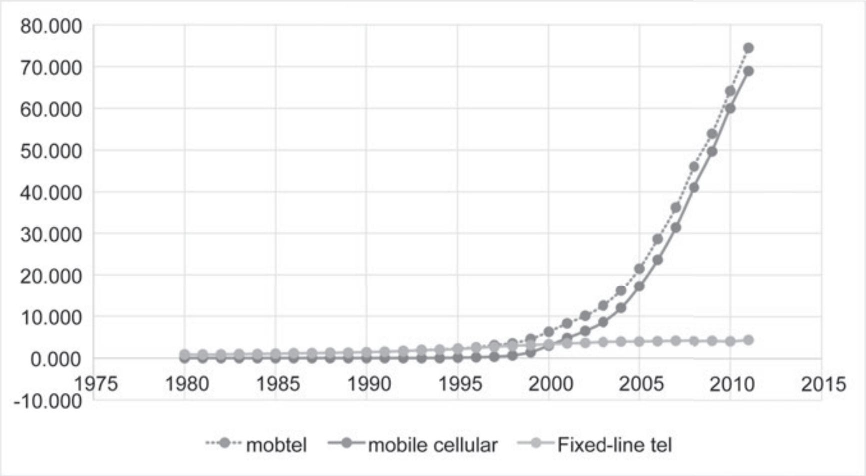

Figure 12.1 Mobile cellular, fixed-line telephone, and sum of mobile cellular and fixed-line telephone (mobtel) all expressed per 100 people, Africa

Source: World Bank's African Development Indicators (online database)

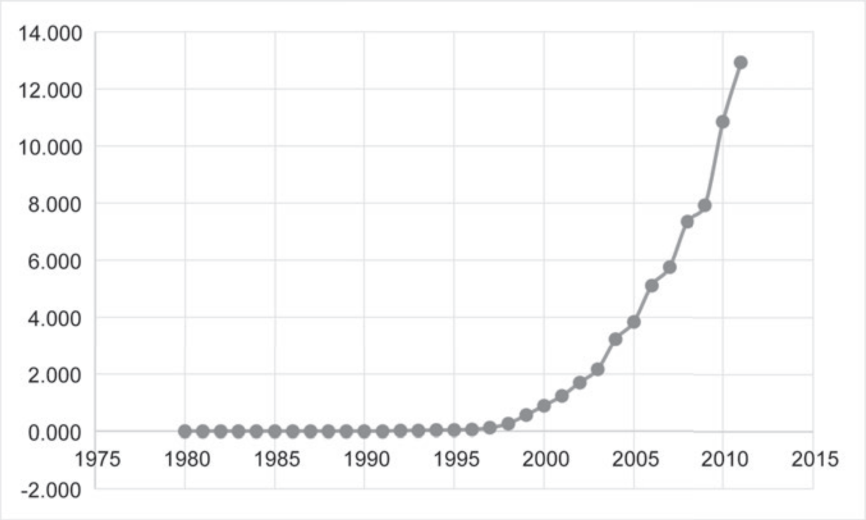

Figure 12.2 Internet users (per 100 people) in Africa

Source: World Bank's African Development Indicators (online database)

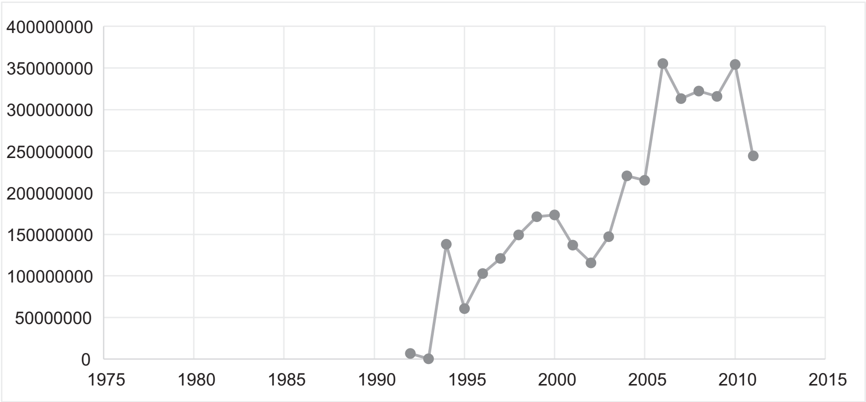

Figure 12.3 Investment in telecoms with private participation (current US$), Africa

Source: World Bank's African Development Indicators (online database)

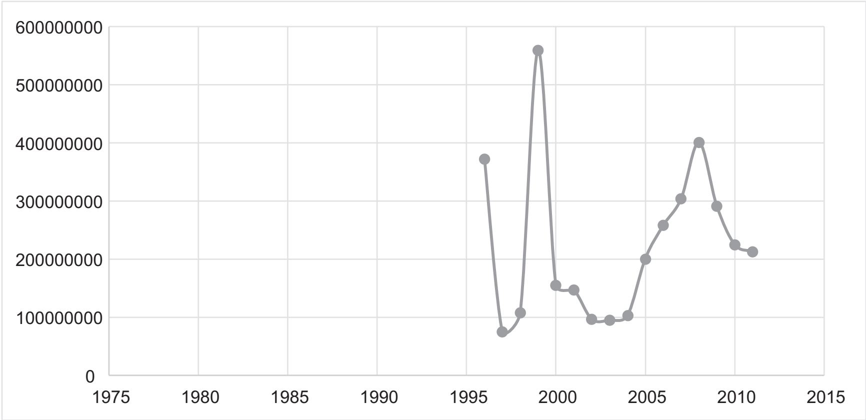

Figure 12.4 Mobile communication investment (current US$), Africa

Source: World Bank's African Development Indicators (online database)

and mobile cellular (Andrianaivo and Kpodar, 2011; Lee, Levendis, and Gutierrez 2012) telephones have also been shown to promote economic growth.

This chapter examines the contributions of ICTs indicators to long run economic growth as well as employment in a large sample of African countries over the period 1975–2011 using a combination of parametric and nonparametric techniques. First, we estimate a number of regression models to quantify the impact of ICTs on economic growth and employment. Next, we employ kernel densities to analyse the distributional dynamics of ICTs indicators and to test for club convergence. Last, nonparametric regressions enable us to detect various forms of nonlinearity and to identify the thresholds where the output elasticities of ICTs reverse signs.

The existing literature on the nexus between ICTs and growth uses either growth accounting (Oliner and Sichel, 2000; Oulton, 2002; Jorgenson and Vu, 2007) or cross-country regressions (Andrianaivo and Kpodar, 2011; Gruber and Koutroumpis, 2011; Vu, 2011). The latter approach indicates that the effects of ICTs are not linear, with some publications reporting increasing (Roller and Waverman, 2001; Gruber and Koutroumpis, 2011) and others diminishing returns to growth (Hawash and Lang, 2010; Vu, 2011). One of the major contributions of our chapter is the application of nonparametric regressions that are optimal in the presence of nonlinearities. In contrast to parametric methods that attempt to model nonlinear effects by including polynomial terms into the regression equation, the nonparametric approach offers more flexibility, as it can reveal multiple thresholds of reversal in the marginal effect. In addition, it can determine whether ICTs are a substitute or a complement of other confounding variables in their impact on the changes in economic growth. For instance, infrastructure and human capital have been identified as crucial complements of ICTs in advanced economies (Roller and Waverman, 2001; Ketteni, Mamuneas, and Stengos, 2011).[2] Further, we complement the parametric results of ICTs effects on growth with an analysis of ICTs impact on employment in these countries. Very few studies have explored this latter relationship in the context of Africa. Last, but not least, we employ a larger sample of African countries over a longer period of time than previous studies on ICTs in Africa.

Africa represents an interesting case for exploring the link between growth and ICTs, and employment and ICTs for various reasons. First, the economic expansion coincided with a rapid penetration of mobile cellular phones and the internet. Second, most African countries lack complementary investments in physical infrastructure (e.g., paved roads and electricity), human capital and information-oriented business processes, which have often prevented ICTs from making a significant contribution to growth and employment in developing countries (Dewan and Kraemer, 2000; Kraemer and Dedrick, 2001). Third, mobile phones in particular have the potential to reduce the cost of information dissemination, increase market efficiency, create new jobs and facilitate the delivery of financial, agricultural, health and educational services (Norton, 1992; Aker and Mbiti, 2010) in Africa. In fact, the explosive growth of mobile cellular platforms such as M-PESA,[3] Esoko, mFarm[4] and Niger's horticultural remote irrigation system suggests that ICTs have various channels through which they can foster economic development, and in turn, create employment opportunities in Africa (Kimenyi and Moyo, 2011; Yonazi, Kelly, Halewood, and Blackman, 2012).

The rest of the chapter is organised as follows: the next two sections explain the methodology and data sources, respectively. This is followed by an analysis of the results and concluding remarks.

