Chapter 2
ICT Diffusion Trajectories and Economic Development: Empirical Evidence for 46 Developing Countries

Ewa Lechman

Abstract In economic theory, technology is treated as a crucial factor contributing significantly to economic development. Seminal works of Schumpeter (Theory of economic development. Transaction Publishers, New Brunswick, 1934, J Econ Hist 7:149–159, 1947), Baumol (Am Econ Rev 76:1072–1084, 1986), Gerschenkron (Economic backwardness in economic perspective. Belknap Press, Cambridge, MA, 1962) or Abramovitz (J Econ Hist 46(2):385–406, 1986) emphasize the special role of technological progress in the process of economic development. The objective of the study is twofold. Firstly, using panel data, we analyze diffusion trajectories of ICTs in developing countries, assessing dynamics of the process. Secondly, we hypothesize about the existence of quantitative links between the adoption of ICT and economic development. The time framework for the analysis is the period 2000–2011. Statistical data are derived from the World Telecommunication/ICT Indicators Database (2012), World Development Indicators (2013), and Human Development Report (2013).

Keywords ICT • Diffusion • Economic development • Developing countries • S-shaped curve

2.1 Introduction

New information and communication technologies (ICTs) are widely recognized as an important source of economic development. Dynamic adoption of ICTs worldwide is causing tremendous changes in countries' economic performance, which is mainly due to its unique features, changing the ways of doing business, and enhancing

E. Lechman (✉)
Faculty of Management and Economics, Gdansk University of Technology, Gdańsk, Poland
e-mail: eda@zie.pg.gda.pl

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increases in human and social capital. ICTs can be adopted fast, at low cost, and require minimal capabilities for their usage. Case studies from around the world have shown that ICTs are of crucial importance for economic and social development (see, e.g., reports of infoDev.org; UNCTAD; globalvoicesonlone.org; ict4d.org.uk). From an economic policy perspective, deep insight into potential links between ICT implementation and economic development remains of crucial importance.

2.2 Technology Diffusion: Theoretical Outline

2.2.1 Definitions and Concepts

Related literature, considering both theoretical and empirical aspects of technology diffusion, is vast. A critical introduction of technology to economic science was done by Joseph Schumpeter and his seminal works (1934, 1947). Notwithstanding its innovation, Schumpeterian analysis did not receive much attention, mainly due to its highly theoretical, strict, and simplifying assumption about the linearity of the diffusion process, along with ignorance of the distinction between invention and innovation.

In the late 1950s, a pervasive contribution to the field was made. Broad studies of the phenomenon of technological diffusion were carried out and resulted in elaboration of "epidemic models"[1] of diffusion. Many claimed these models to explain fully the process of adoption of new technologies by societies (see, e.g., Griliches 1957; Mansfield 1968; Romeo 1977; Davies 1979; Metcalfe 1988; Karshenas and Stoneman 1995; Stoneman 2001). This innovative approach, however, had many limitations and omissions. The concept was built on the strict assumption that diffusion and speed of adoption by potential users are highly limited by lack of information about the possibilities of new technologies (products), and poor skills and knowledge about how to use "new technology."

Today, most theoretical and empirical works on technology diffusion refer to the ideas of Everett Rogers and his seminal work, *Diffusion of Innovation* (Rogers 1962). Rogers' model of technology diffusion is widely applied in political sciences, economics, public health policies, history, and education, defining technology as "design for instrumental action that reduces the uncertainty in the cause–effect relationships involved in achieving a desired outcome" (Rogers 1962, p. 6), while diffusion refers to the "process by which an innovation [i.e., technology] is communicated through certain channels over time among members of a social system" (Rogers 1962, p. 10). The process is highly dependent on the functioning of a societal system, where society's members individually make decisions[2] about the adoption or rejection of using a given innovation.

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[1] The concept of *epidemic models* was originally derived from the medical sciences. The term *epidemic* referred to spontaneously and uncontrolled spread of diseases.

[2] The decisions are not collective, but rather individual.

2.2.2 S-Shaped Curves: Estimating Technology Diffusion Trajectories

Concepts based on S-shaped curves (Geroski 2000) offer a theoretical specification for capturing the dynamics of diffusion, leading to identification of its unique growth phases. The mathematical background for analysis of the S-shaped curve phenomenon is rooted in single growth models, originating from ordinary differential equations which, can be formalized[3] as:

$$P(t) = \beta e^{\alpha t} \tag{2.1}$$

where $P(t)$ specifies the growing variable, t is time, and α is the growth rate.