Methodology

Parametric regression

In the parametric regressions, we estimate the effects of ICTs on economic growth, as well as employment using two baseline specifications below:

$$\gamma_{it} = \beta_0 + \beta_1 \gamma_{it-1} + \beta_2 ICT_{it} + \beta_3 PC_{it} + \beta_4 HC_{it} + \beta_5 OPEN_{it} tt + \eta_t + \upsilon_i + \varepsilon_{it} \quad (1)$$

$$EMPT_{it} = \gamma_0 + \gamma_1 Growth_{it} + \gamma_2 ICT_{it} + \gamma_3 HC_{it} + \gamma_3 OPEN_{it} + \tau_t + \varphi_i + \varepsilon_{it} \quad (2)$$

where γ_{it} and $EMPT_{it}$ are real GDP growth rate, and employment rate [measured as percentage of the employed in the population of people age 15 years and older], respectively, in country *i* at time *t*. Initial level of real GDP (γ_{it-1}) is included to test for the presence of β-convergence (Barro and Sala-i-Martin, 1992). Country-specific and time fixed effects are denoted by $\upsilon_{i,}$ φ_i and η_t, τ_t, respectively, while ε_{it} is the standard error term.

The major right hand side variable of interest is *ICT*, which is measured by two indicators: the sum of mobile cellular technology and fixed-line telephone subscribers, and mobile cellular subscribers, all expressed per 100 people. The rest of the regressors are selected in accordance with the standard growth (Barro, 1991; Levine and Renelt, 1992; Sala-i-Martin, Doppelhofer, and Miller, 2004) and employment literature (Wamboye and Seguino, 2015; Aydiner-Avsar and Onaran, 2010; Asiedu, 2004; Greenaway, Hine, and Wright, 1999), with most of them having also been identified as complements of ICTs in enhancing growth and employment.

Physical capital (*PC*) is one of the key contributors to GDP growth in the neoclassical model and its effect is expected to be positive. ICTs infrastructure (e.g., mobile cellular towers, and fixed-line telephone cables) and end-user equipment (telephone handsets and computers) are part of the capital stock; however, the contribution of non-ICTs capital to growth in Africa countries is more than twice as large as the ICTs share (Jorgenson and Vu, 2005). Unfortunately, we are unable to disentangle the effect of ICTs capital on growth due to lack of data. Physical capital is measured by gross fixed capital formation (% of GDP).

Trade openness (*OPEN*) is usually positively associated with growth and employment. It allows countries to achieve productivity gains through specialisation driven by comparative advantage. Trade also exposes domestic firms to competition on the global market, which can lead to efficiency improvements. Moreover, openness has been shown to foster ICTs adoption and diffusion (Caselli and Coleman, 2001; Baliamoune, 2002), which in turn can stimulate growth and employment. Openness is measured using two indicators: (1) Imports of goods and services, and (2) Trade (sum of imports and exports) in goods and services, both expressed as a percentage of GDP. The sign of trade openness – in the context of African countries – is unknown prior to empirical estimations given that most of these countries are net importers.

Human capital (*HC*) directly adds to labour productivity and indirectly leads to efficiency gains through more rapid absorption of modern technology. This in turn stimulates economic growth and employment. ICTs adoption and dissemination also rely heavily on educational attainment (Caselli and Coleman, 2001; Kiiski and Pohjola, 2002). Two proxies of human capital are used: education, and population growth rate. These proxies capture the quality and quantity of human capital, respectively. Education is measured by (1) primary and (2) secondary school gross enrolment ratio of total enrolment (regardless of age), to the population of the age group that officially corresponds to the level of education shown. *Growth* is real GDP growth rate, which captures the impact of economic growth on employment.

Dynamic OLS (DOLS), unit root, and cointegration tests

Consistent with estimations of long run cointegrating relationships, we test the model variables for unit roots and cointegration. Panel unit root tests, analogous to the time series augmented Dickey-Fuller tests [(Im, Pesaran, and Shin, 2003)'s Im-Pesaran-Shin (IPS) and (Choi, 2001)'s *Fisher-type* (with the *pperron* option, which uses Phillips–Perron unit root)] are used. Test results show that we cannot reject the null hypothesis of no cointegration at levels. Consequently, the *IPS* and *pperron* unit root tests results reported in Table 12.1 are based on first-differenced data.

Table 12.1 Im-Pesaran-Shin, and Fisher-type tests, 1980–2011, 42 African countries

	Im-Pesaran-Shin (Z-t-tilde-bar) (IPS)	*Fisher-type tests, based on Phillips-Perron test (Inverse normal, Z)* (pperron)
Real GDP growth	–17.478	–25.747
	(0.000)	(0.000)
Real GDP	–12.326	–16.982
	(0.000)	(0.000)
Employment rate	–18.831	–27.964
	(0.000)	(0.000)
Investment	–3.432	–3.975
	(0.000)	(0.000)
Imports	–3.244	–3.903
	(0.000)	(0.000)
Mobile cellular + Fixed-line Tel	–18.712	–34.038
	(0.000)	(0.000)
Mobile cellular	–18.741	–33.795
	(0.000)	(0.000)
M2	–13.923	–19.700
	(0.000)	(0.000)
Trade	–21.190	–34.047
	(0.000)	(0.000)
Pop growth	–4.530	–8.764
	(0.000)	(0.000)

Note: All statistics are based on first-differenced data, *p*-values are in parentheses, time trend is included in both tests. Ho: All panels contain unit roots; Ha: Some panels are stationary *(IPS)*, Ha: At least one panel is stationary *(pperron)*.

Table 12.2 Pedroni (2004, 2001, 1999) Panel cointegration tests (1980–2011), dependent variables: real GDP growth, 42 African countries

Variables	*Pooled tests*				*Group mean tests*		
	v	*rho*	*t*	*ADF*	*rho*	*t*	*ADF*
Real GDP growth, Initial real GDP	16.45	–23.16	–21.28	–17.13	–20.13	–24.75	–17.24
Real GDP growth, Initial real GDP, Mobile celluar + Fixed-line Tel.	8.917	–14.5	–18.87	–14.22	–13.41	–23.47	–16.46
Real GDP growth, Initial real GDP, Mobile celluar + Fixed-line Tel., Physical capital	6.188	–10.75	–18.56	–14.27	–9.802	–23.04	–16.23
Real GDP growth, Initial real GDP, Mobile celluar + Fixed-line Tel., Physical capital, Openness (imports)	6.539	–6.92	–16.19	–12.01	–5.694	–19.61	–11.13
Real GDP growth, Initial real GDP, Mobile celluar + Fixed-line Tel., Physical capital, Openness (imports), Human capital	4.698	–4.295	–15.43	–9.496	–2.702	–18.32	–7.903

Note: The reported test statistics are Pedroni (1999, 2001, 2004), nonparametric (rho-statistic and v) are parametric [augmented Dickey-Fuller (ADF) and v]. All test statistics are distributed N(0,1), under a null of no cointegration, and diverge to negative infinity (save for panel v). Time trend is included.

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Panel cointegration tests (Pedroni, 2004, 2001, 1999), done as pooled (within dimension) and group mean (between-dimension), which include nonparametric (rho-statistic and v) and parametric [augmented Dickey-Fuller (ADF) and t-statistic] tests, are presented in Tables 12.2 and 12.3 for the growth and employment equations, respectively. Results in Table 12.2 (growth equation) are robust at one percent level for all the relationships specified regardless of the test statistic used. In the case of employment equation (Table 12.3), statistically significant (at one-percent level) cointegrating relationships are established in the cases of t-statistic and ADF tests. These relationships hold in both the pooled and group mean tests, which suggest that meaningful long-run relationships can be estimated using either pooled or group mean estimation techniques.

Pedroni's (2004, 2001, 1999) dynamic OLS (PDOLS) – an extension of the individual time-dynamic ordinary least squares (DOLS) – is used to estimate the long-run relationship between real GDP growth and ICTs, and employment rate and ICTs while controlling for other key determinants of economic growth (equation 1) and employment rate (equation 2), respectively. DOLS technique, introduced by Saikkonnen (1991), has received wide recognition due to its simplicity as well as its inclusion of the lead and lag terms of first-differenced explanatory variables in the regression equation. It corrects the nuisance parameter, hence, providing coefficients with improved limiting distribution properties (Kao, Chiang, and Chen, 1999). Moreover, it can be applied to data that are non-stationary and exhibit cointegrating relationships between variables.

Table 12.3 Pedroni panel cointegration tests (1980–2011), dependent variables: employment rate, 42 African countries

Variables	*Pooled tests*				*Group mean tests*		
	v	*rho*	*t*	*ADF*	*rho*	*t*	*ADF*
Employment rate, Real GDP growth	–0.647	1.457	1.524	3.134	2.126	2.223	3.851
Employment rate, Real GDP growth, Mobile celluar + Fixed-line Tel.	1.441	–1.261	–2.641	–2.229	0.2989	–2.464	–2.378
Employment rate, Real GDP growth, Mobile celluar + Fixed-line Tel., Trade	0.5292	–0.5882	–3.499	–2.401	1.287	–3.269	–2.503
Employment rate, Real GDP growth, Mobile celluar + Fixed-line Tel., Trade, Human capital	0.4965	0.3232	–3.252	–2.659	2.416	–2.845	–2.287

Note: The reported test statistics are Pedroni (1999, 2001, 2004), nonparametric (rho-statistic and v) are parametric [augmented Dickey-Fuller (ADF) and v]. All test statistics are distributed N(0,1), under a null of no cointegration, and diverge to negative infinity (save for panel v). Time trend is included.

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Pedroni extended DOLS estimation technique to panel data, which estimates each individual in the panel as follows:

$$y_{i,t} = \alpha_i + \beta_i x_{i,t} + \sum_{j=-p}^{p} \gamma_{i,j} \Delta x_{i,t-j} + \varphi_{i,t}^{\star} \tag{3}$$

where i is the number of units in the panel, t is the number time periods, p is the number of leads and lags in the DOLS regression, β_i is the slope coefficient, $x_{i,t}$ are the explanatory variables and, $\varphi_{i,t}^{\star}$ is the residuals term. The β coefficient and associated t-statistics are averaged over the entire panel by using Pedroni's group mean methods [for details, see Neal (2014)].

Pedroni's PDOLS is averaged along the between-dimension (group mean). Thus, the panel test statistic test is specified as $H_0 : \beta_i = \beta_0$ against $H_A : \beta_i \neq \beta_0$, which implies that the alternative hypothesis does not constrain regressors to a constant β_A. Moreover, estimates from PDOLS are robust to biases related to endogeneity issues, omitted variables and measurement errors (Baltagi and Kao, 2001; Banerjee, 1999; Phillips and Moon, 2000). Alternatives to DOLS are OLS and fully modified OLS (FMOLS) estimators. Although OLS is a consistent estimator, it is inefficient in models with endogenous regressors. On the other hand, FMOLS is an asymptotically efficient estimator for homogenous cointegrating vectors, and adjusts for the effects of endogenous regressors and short run dynamics of the errors (serial correlation). Nonetheless, Kao, Chiang, and Chen (1999) have shown that the fully modified estimator does not improve over OLS estimator.

Kernel densities

The analysis begins with the estimation of the probability density function of ICTs indicators using a kernel function. Let $X_1, \ldots, X_n$ be a sample of n independent and identically distributed observations on a random variable X. The density value $f(x)$ at a given point x is estimated by the following kernel density estimator:

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right) \quad (4)$$

where h denotes the bandwidth of the interval around x and K is the kernel function.[5] The kernel estimator assigns weights to each observation in the interval around x, with the weight being inversely proportional to the distance between the observation and x. The density estimate consists of the vertical sum of frequencies at each observation. The resulting smooth curve allows us to visualise the shape of the distribution of ICTs indicators and detect the presence of "convergence clubs" represented by modes.

Data and descriptive statistics

The study covers 42 African countries. A list of the selected SSA countries is presented in Table A12.1. The annual growth of real gross domestic product (GDP) expressed in 2000 prices and data for employment rate, openness, ICTs, physical and human capital and population growth measures are all drawn from the African Development Indicators of the World Bank database.

Summary statistics presented in Table 12.4 for 42 African countries show that between 1980 and 2011, these countries grew at an average rate of 3.4%

Table 12.4 Summary statistics, 1980–2011, 42 African countries

	Mean	*Std. Deviation*	*Minimum*	*Maximum*	*N*
Real GDP growth	3.403	6.680	–51.030	35.220	1340
Employment rate	61.412	14.125	30.800	88.300	1344
Investment	19.631	9.410	–2.420	74.820	1344
Imports	40.416	22.941	–17.140	157.870	1343
Mobile cellular + Fixed-line Tel	11.938	23.947	0.010	150.180	1337
Mobile cellular	9.767	21.947	0.000	142.820	1344
Fixed-line Tel	2.145	3.916	0.010	30.270	1336
Trade (% GDP)	69.389	35.030	6.320	209.874	1343
Population growth	2.461	1.097	–7.533	9.770	1344
Primary schooling	87.079	30.453	16.022	194.701	1343
Secondary schooling	31.924	21.245	2.344	95.700	1344

with a standard deviation of 6.7%. The employment rate was also above 50%, averaging 61.4%, with some countries registering as high as 88.3%. The mobile cellular telephony penetration rate is still low, with an average of 9.7% for the 42 countries within the 1980–2011 period. The low penetration rate was evident in countries such as Ethiopia (1.13%), Burundi (2.25%) and Malawi (2.98%). In fact, approximately 29% and 61% of the 42 countries had an average mobile cellular telephony penetration rate of less than 5% and 10% or less, respectively (Table 12.5).

Country-level summary statistics of real GDP growth rate, employment rate and mobile cellular penetration rate over 1980–2011 period are reported in Table 12.5. It is evident that the average growth rate and employment rate, as with other variables, have varied widely across these countries, alluding to their economic heterogeneity. For example, countries such as the Democratic Republic of Congo (0.41%), Cote d'Ivoire (0.82%), Central African Republic (1.05%), Zimbabwe (1.33%), Madagascar (1.69%) and Sierra Leone (1.97%) grew at an average rate of less than 2% between 1980 and 2011, whereas Cape Verde and Botswana averaged 6.02% and 7.07%, respectively (Table 12.5). The median growth rate within this period was roughly 3%. On the other hand, the average employment rate also ranged from the lows of below 40% [Mauritania (33.35%), Algeria (33.87%), South Africa (39.83%)] to the highs of over 80% [Burundi (80.41%), Burkina Faso (81.44%), Madagascar (83.43%) and Rwanda (86.03%)] (Table 12.5). The median employment rate equally varied widely, ranging from 32.78% (Mauritania) to 85.4% (Rwanda).

To provide a preliminary understanding of the relationship between ICTs and growth, and ICTs and employment rate, we generated bubble plots for these pair of variables on the basis of the mean values for the 1980–2011 period. These plots, similar to the correlation matrix, provide unconditional correlation between two variables. As expected, we find a positive correlation between ICTs and growth (Figures 12.5 and 12.6), but an inverse one between ICTs and employment (Figures 12.7 and 12.8). This is consistent with the findings from the correlation matrix (Table 12.6). In other words, countries that had relatively high penetration rate of ICTs (such as Cape Verde and Botswana) also had high economic growth. But, on the employment side, those that had relatively lower penetration rate of ICTs had a higher employment rate (Ethiopia, Burundi and Rwanda). The unexpected negative correlation between employment and ICTs implies that there could be augmenting factors that influence the effectiveness of ICTs – such as high skill labour. It could also imply that these ICTs have not be integrated in the economy in a way that benefits employment (Carmody, 2011). We explore further the nature of relationship between ICTs and employment in the regression analysis.

Table 12.5 Summary statistics, averaged over 1980–2011

	Real GDP growth	*Employment rate*	*Mobile cellular + Fixed-line Tel*	*Mobile cellular per 100 people*	*Fixed-line tel per 100 people*	*Internet (per 100 people)*
Algeria	2.69	33.87	22.73	17.86	4.88	4.23
Benin	4.01	71.82	10.96	10.29	0.67	1.12
Botswana	7.07	59.47	25.32	21.02	4.30	1.96
Burkina Faso	4.83	81.44	5.33	4.80	0.38	0.63
Burundi	2.04	80.41	2.57	2.25	0.25	0.21
Cameroon	2.66	65.17	8.49	7.78	0.70	1.59
Cape Verde	6.02	59.64	19.85	12.21	7.64	9.23
Central African	1.05	73.61	3.38	3.45	0.19	0.51
Chad	5.45	67.77	3.73	3.49	0.13	0.57
Comoros	2.07	51.27	4.59	3.13	1.45	1.71
Congo, Dem. Rep.	0.41	67.33	3.25	3.19	0.06	0.25
Congo, Rep.	4.20	63.87	13.62	13.07	0.55	1.61
Cote d'Ivoire	0.82	63.66	13.37	12.37	1.00	0.86
Egypt, Arab Rep.	4.95	42.31	20.36	13.24	6.69	8.71
Ethiopia	4.05	76.30	1.58	1.13	0.46	0.23
Gabon	2.17	50.75	25.39	22.28	2.39	3.23
Gambia, The	3.46	72.21	15.55	13.84	1.71	3.37
Ghana	4.35	65.68	11.85	11.13	0.72	2.73
Guinea-Bissau	2.42	65.83	7.29	6.81	0.56	1.30
Kenya	3.48	62.64	10.29	9.44	0.85	4.87
Lesotho	3.63	45.98	8.63	7.52	1.11	1.75
Liberia	2.75	57.24	5.32	5.46	0.25	0.50
Madagascar	1.69	83.43	5.39	5.01	0.38	0.63
Malawi	3.43	73.08	3.47	2.98	0.49	0.65
Mali	3.26	46.86	6.90	6.61	0.29	0.63
Mauritania	3.29	33.35	14.74	13.99	0.76	1.10
Mauritius	4.56	54.03	38.25	22.48	15.77	13.08
Morocco	3.83	46.83	23.61	19.61	4.00	13.92
Mozambique	4.69	78.91	5.05	4.69	0.36	1.00
Namibia	3.42	45.53	18.68	13.64	5.04	3.51
Niger	2.03	58.34	3.31	3.12	0.20	0.30
Rwanda	4.69	86.03	4.20	4.02	0.18	1.96
Senegal	3.05	68.55	12.21	10.88	1.34	4.78
Sierra Leone	1.97	63.85	4.75	4.18	0.43	0.12
South Africa	2.46	39.83	35.50	26.25	9.25	5.74
Sudan	5.02	46.90	9.14	8.23	0.90	3.54
Swaziland	5.02	43.91	14.48	11.78	2.69	4.12
Togo	2.45	73.34	7.66	6.71	0.95	0.75
Tunisia	4.18	40.43	28.12	21.06	7.07	10.77
Uganda	5.41	78.47	5.89	5.60	0.30	2.96
Zambia	2.63	66.25	7.66	6.89	0.77	2.60
Zimbabwe	1.33	73.13	8.53	6.74	1.79	5.11
Total	3.40	61.41	11.94	9.77	2.14	3.42