Equation 2.1 imposes no limits to growth, unless the conditions are changed. But, due to many restrictions and barriers, variables cannot grow infinitely, which makes the process slow down, generating the S-shaped (sigmoid) curve. The growth rates begin as exponential, but then start to slow down as the variable value approaches the upper limit defined by κ. If $(P(t) \rightarrow \kappa)$ the sigmoid growth curve is revealed. By adding the "slowing factor," defined as

$$\left(1 - \frac{P(t)}{\kappa}\right) \tag{2.2}$$

we estimate the logistic growth model defined as

$$P(t) = \frac{\kappa}{1 + exp\left(-\alpha\left(t - \beta\right)\right)}, \tag{2.3}$$

or alternatively,

$$P(t) = \frac{\kappa}{1 + e^{-\alpha t - \beta}}. \tag{2.4}$$

The κ imposes the upper limit of growth (i.e., the upper asymptote of the curve); the α specifies the "steepness" ("width") of the curve (i.e., it approximates the growth rates), and indicates time needed for a variable to grow from 10 % of saturation to 90 %; finally, β explains the "midpoint" of the curve which stands for the time when 0.5κ. Figure 2.1 shows the idealized S-shaped patterns with clearly distinguished phases of growth.

In the S-shaped curve, four characteristic phases of growth are distinguishable. The initial phase stands for the prime phases of diffusion where the adoption rate is both slow and gradual. Next occurs the second phase of exponential growth,

[3] With e introduced.

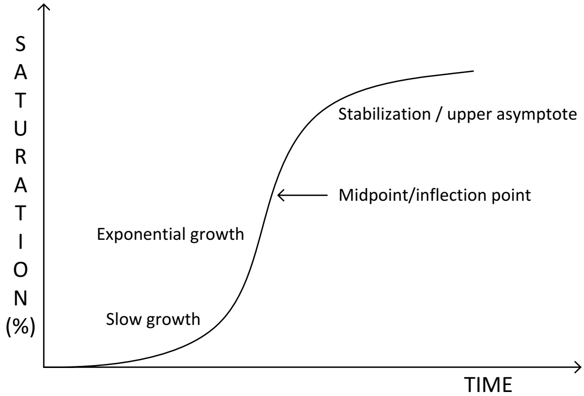

Fig. 2.1 S-shaped curve and phases of diffusion

where the adoption rates are rapid and the diffusion of technology is massive. Third, having passed the inflection point, the slow growth phase reveals. Finally, fourth, we identify the stabilization phase approximated by κ, when the growth potentially stops.

2.3 Dissemination of New Technologies in the Developing World: A Promise for Success?

The near-ubiquitous spread of information and communication technologies offers unprecedented opportunities for low-income economies to take-off on the path of development. ICTs enable a significant reduction in information asymmetries that improves access to economic activities for a multitude of agents, fostering participation in the labour market of disadvantaged societal groups. ICTs bring to developing markets new business models, innovations, capital-labour substitution, and improved goods and services. The full potential of new technologies can be easily unleashed when deploying them as an economic development accelerator in the least developed countries (LDCs). Least developed countries, permanently lacking financial resources, good infrastructure, free and easily accessed educational and healthcare systems, and sound governments, remain in poverty traps, unless a breakthrough such as the explosion of ICT occurs.

Samiullah and Rao (2000) argue that new technologies bring to developing countries opportunities to fight rural and urban poverty. By improving economic performance and the ability to compete in global markets, they provide a means for exploiting the unused labour force and increasing social capital. The nexus between new technologies and achievements of Millennium Development Goals (MDGs) is recognized and is based on mutually shared objectives, which are “efficient, scalable, affordable, and pervasive delivery of goods, services, and information flows between people, government, and firms” (see, e.g., Gilhooly 2005).

2.4 Data Explanation and Rationale

For analytical purposes, we have selected a set of variables that approximate the level of technological advancement—on the grounds of information and communication technologies (ICTs)—and data explaining socioeconomic development. For empirical evidence we construct a cross-country panel data set that covers 46[4] low- and lower-middle-income economies. The period of the analysis is set for 2000–2011. All data on ICTs are exclusively obtained from the World Telecommunication/ICT Indicators Database (2012; 16th online edition).

We have selected the following variables: Fixed telephone lines per 100 inhabitants ($FTL_{i,}$[5]$_{y}$[6]), mobile–cellular telephone subscriptions per 100 inhabitants ($MCS_{i,y}$), and Internet users[7] as a share of total population ($UI_{i,y}$). We have transformed[8] the data on $FTL_{i,y}$ and $MCS_{i,y}$ so that they present the share of population using the given ICT tool. Selected variables describe an individual country's achievements and track progress made in ICT infrastructure, access, and usage. In the study we also deploy three variables to examine the level of socio-economic development. All data are derived from World Development Indicators (2013) (accessed June 2013) and Human Development Report (2013). These include gross domestic product (GDP) per capita in purchasing power parity ($GDPPPPpc_{i,y}$), the human development index ($HDI_{i,y}$), and female labour participation[9] ($FLP_{i,y}$). The value of the HDI variable explains the general well-being of societies, reflecting the effectiveness of the educational system and healthcare, allowing assessment of people's possibilities for wealth creation (measured in per capita incomes). We also add to the panel the female labour participation ($FLP_{i,y}$) variable. This indicator reports on women's access to the labour market, as well as their ability to obtain financial assets that enable them to set up a business.