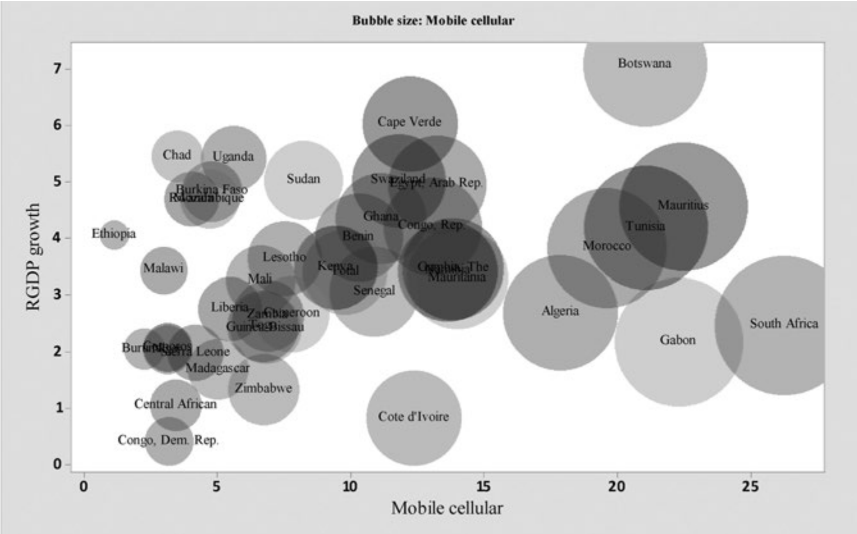

Figure 12.5 Average real growth rate vs mobile cellular telephony, 1980–2011

Source: Authors' calculations based on World Bank's African Development Indicators (online database)

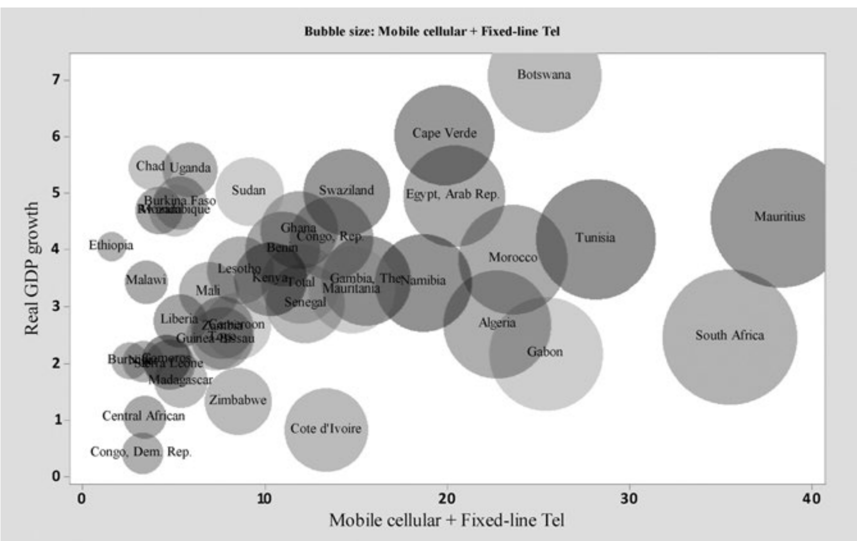

Figure 12.6 Average RGDP growth vs mobile cellular + fixed-line tel, 1980–2011

Source: Authors' calculations based on World Bank's African Development Indicators (online database)

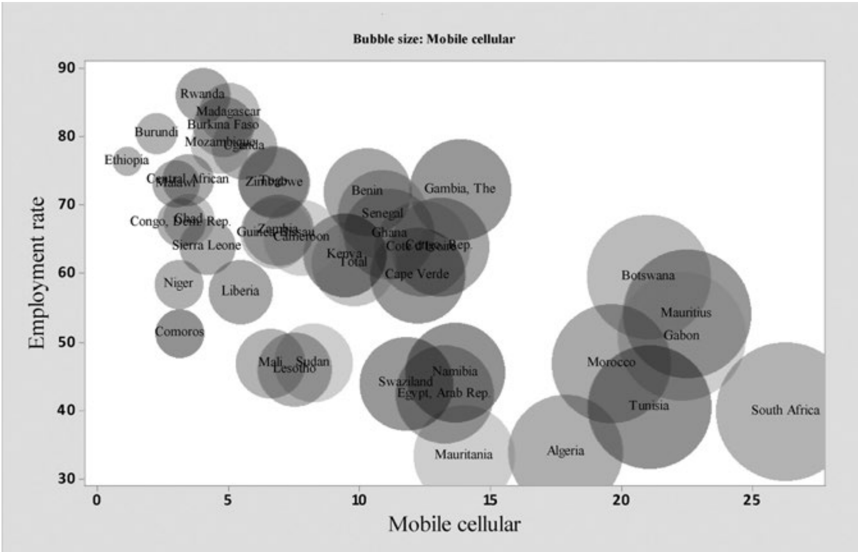

Figure 12.7 Average employement rate vs mobile cellular telephony, 1980–2011

Source: Authors' calculations based on World Bank's African Development Indicators (online database)

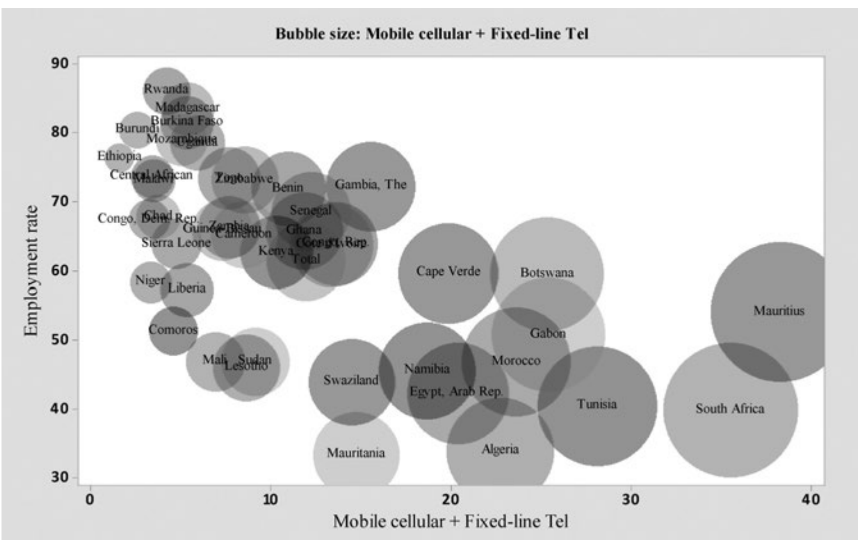

Figure 12.8 Average employement rate vs mobile cellular + fixed-line tel, 1980–2011

Source: Authors' calculations based on World Bank's African Development Indicators (online database)

Table 12.6 Correlation matrix for selected variables, 1980–2011, 42 African countries

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Real GDP growth (1)	1											
Employment rate (2)	–0.015	1										
Physical capital (3)	0.198	–0.341	1.000									
Real GDP(4)	0.008	–0.425	0.070	1.000								
Imports (% GDP) (5)	0.112	–0.286	0.542	–0.181	1.000							
Mobile cellular + Fixed-line Tel (6)	0.057	–0.206	0.172	0.337	0.125	1.000						
Mobile cellular (7)	0.055	–0.157	0.149	0.289	0.113	0.989	1.000					
Fixed-line tel (8)	0.043	–0.377	0.210	0.436	0.145	0.561	0.432	1.000				
Trade (% of GDP) (9)	0.092	–0.375	0.482	–0.126	0.899	0.215	0.190	0.254	1.000			
Pop growth (10)	0.284	0.177	–0.059	–0.168	–0.139	–0.270	–0.231	–0.353	–0.164	1.000		
Primary schooling (11)	0.088	–0.091	0.297	0.129	0.293	0.284	0.270	0.228	0.364	–0.093	1.000	
Secondary schooling (12)	0.062	–0.509	0.250	0.587	0.169	0.581	0.506	0.715	0.322	–0.288	0.515	1.000

Nonparametric regression

As previously noted, in order to capture the nonlinear effects of ICTs on growth, regression models tend to include a squared term of the ICTs variables. However, this imposes a particular functional form onto the relationship between the two variables, even if the specification is more general in nature than the standard linear regression. In case this functional form does not correspond to the true functional relationship between ICTs and growth, the estimated coefficients will be biased. Furthermore, by including a squared term of the ICTs variables, we assume that the nonlinearity between ICTs and growth is either concave or convex, and that there is only one threshold where the marginal effects of ICTs reverse signs. However, multiple thresholds and various forms of nonlinearity are equally plausible.

To address these issues, we choose instead to employ a nonparametric regression, which has the advantage of being very flexible in that it relaxes all assumptions about functional form and linearity, homoscedasticity and serial correlation. The nonparametric model is specified as follows:

$$\Delta y_{it} = m\left(ICT_{it-\tau}, \mathrm{x}\right) + \varepsilon_{it} \tag{5}$$

where m(•) is an unknown function that is only assumed to be smooth and continuous and is estimated directly without the need of parameters for the explanatory variables x=$(x_{1it-\tau}, \ldots, x_{nit-\tau})'$. The nonparametric regression suffers from the "curse of dimensionality," which makes it difficult to fit a regression in the presence of too many predictors. For this reason, we include only three explanatory variables (investment, education and openness) specified in equation (1) and explore two additional variables (financial development and FDI) in the estimation, as they have been identified in the literature as key complements of ICTs in promoting growth.

Given that the nonparametric regression does not yield scalar estimates of marginal effects, the results are presented in three-dimensional plots, whereby each axis denotes the average annual growth rate, the ICTs variable, and the conditioning variable, respectively. Furthermore, we show the corresponding two-dimensional growth curve profiles, which represent the nonparametric regression line of the ICTs-growth relationship for three different levels of the conditioning variable. These profiles allow us to identify the thresholds for reversals in the sign of the marginal effect and help us determine which factors create the optimal environment for ICTs to stimulate growth.

The analysis is based on two sampling periods (1975–2010 and 1995–2010) and uses three ICTs indicators: mobile cellular, fixed-line telephone and internet, all expressed per 100 people. Moreover, the growth rates are averaged over three-year periods.

Results analysis

Parametric analysis

Growth regressions

The baseline regression model in equation (1) is estimated for 1980–2011 period. ICTs are represented by the sum of mobile cellular and fixed-line telephone subscriptions. We focus on this measure, for two reasons: (1) the penetration rate of mobile telephony in African countries is higher relative to that of internet and fixed-line telephone, and (2) the sum of mobile cellular and fixed-line telephone subscriptions is used on the basis that they both capture the primary function of telephones, which is communication via voice, whereas the mobile cellular adds the relevance of other ICTs functionalities such as sharing of information via data [Fixed-line telephone is also used to transfer information via fax and dial-up internet connect]. Besides, preliminary results confirmed that using the sum of the two measures of ICTs [as compared with entering into the regression equation the mobile cellular or fixed-line telephony as separate augments], increases the data points and, in turn, the explanatory power of the ICTs indicator.

The estimated coefficients of the ICTs indicator are robust and exhibit increasing returns to growth. In particular, an increase by one percentage point in the penetration rate of the sum of mobile cellular and fixed-line telephones increases long run economic growth rate by approximately 0.01–0.98% per annum (Table 12.7). These effects are higher when human capital is measured by education (secondary school) [0.98% (column 1), 0.19% (column 2)], and lower when population growth rate is used [0.01% (column 3), 0.04% (column 4)]. It is important to note that education and population growth rate are not comparable measures of human capital. Specifically, whereas the former captures the quality of human capital, and thus, a country's absorptive capacity of new technologies, the latter measures the quantity of human capital [population growth is also often used as a proxy for the rate of growth of labour input in the production

Table 12.7 Dynamic OLS estimation [DOLS, within, fixed effects] for real GDP growth rate impact of ICTs in Africa, 1980–2011

	(1)	*(2)*	*(3)*	*(4)*
Real GDP	–0.132	–0.080	–0.587	–0.183
	(0.039)	(0.275)	(2.183)	(5.116)
Mobile cellular + Fixed-line Tel	0.986	0.187	0.013	0.041
	(10.730)	(5.954)	(2.959)	(2.299)
Investment	–0.079	–0.060	–0.035	–0.012
	(4.035)	(4.738)	(4.840)	(3.344)
Openness (Imports)	0.008		0.009	
	(1.055)		(6.858)	
Openness (Trade)		0.023		0.001
		(7.102)		(5.062)
Pop growth			–0.316	–0.332
			(1.057)	(–0.650)
Education (Secondary)	–0.375	–0.227		
	(5.210)	(0.136)		
No. of Countries	42	42	42	42
Observations	1,175	1,175	1,175	1,210

Note: t-statistics in parentheses and regressions included one lead and lag of the differenced regressors.

process]. These differences could explain why models controlling for the quality of human capital increases the magnitude of impact of ICTs relative to those using population growth rate.

However, the direct impacts of education and population growth rate on long-run economic growth are negative but insignificant with exception of one model where the effects of education are significant (column 1). In the context of African economies, and especially in the case of education as a measure of human capital, the negative effects are not alarming. African countries have been associated with poor quality and low quantity of human capital (Kigotho, 2014, 2015; AEO, 2012; UNESCO, 2015). Therefore, it is possible that both quantity and quality effects (especially the mismatch between the skills offered by job seekers in these countries and those sought by employers) are at play, resulting in non-significant effects on economic growth.

Increased population growth can penalise economic growth in a number of ways. It can divert resources away from the production of goods towards reproduction-related consumption (Becker and Barro, 1988). It can also penalise the steady state level of output per worker in the neoclassical growth model. Specifically, if the population is growing faster than the level of economic growth, then a portion of the economy's investment is allocated towards providing capital for new workers, rather than increasing capital per worker (Barro, 1994). On the other hand, declining population growth rates can be an indication of emerging social institutions, such as healthcare and education, which expand with economic growth (Barro and Lee, 1994; Behrman, 1990; Schultz, 1989).

The technology transfer indicators – trade and imports as shares of GDP – have growth-enhancing effects that are robust in three of the four model specifications in Table 12.7. In particular, growth increases by around 0.009% and 0.001–0.023% per year in response to a one-percentage-point rise in the share of trade and imports in GDP, respectively. Contrary to expectations, the marginal impact of physical capital retards long-run economic growth.[6] Furthermore, the results provide evidence of β-convergence among African economies as the initial level of real GDP is negatively correlated with consequent growth across all models.

Employment regressions

Table 12.8 summarises the regression results of ICTs effects on long-run employment rate in Africa. Stepwise regressions are used. However, to maximise space we report only results for the full model as specified in the baseline equation 2. The motivation for employing stepwise regressions is the negative unconditional correlation between ICTs indicators and employment rate that was observed in the bubble plots (Figures 12.7 and 12.8) and correlation matrix (Table 12.6). The results show positive conditional relationship between

Table 12.8 Dynamic OLS estimation [DOLS, within, fixed effects] for employment rate impact of ICTs in Africa, 1980–2011

	Primary schooling		*Secondary schooling*	
	(1)	*(2)*	*(3)*	*(4)*
Real GDP growth	0.040	0.039	–0.019	–0.024
	(2.690)	(2.134)	(0.719)	(0.071)
Mobile cellular + Fixed-line Tel	0.045		0.023	
	(6.288)		(6.479)	
Mobile cellular		0.075		0.121
		(5.638)		(6.835)
Openness (Trade)	0.017	0.022	–0.003	–0.008
	(6.439)	(6.540)	(4.504)	(4.823)
Education	–0.022	–0.022	0.073	0.057
	(4.205)	(5.020)	(3.862)	(4.146)
No. of Countries	42	42	42	42
Observations	1,202	1,209	1,206	1,213

Note: t-statistics in parentheses and regressions included one lead and lag of the differenced regressors.

these ICTs and employment, regardless of the model specification and type of ICTs indicator used. For example, when mobile cellular subscriptions or sum of mobile cellular and fixed-line telephone subscriptions are used as the only regressors, robust positive employment effects are observed, whereby these indicators enhance employment rate in the long run by 0.104% *(t-value, 4.655)* and O.074% *(t-value, 5.136)* for every one percent increase in mobile cellular subscription and sum of mobile cellular and fixed-line subscriptions, respectively. This implies that despite the fact that other control variables are excluded from the model, the relationship is positive, suggesting that the lead and lag terms of the regressor inbuilt in the PDOLS estimation technique could be providing the conditional effects (absent in the bubble plots and correlations matrix) that are impacting the effectiveness of these ICTs. When all the control variables specified in equation 2 are included, ICTs continue to have employment enhancing effects, with the magnitude of 0.075–0.121% and 0.023–0.045% for every one percent increase in mobile cellular subscription (columns 2 and 4, Table 12.8) and sum of mobile cellular and fixed-line subscriptions (columns 1 and 3, Table 12.8), respectively.

Moreover, trade openness enhances employment rate when primary schooling is used as a measure of human capital, and retards when secondary schooling is used. Also, secondary schooling positively contributes to employment rate, whereas primary schooling retards it. This suggests that relatively high skills are generally valued on the formal labour markets of Africa's economies, and that the trade sector in these countries is complemented by relatively low-skill workers.

Nonparametric analysis

Convergence

The density distributions of the three main ICTs variables are presented in Figure 12.9. The three-dimensional graphs in the first row show the distributions over the entire sample period, whereas the two-dimensional plots in the second and third rows display snapshots for specific years. Common to all three variables is the high concentration of the probability mass at very low levels in the early years of the sample periods. In addition, there is a significant change in the shape of the distribution in subsequent periods, but the speed and pattern vary widely across indicators.