2.5 Estimating ICT Diffusion Patterns in Low- and Lower-Middle-Income Countries: Empirical Evidence

Empirical objectives of the first part of the analysis are twofold. Firstly, we concentrate on detecting changes in distribution of the ICT variables in the period 2000–2011 in 46 analyzed countries. Secondly, we verify the hypothesis about the existence of S-shaped ICT diffusion patterns, along with estimates of logistic growth models.

[4] Countries in the panel represent different regions of the world (including Europe).

[5] Country.

[6] Year.

[7] Refers to individuals using Internet.

[8] For data transformation we have used statistics on total population and total number of given ICT tool in each country. Based on that we have estimated the share of total population using (having access) to fixed telephony and mobile telephony.

[9] Labour participation rate: the share of the female population aged 15+ that are active participants in the labour market (WDI 2013).

Table 2.1 Descriptive statistics for $FTL_{i,y}$, $MCS_{i,y}$, and $IU_{i,y}$ in 46 countries (2000–2011)

Variable	Average (%)	Min. value (%)	Max. value (%)	Lower quintile	Upper quintile	Gini coeff.	Atkinson index	Entropy index
$FTL_{i,2000}$	4.3	0.18	21.3	0.76	5.29	0.57	0.27	0.66
$FTL_{i,2011}$	7.3	0.34	33.28	1.33	10.53	0.56	0.26	0.63
$MCS_{i,2000}$	2.34	0.018	15.36	0.21	2.85	0.66	0.38	1.07
$MCS_{i,2011}$	77.08	21.31	143.3	55.7	99.4	0.21	0.037	0.069
$IU_{i,2000}$	0.69	0.036	5.96	0.15	1.04	0.56	0.26	0.93
$IU_{i,2011}$	17.51	1.3	51.0	7.0	28.0	0.39	0.13	0.25

Source: Author's estimates using data from World Telecommunication/ICT Indicators Database (2012, 16th online edition)

2.5.1 ICT in Developing Countries: Descriptive Statistics of the Data

Preliminary analysis consists of two essential parts. Firstly, we present basic statistics on $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$ deployment in the economies of 46 selected countries. We report on averages, minimum and maximum values of variables in the sample, and we contrast the lower quintile with the upper quintile, as well as identify basic inequalities in distribution of ICTs. Secondly, we plot nonparametric estimates of density functions[10] for each ICT variable, to identify trends in graphical distributions (involving smoothed structure) of data. Table 2.1 lists cross-country descriptive statistics, along with Gini coefficients, Atkinson, and entropy indexes. The most prominent observation that can be derived from the table is that in 2000–2011, the dynamic of the process of ICT adoption was exceptionally high. Changes in mobile telephony and Internet usage were massive, and this explains the worldwide tendency toward a broad adoption of "new" forms of ICT in developing countries.

Focusing exclusively on changes in $MCS_{i,y}$, we clearly see that in 2000 the average level of adoption of mobile cellular telephony was at $MCS_{AverAllCountries,2000} = 2.34\ \%$; while the analogous value in 2011 resulted in $MCS_{AverAllCountries,2011} = 77.08\ \%$. Analyzing changes in the lower and upper quintiles, we conclude that in 2000 the average adoption of $MCS_{i,y}$ in the group of 20 % poorest of countries was at 0.22 % (of total population), while in 2011 it was 55.7 %. The analogous values but referring to the upper quintile (which accounts for the 20 % best performing countries) in 2000 and 2011 were, respectively, 2.85 % and 99.4 %.

Similarly, less explosive changes are noted for Internet use by individuals. The average use of the Internet increased from $IU_{AverAllCountries,\ 2000} = 0.69\ \%$ to $IU_{AverAllCountries} = 17.51\ \%$. Countries that underwent the most impressive increases in Internet usage were: Nigeria ($IU_{Nigeria,2000} = 0.06\ \% \rightarrow IU_{Nigeria,2011} = 28.48\ \%$), Albania ($IU_{Albania,2000} = 0.11\ \% \rightarrow IU_{Nigeria,2011} = 49\ \%$), Morocco ($IU_{Morocco,2000} = 0.69\ \% \rightarrow$

[10] Kernel Epanechnikov.