Between 1975 and 1990, the number of fixed lines per 100 people increased as revealed by the reduction in the height of the main mode. However, most of the probability mass remained in the range between zero and two lines per 100 people. A decade later, the mode has widened further, but the main change is the rapid extension of the tail of the distribution towards the top. In other words, a few countries have managed to expand telephone access dramatically, whereas most of the sample has recorded modest increases. The former group consists mostly of North African countries and island nations, such as the Seychelles and Mauritius. Over the 2000s, the shape of the distribution barely changes, indicating the slowdown in the building of new landlines as a result of the boom in mobile cellular technology.

The evolution in the shape of the density distribution for mobile cellular phones offers a very different pattern of dynamics. Within two years (1998–2000), the distribution changed in the same manner as the one for fixed lines did over a 25-year period. By the mid-2000s, most of the probability mass had shifted to between zero and 20 phones per 100 people, whereas only five years later, the range moved to between 20 and 80. Among the countries with more than 100 mobile phone subscriptions per 100 people in 2010 are again the frontrunners in the fixed-line ranking, which are now joined by Botswana, Gabon and South Africa.

Internet usage has experienced less dramatic growth as compared with mobile phones. At the turn of the century, most African countries had fewer than one internet user per 100 people. In 2005, the main mode of the distribution was now concentrated around the value of 2.5. The most pronounced shift appears to have occurred in the second half of the 2000s, as shown by the considerable widening of the major mode towards values above 20.

Nonlinearities

To explore the presence of nonlinearities in the nexus between growth and ICTs, we employ a nonparametric regression that offers substantial advantages over parametric methods. Given the limitations of the nonparametric approach in terms of dimensionality, we focus on five conditioning variables (investment, education, financial development, openness and FDI) that are likely to complement the growth-enhancing effects of ICTs indicators. The results are illustrated in Figures 12.10 through 12.12.

Figure 12.10 shows the marginal effects of ICTs conditioned on fixed investment rates. The two-dimensional graphs provide snapshots of the regression

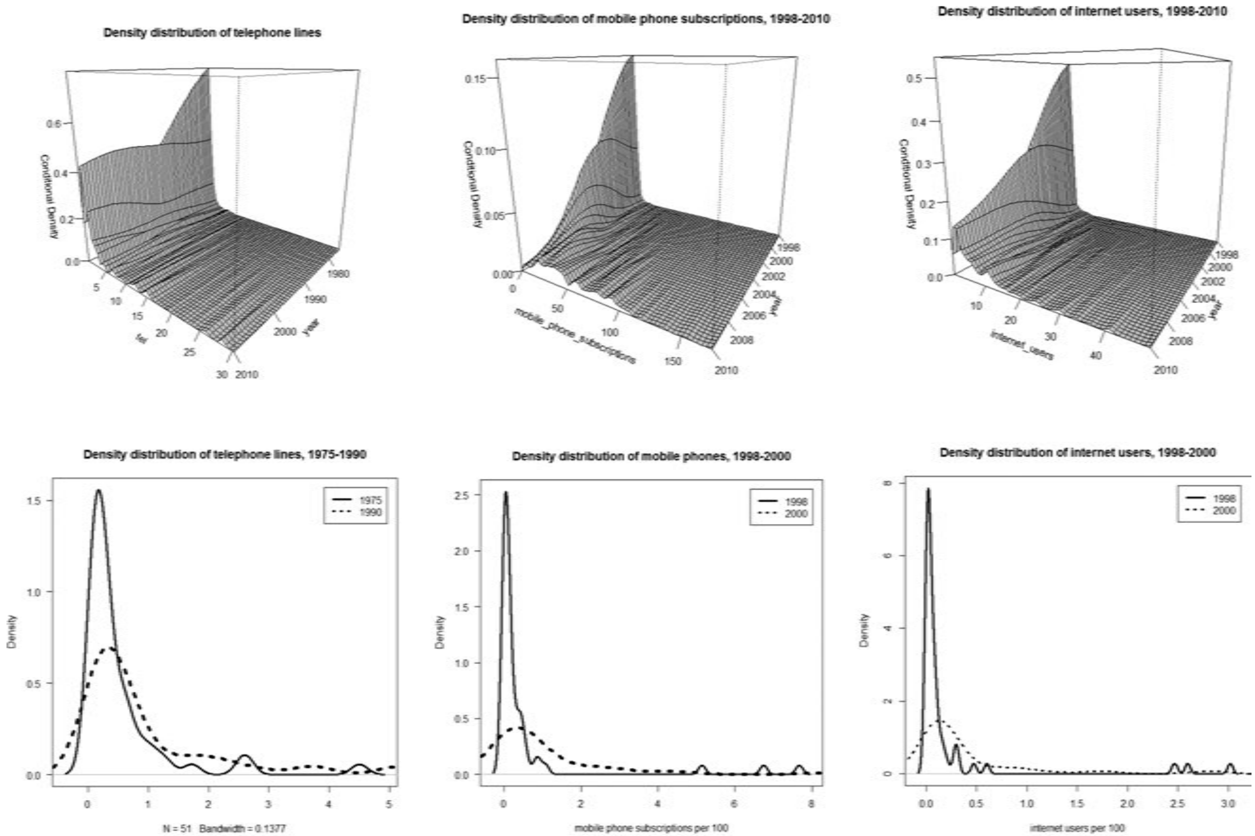

Figure 12.9 Density distributions of telephone lines, mobile phones, and internet users

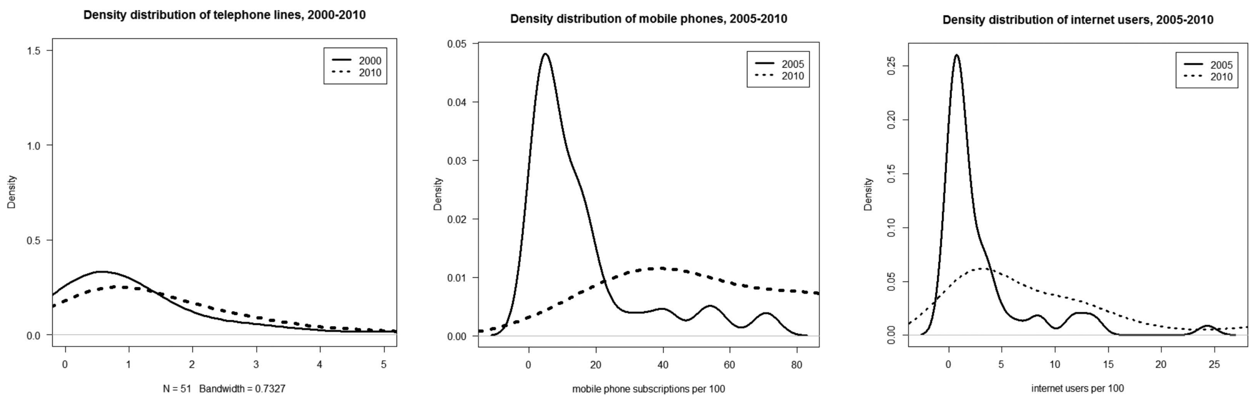

Figure 12.9 (Continued)

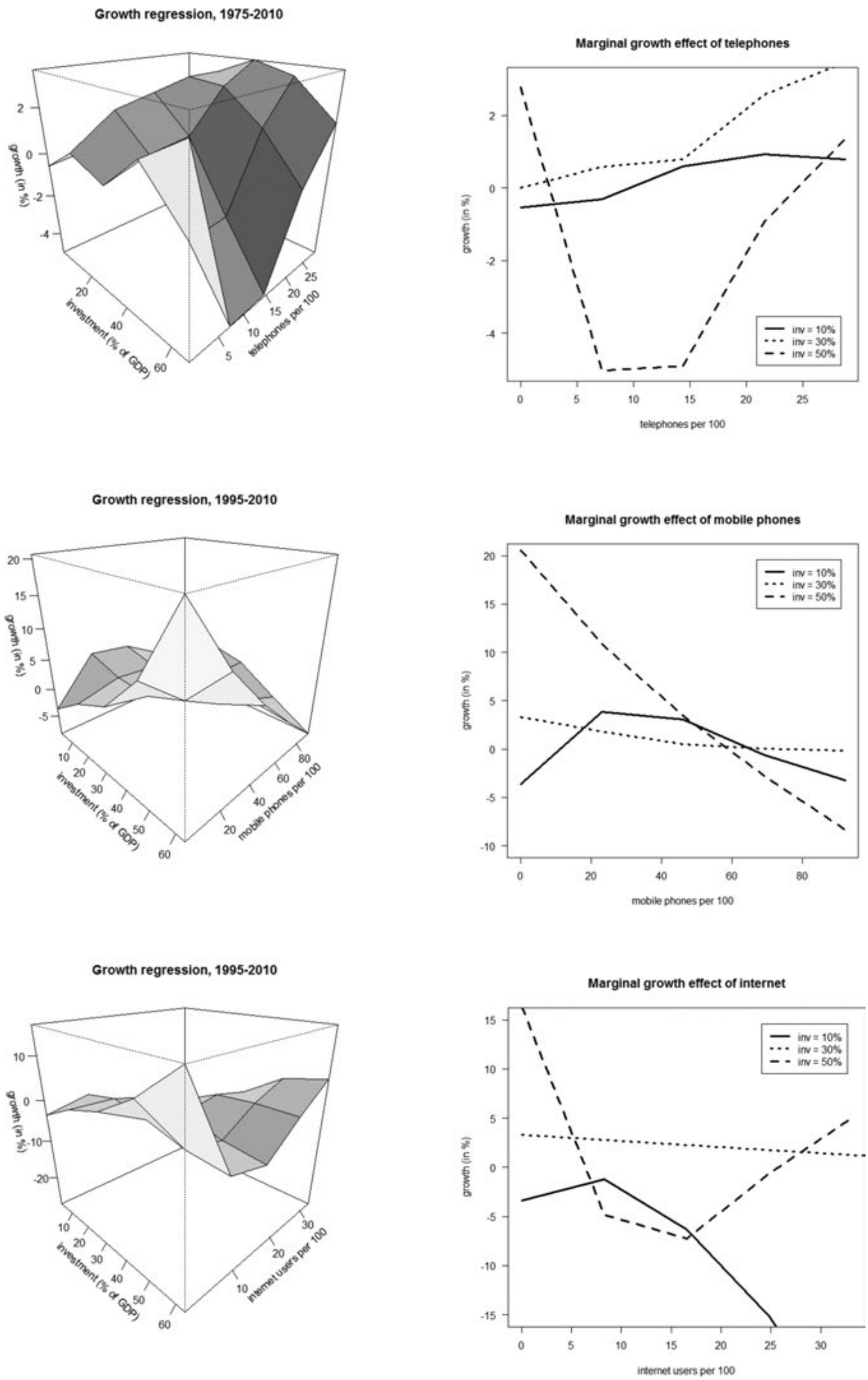

Figure 12.10 The growth effects of ICTS variables conditioned on investment, three-year growth rates

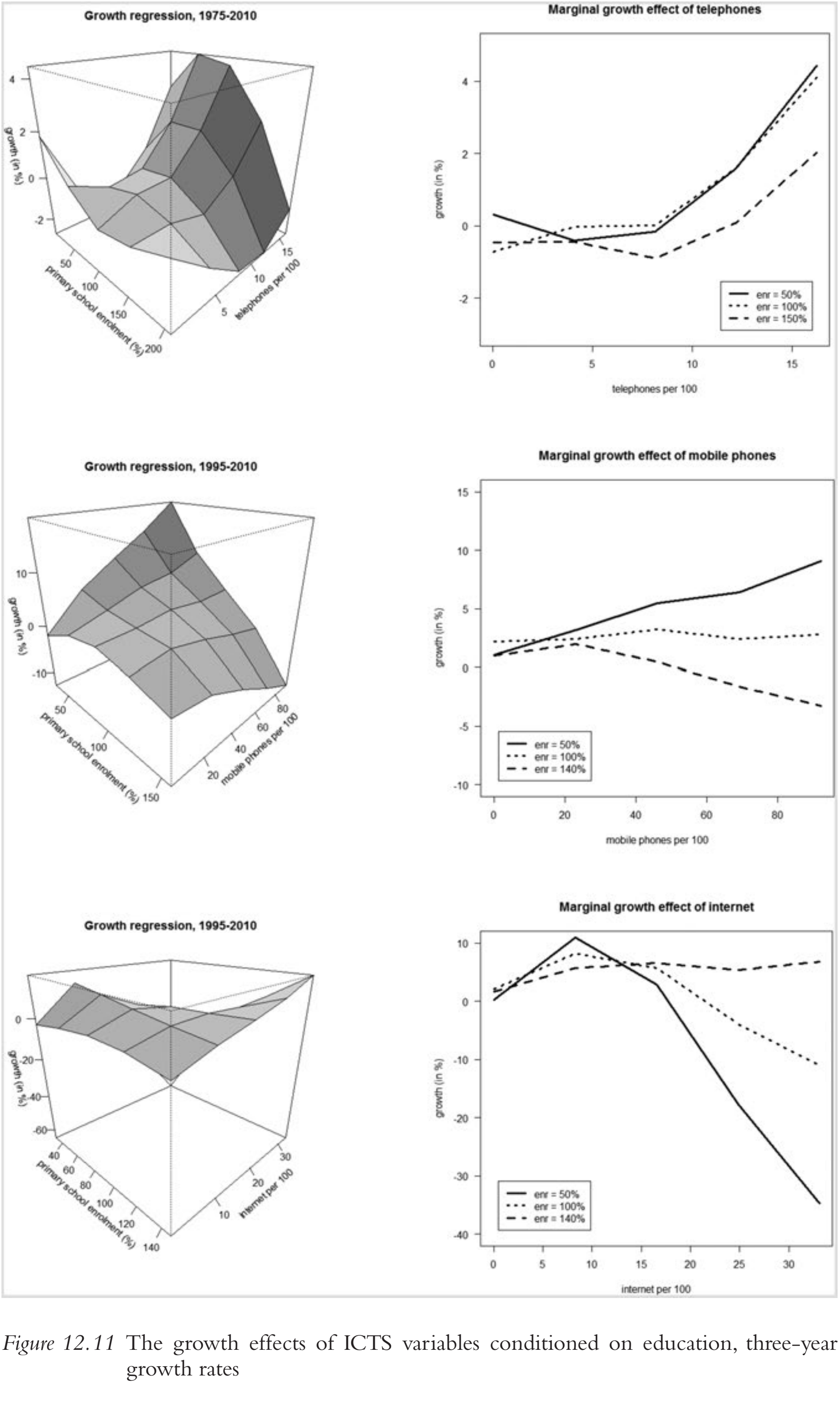

Figure 12.11 The growth effects of ICTS variables conditioned on education, three-year growth rates

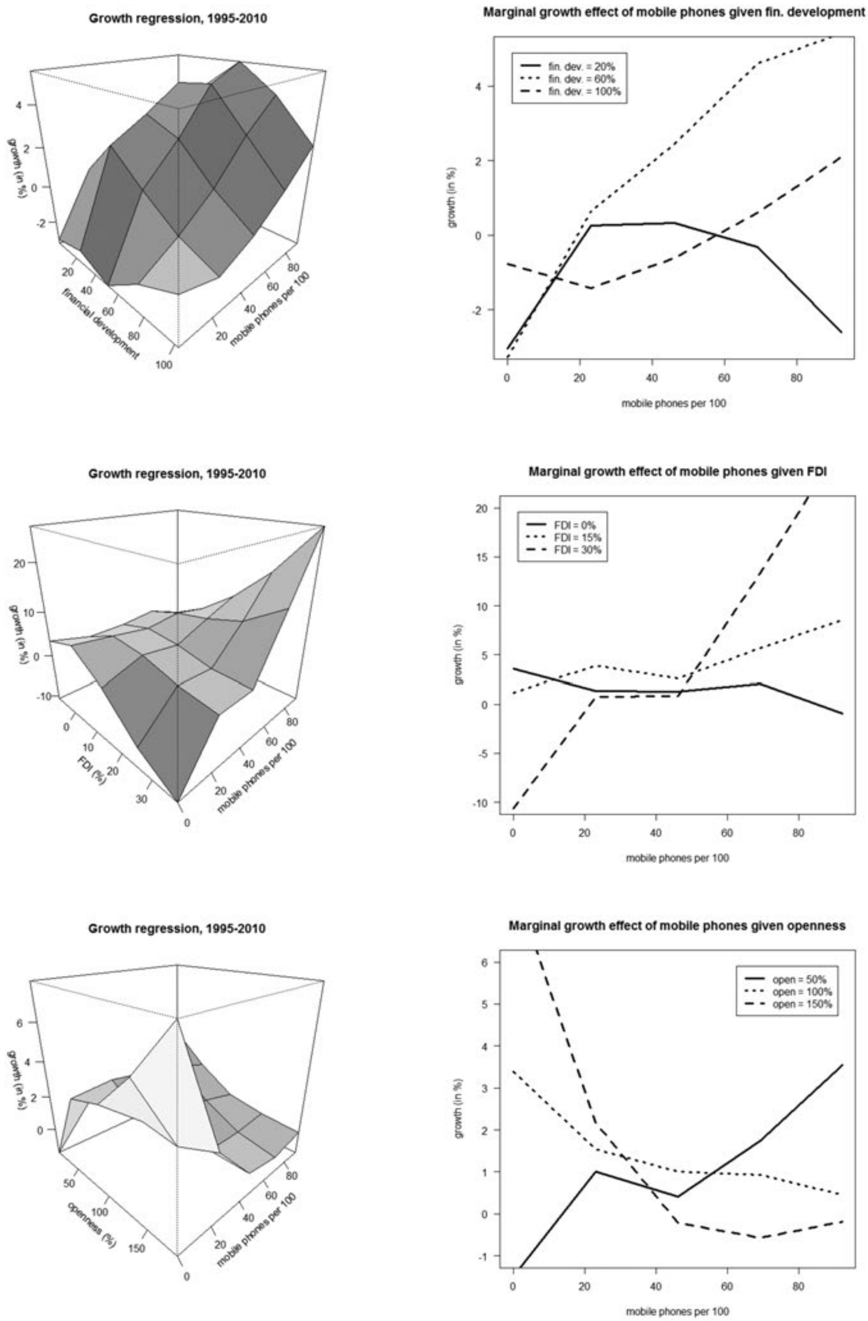

Figure 12.12 The growth effects of mobile cellular phones conditioned on financial development, FDI and openness, three-year growth rates

line for low (10%), average (30%) and high (50%) levels of investment. The results indicate that fixed-line telephone subscriptions have a strong and positive marginal effect for countries with average and high levels of investment but only above a threshold of 15 lines per 100 people. By contrast, low rates of capital deepening ensure that more subscriptions promote economic growth but with diminishing returns. These findings point to the existence of network externalities. Such effects for fixed-line telephony have been reported for developed countries (Roller and Waverman, 2001) as well as for African economies (Gyimah-Brempong and Karikari, 2010). Roller and Waverman (2001) estimated the critical mass of penetration that triggers increasing returns in advanced economies to be 40%, which corresponds to universal service assuming 2.5 people per household. This threshold is more than twice as large as the one we estimated for African countries (15%). In other words, developing countries can start reaping the additional benefits to growth from an expanding network of fixed lines at much lower penetration rates.