$IU_{Morocco,2011} = 51\ \%$), Moldova ($IU_{Moldova,2000} = 1.28\ \% \rightarrow IU_{Moldova,2011} = 38\ \%$), and Georgia ($IU_{Georgia,2000} = 0.48\ \% \rightarrow IU_{Georgia,2011} = 36.56\ \%$). As expected, changes in adoption and usage of the "old" form of mass communication—fixed telephone lines ($FTL_{y,i}$)—are relatively slight when compared to the $MCS_{i,y}$ and $IU_{i,y}$. Weak increases in adoption of fixed telephony are probably due to substitution of "old" forms by "new" forms of communication. This might also be explained by the fact that mobile telephony is in general cheaper to use, is more easily acquirable, and requires a minimum amount of hard infrastructure. This ease and low cost of adoption of mobile telephony even in low- and lower-middle-income countries supports the hypothesis that ICT is adequate as a tool for development in even economically developing countries.

However, descriptive statistics do not contain much information about the distribution ICT variables ($FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$) across countries, so we provide a complementary analysis for the previously obtained results. In Fig. 2.2, we draw separate density plots to illustrate significant variations that occurred in ICT distribution over the period 2000–2011 both in low- and lower-middle-income countries. The solid line represents the distribution approximation of $FTL_{i,y}$, $MCS_{i,y}$ and $IU_{i,y}$ in 2000, while the dashed line represents the same measures in 2011. As expected, in the case of fixed telephony density plots, changes are not significant and density lines hardly change in shape and location.

When turning to the analysis of density plots for $MCS_{i,y}$ and $IU_{i,y}$, the changes, both in shape and location, are striking. In the case of $MCS_{i,y}$, density lines have "moved" to the right, making them unimodal, highly peaked, and tall in 2011. This again confirms the observation about diminishing inequalities in access to this kind of ICT by society members in the analyzed countries. Analogous results are revealed in the case of $IU_{i,y}$ data smoothing using kernels. Rather unimodal lines, in both country income sets, again similar in shape, but more right-located in 2011 than in 2000.

2.5.2 *ICT Diffusion Trajectories in Developing Economies*

Graphical approximations of ICT diffusion patterns allow for general assessment and intercountry comparisons of process dynamics over time. Such an approach also lets us discover existing regularities and tendencies in the technology diffusion process in developing countries. For many countries, we have data for the first years in which ICTs were implemented, so the estimates of a "full" S-shaped curve are highly realized. To obrain detailed estimates of the S-shaped curve parameters, we run 46[11] logistic models, with a highly predictive capacity, assuming time (t) to be the explanatory variable.

[11] We estimate the model for each country separately.