Furthermore, investment in ICTs infrastructure is part of the gross fixed capital formation. The presence of externalities implies that a larger network of fixed lines provides incentives for further investment in ICTs infrastructure. This feedback loop is particularly damaging to the growth prospects of developing countries because their low levels of ICTs diffusion impair improvements in productivity and discourage further investment in the expansion of the ICTs infrastructure (Gruber and Koutroumpis, 2011). Our results concur by showing that low investment rates are associated with diminishing returns of fixed-line telephony's output elasticity in Africa.

The marginal effect of internet usage exhibits a pattern similar to the one for fixed lines. Internet stimulates growth in countries with low capital accumulation but only for fewer than ten users per 100 people, whereas high investment rates ensure that the positive impact of the internet is observed for a penetration rate of more than 17%. In contrast, fixed investment does not seem to be a complement for mobile telecommunication. One possible explanation is that the infrastructural requirements for mobile cellular technology are significantly lower than for fixed lines, and therefore the overall level of capital deepening is less relevant.

Figure 12.11 presents the results for the regressions with primary education as the conditioning variable.[7] Previous studies have shown that human capital is a key factor in the adoption of ICTs (Caselli and Coleman, 2001; Pohjola, 2003; Chinn and Fairlie, 2010) and that ICTs capital and educational attainment complement each other in their effect on productivity change (Ketteni, Mamuneas, and Stengos, 2011).[8] Our results indicate that education indeed matters in the case of internet usage. The marginal effect on growth for the highest levels of human capital is positive, whereas for low levels, it turns negative above a 10% penetration rate. By comparison, the marginal effect of fixed-line telephones confirms the increasing returns on growth due to network externalities but the slope of the regression line is largely identical across different educational levels. In fact, operating a computer and using the internet for productive purposes require a more advanced set of skills than making a telephone call. This is further supported by the finding that mobile cellular phones are mostly irrelevant for growth at average and high levels of human capital; however, they seem to have a positive growth-enhancing effect at low levels of educational attainment.

In Figure 12.12, growth is regressed on mobile cellular penetration with financial development, FDI and openness serving as conditioning variables. Given the rapid spread of mobile payment platforms in Africa, we expect that financial deepening and mobile technology complement each other in fostering growth. Our results in the first row of Figure 12.12 confirm this hypothesis by demonstrating that at low levels of financial development mobile cellular phones lose their growth-enhancing effects above a penetration rate of 20%. By contrast, mobile telecommunication in more financially advanced countries exhibits increasing returns to growth. These findings are largely in line with the evidence reported by Andrianaivo and Kpodar (2011).

There seems to be no complementarity between openness and mobile cellular subscriptions (row 3, Figure 12.12), but FDI helps mobile telecommunication to stimulate growth, albeit mostly above a relatively high penetration rate of around 45% (row 2, Figure 12.12).[9] On the one hand, African countries could benefit from FDI to get access to advanced ICTs technology, but foreign investors may be willing to commit funds only after a certain critical mass of subscribers has been reached. This vicious circle could leave developing countries in Africa in a low-level ICTs equilibrium trap (Addison and Heshmati, 2003), which prevents them from reaping the benefits of mobile technology and ultimately impairs their growth and development.

Conclusion

A period of robust economic growth in Africa since the mid-1990s has occurred simultaneously with a rapid diffusion of ICTs, which suggests that these two processes might be interrelated. The chapter examines this nexus over 1975–2011 period by employing a combination of parametric and nonparametric methods that allow us to gain detailed insights into the nonlinearities involved.

The parametric results reveal the presence of growth and employment enhancing effects of ICTs. These effects are robust across various specifications of the model. One of the main contributions of the chapter is the application of nonparametric methods that are optimal for detecting nonlinear patterns and determining the thresholds for reversal in the marginal effects with minimal assumptions involved. The corresponding results show that physical capital accumulation is a complement for fixed-line telephones and the internet but not for mobile telecommunication. In particular, moderate and high investment levels enable ICTs to stimulate growth above a penetration rate of around 15%, whereas low levels exhibit diminishing returns. Educational attainment also serves as a complement but only for the internet, which is explained by the higher complexity involved in using computers relative to telephones. We further demonstrate that financial development functions as conduit for the effects of mobile cellular telephones on growth, especially above a subscription threshold of around 20%.

Our findings suggest that both traditional and more recent ICTs play an important role in fostering growth in Africa. To be able to enjoy these benefits in the presence of network effects, countries need to expand the penetration levels of these technologies above certain thresholds that are considerably lower than in developed economies. Moreover, investing in physical infrastructure, raising the educational attainment, attracting FDI and promoting financial deepening can boost the impact of ICTs on growth. In contrast, economies that fail to achieve the critical mass of network expansion face diminishing returns to growth, which discourage further investment in ICTs and create a vicious cycle that damages their development prospects.

Appendix

Table A12.1 List of African countries (parametric analysis)

Algeria	Ethiopia	Mozambique
Benin	Gabon	Namibia
Botswana	Gambia, The	Niger
Burkina Faso	Ghana	Rwanda
Burundi	Guinea-Bissau	Senegal
Cameroon	Kenya	Sierra Leone
Cape Verde	Lesotho	South Africa
Central African Republic	Liberia	Sudan
Chad	Madagascar	Swaziland
Comoros	Malawi	Togo
Congo, Dem. Rep.	Mali	Tunisia
Congo, Rep.	Mauritania	Uganda
Cote d'Ivoire	Mauritius	Zambia
Egypt, Arab Rep.	Morocco	Zimbabwe

Note: Countries used in the nonparametric analysis include those in the table and Angola, Djibouti, Equatorial Guinea, Nigeria and Tanzania.

Notes

1 These statistics were collected from the World Bank's *World Development Indicators* database and the International Telecommunication Union's *World Telecommunication/ICT Indicators* database.

2 To the best of our knowledge, Ketteni, Mamuneas, and Stengos (2007, 2011) are the only other studies that have employed nonparametric methods in the context of ICTs and growth. However, their sample is limited to developed countries over the period 1980–2004 and they measure ICTs as a component of the capital stock.

3 M-PESA is a mobile phone application pioneered in Kenya, which allows users to create e-bank accounts and complete financial transactions electronically via their mobile

phones. It is estimated that in Kenya alone, one of the seven countries that are currently using M-PESA, active bank accounts have grown fourfold since 2007, aided by $17 million M-PESA mobile money accounts (Yonazi, Kelly, Halewood, and Blackman, 2012).

4 Esoko and mFarm are mobile phone platforms that were developed in Ghana and Kenya, respectively. They provide users with agricultural market information services such as up-to-date prices and their recent trends, weather forecasts and alerts and crop production levels with the objective of helping farmers improve their productivity and sell their products at the right price, the right place, and the right time.

5 We use data-driven bandwidth selection and a Gaussian kernel.

6 See studies that evaluate the impact of the Dutch disease on the long-run economic growth of countries that heavily rely on the primary sector and foreign aid (Frankel and Romer, 1999; Gylfason, Herbertsson, and Zoega, 1999; Nordhaus, 1992; Knight, Loayza, and Villaneuva, 1996; Woolcock, 1998; Paldam and Svendsen, 2000; Burnside and Dollar, 2000)

7 We also conducted the analysis using secondary school enrolment. The results were very similar and are available from the authors upon request.

8 Although Ketteni, Mamuneas, and Stengos (2011) also use a nonparametric methodology, their results are not directly comparable to ours because they explore the effects of average years of schooling (rather than school enrolment rates) and ICTs capital (rather than ICTs indicators) on TFP (rather than labour productivity) growth in a sample of advanced (rather than developing) economies.

9 Our analysis further indicates that higher levels of openness result in fixed-line telephony and internet usage exhibiting increasing returns to growth. FDI, on the other hand, does not seem to be a complement of these two ICTs indicators. These results are available upon request.

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