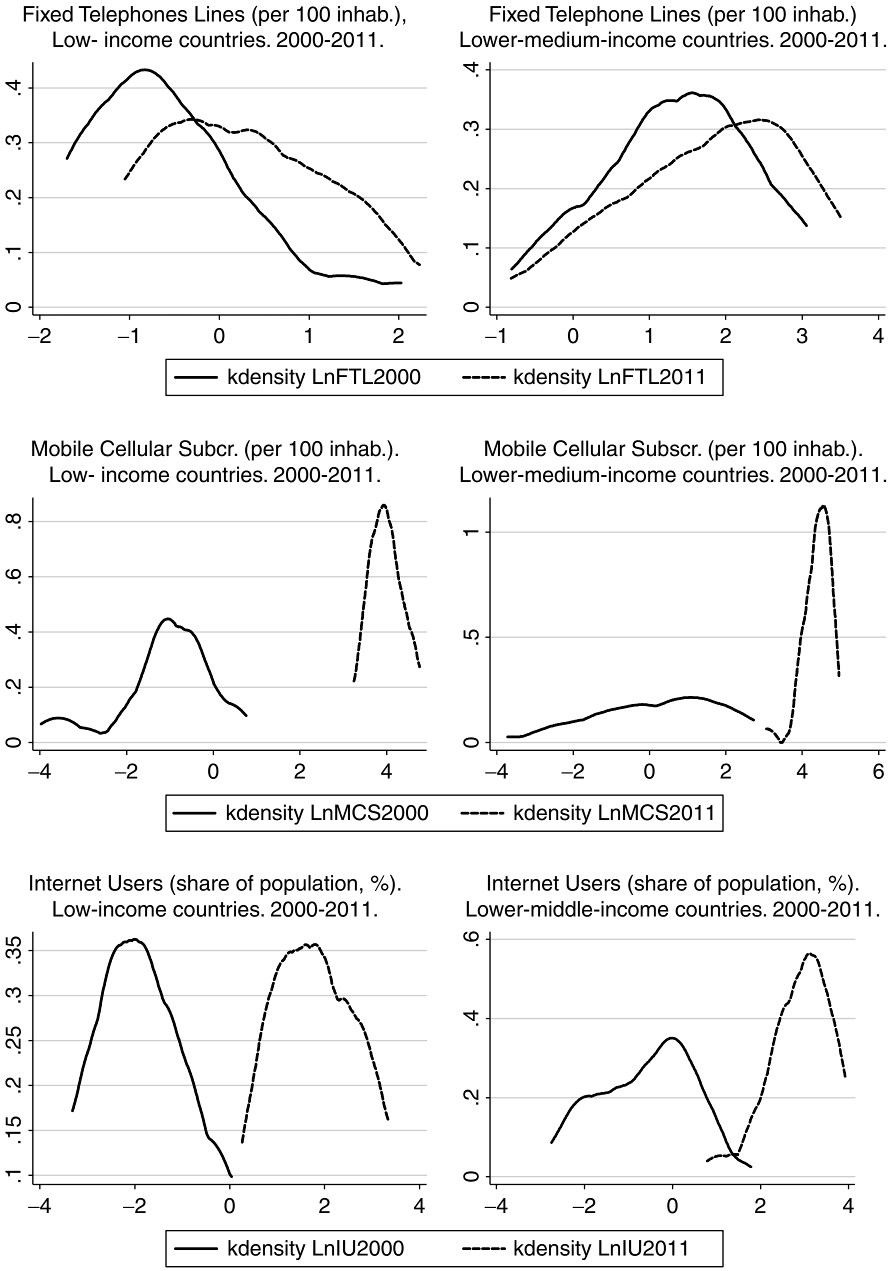

Fig. 2.2 Density representations for $FTL_{i,y}$, $MCS_{i,y}$, and $IU_{i,y}$ by income groups. The solid lines are for 2000, the dashed lines for 2011

The individual country model specification is formalized as:

$$\left\{ P(t)_{(\mathrm{i},2000-2011)} = \frac{\kappa_{(\mathrm{i},2000-2011)}}{1+\exp\left(-\alpha_{(\mathrm{i},2000-2011)}\left(t-\beta_{(\mathrm{i},2000-2011)}\right)\right)} \right\} \tag{2.5}$$

Following (2.5), we estimate: α (specific duration), β (midpoint), and κ (limit of growth, maximum/potential level of saturation). Along with the previous data, we plot the ICT diffusion curve for each of the studied countries. A set of plots (see Fig. 2.3) presents diffusion trajectories for $FTL_{i,y}$, $MCS_{i,y}$, and $IU_{i,y}$. In many analyzed cases the fit of the data to a theoretical S-shaped curve is rather good. Moreover, many low- and lower-middle-income countries show very clear S-shaped patterns of ICT diffusion, especially with respect to mobile telephony ($MCS_{i,y}$). Additionally, for many countries the full S-shaped trajectory is revealed. This is reported, for example, in the cases of Ukraine, Fiji, El Salvador, Sri Lanka, Paraguay, Pakistan, Côte d'Ivoire, and Zimbabwe, where diffusion of mobile telephony was relatively slow in the initial years, then it sped up in the "middle years," and finally it slowed down (in 2011, and even a few years earlier). It is worth a reminder that in 2000 the average level of adoption of mobile telephony was close to zero.

After an 11-year period of extraordinary dynamic growth, the average level of adoption of $MCS_{i,y}$ reached a level of almost 100 % saturation. The number of countries that could be cited as examples of this pattern is abundant. The share of total population using mobile phones exceeding 100 %, occurred, for example, in Armenia ($MCS_{Armernia,2011} = 103$ %), Honduras ($MCS_{Honduras,2011} = 103$ %), Kyrgyzstan ($MCS_{Kyrgystan,2011} = 113$ %), Viet Nam ($MCS_{VietNam,2011} = 144$ %). In each of these countries, in 2000, the share of population using MCS ranged between <$MCS_{i,2000} = 0.18$ %> and <$MCS_{i,2000} = 2.5$ %>.

Full S-shaped trajectory was not reported in any case. It suggests that most of low-, and lower-middle-income countries are about to enter exponential growth phase.

More detailed analysis of countries' specific statistics on $IU_{i,y}$, both in 2000 and 2011, provides a picture of the average level of adoption of the Internet in the analyzed countries. In 2011, the best performing countries were Morocco—$IU_{Morocco,2011} = 51$ %, Albania—$IU_{Albania,2011} = 49$ %, Moldova—$IU_{Moldova,2011} = 38$ %, and Georgia—$IU_{Georgia,2011} = 36$ %. These results, although impressive, are significantly lower than for $MCS_{i,y}$. Following (2.5), we estimate the logistical model parameters for each country separately. Based on the graphical approximations of the diffusion patterns, we conclude that full S-shaped curve estimates are only reasonable for the variable $MCS_{i,y}$. As for $IU_{i,y}$ and $FTL_{i,y}$ the S-shaped curves are not revealed. All generated results are presented in Table 2.2.

Applying *ceteris paribus*, we conclude that parameter κ explains the potential limits of growth of $MCS_{i,y}$ and is generated basing on the tacit assumption that the trend of diffusion will be maintained. For low-income countries, the estimated limits of growth of $MCS_{i,y}$ are definitely lower than for lower-middle-income countries.

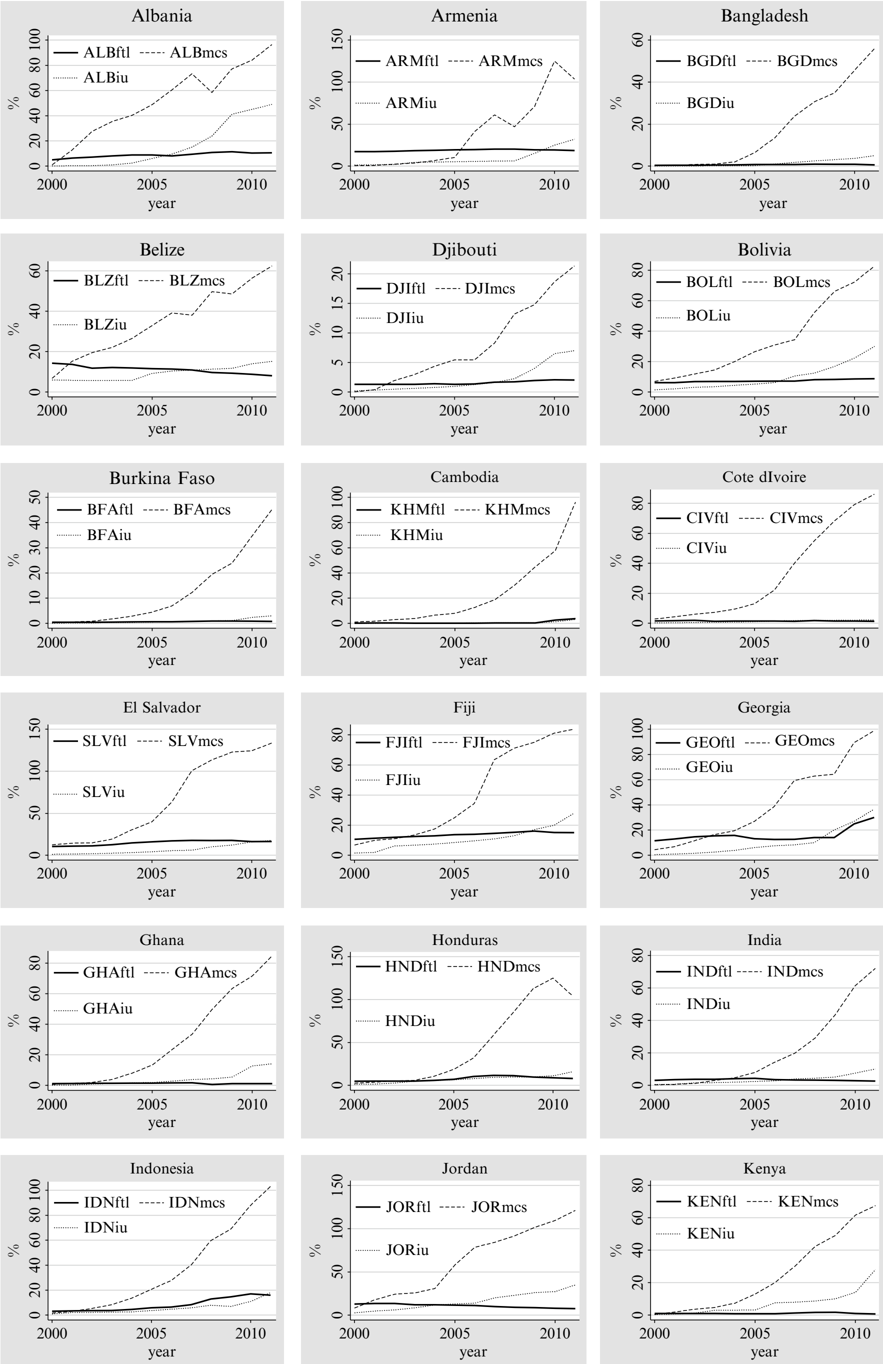

Fig. 2.3 ICT diffusion trajectories in 46 low- and lower-middle-income countries (2000—2011). *Source:* Author's own elaboration

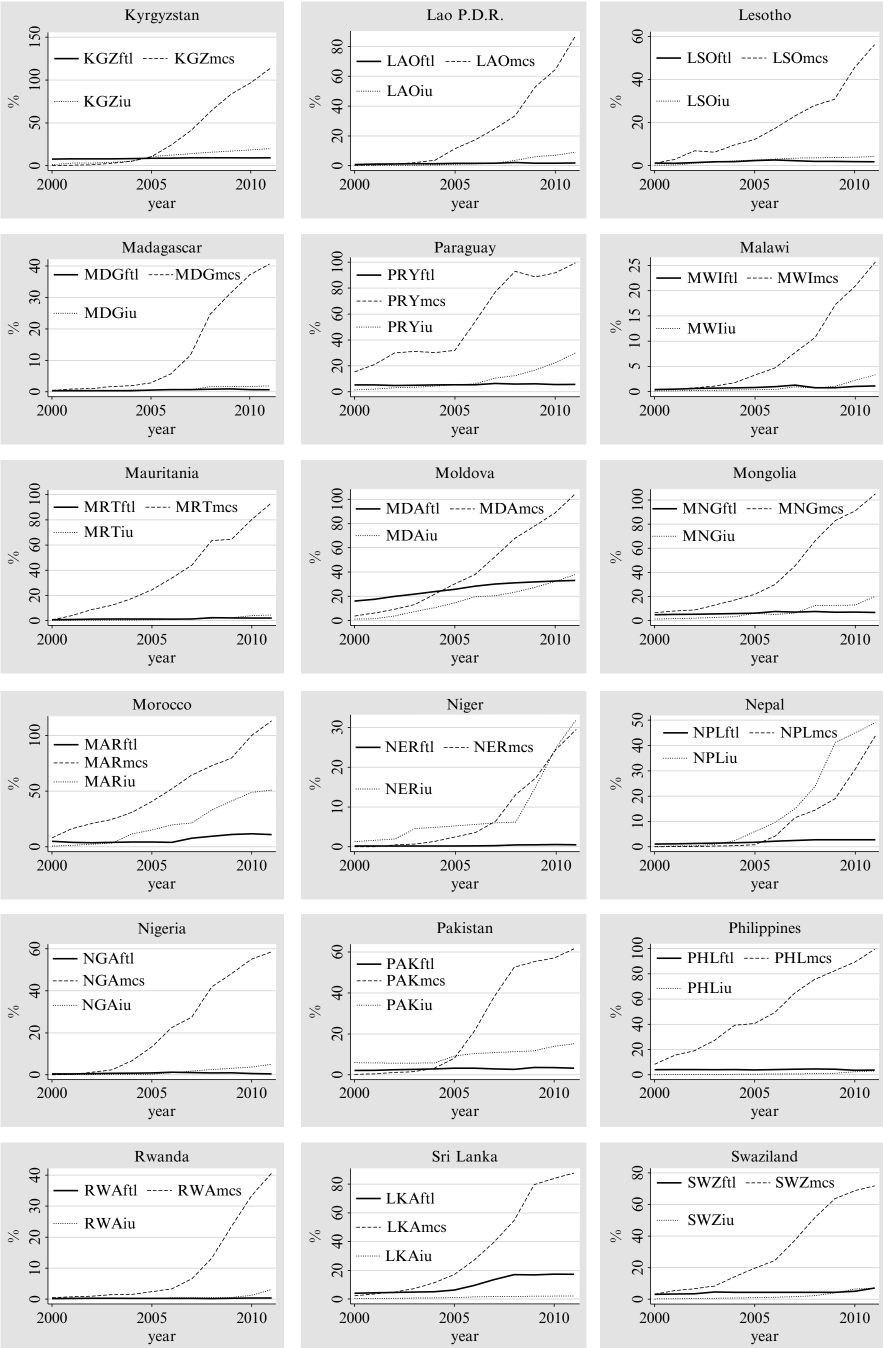

Fig. 2.3 (continued)

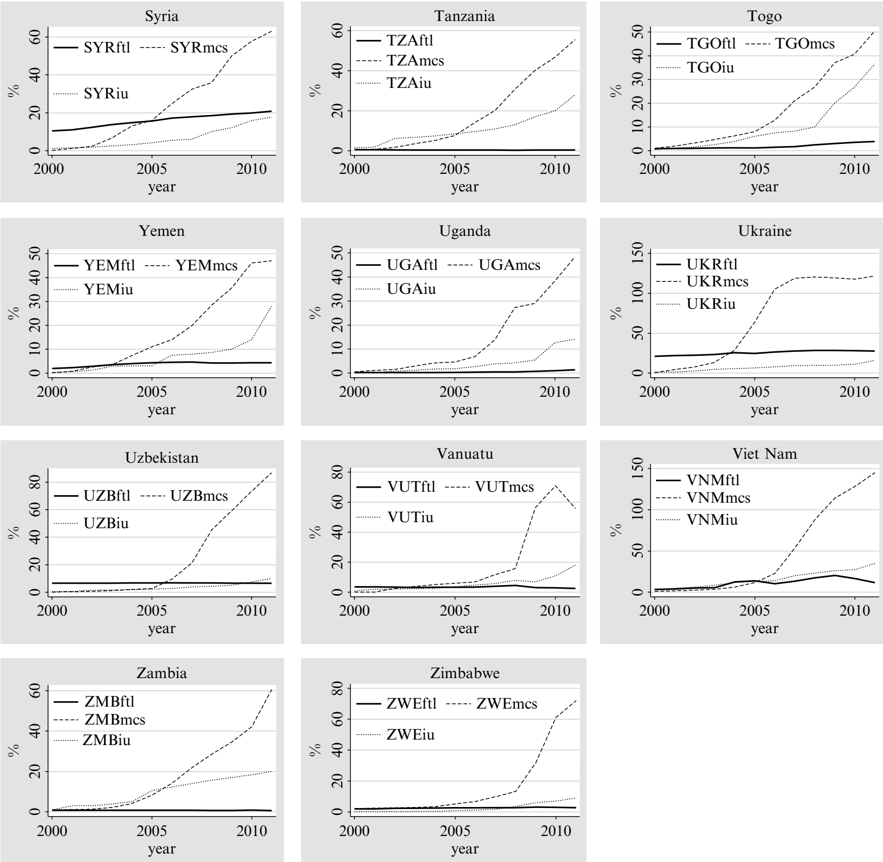

Fig. 2.3 (continued)

Unreasonably high κ results are seen in Cambodia ($\kappa_{Cambodia} = 345$), but such overestimates are probably due to a specific jump in the $MCS_{Cambodia,y}$ value in the period 2000–2011 (it was at 60 % of annual growth). The parameter α controls for the specific duration, approximating time (years) needed for a country to pass from 10 to 90 %. As we see in Table 2.2, the average characteristic duration in low-income countries was $\alpha_{AverageLowIncomeCountries} = 8.5$ years. This suggests that an "average" low-income country needs 8.5 years to achieve 90 % acceptance with respect to mobile telephony. The β identifies the midpoint, identifying the specific number of years when a given country passes from exponential growth to the stabilization phase. The average value of β in low-income counties is reported as $\beta_{AverageLowIncomeCountries} =$ (year) 2009, as after 2009 diffusion slows, approaching the upper asymptote κ.

Analogous estimates are reported for 31 lower-middle-income countries (see again Table 2.2). The κ in this income group is generally higher, achieving on average $\kappa_{AverageLowerMiddleIncomeCountries} = 94.6$ %, while $\alpha_{AverageLowerMiddleIncome} = 8$ (years), and $\beta_{AverageL}$

Table 2.2 MCS variable logistical model estimates for 46 countries (2000–2011)

Country	κ (%) (upper asymptote)	α (years) (specific duration)	β (year) (midpoint)	Country	κ (%) (upper asymptote)	α (years) (specific duration)	β (year) (midpoint)
Low-income countries				*Lower-middle-income countries*			
Bangladesh	65.6	7.5	2008	Ghana	96.5	7.3	2008
Burkina F.	84.2	9	2011	Honduras	117.0	4.2	2007
Cambodia	*345*	11.3	2014	India	108.5	8.0	2010
Kenya	79.4	7.9	2004	Indonesia	132.1	8.7	2009
Kyrgyzstan	123.5	6	2008	Lao P.D.R.	148.0	8.9	2010
Madagascar	42	4.5	2008	Lesotho	77.3	12.5	2010
Malawi	36	7.9	2008	Moldova	118.1	9.1	2008
Mauritania	118.7	10.9	2008	Mongolia	119.9	7.0	2008
Nepal	101.1	8.2	2012	Morocco	145.0	12.1	2009
Niger	37.8	6.5	2009	Nigeria	62.8	6.6	2007
Rwanda	49.9	5.3	2009	Pakistan	59.7	3.7	2006
Tanzania	66.9	7.6	2008	Paraguay	86.0	6.1	2006
Togo	61.5	8.3	2009	Philippines	102.7	10.2	2007
Uganda	62.9	7.7	2009	Sri Lanka	95.7	6.3	2007
Zimbabwe	51.9	12.1	2015	Swaziland	77.0	7.0	2007
Lower-middle-income countries				Syria	77.1	9.3	2008
Albania	94.6	10.9	2005	Ukraine	121.4	3.2	2005
Armenia	134.9	7.5	2008	Uzbekistan	91.2	4.8	2008
Belize	64.5	12.6	2006	Vanuatu	59.1	12.5	2014
Bolivia	100.9	6.9	2009	Vietnam	146.2	4.6	2008
Cote d'Ivoire	89	5.9	2008	Yemen	59.9	8.5	2008
Djibouti	32.8	11	2009	Zambia	114.1	10.6	2011
El Salvador	119.3	4.6	2006				
Fiji	76.9	4.9	2006				
Georgia	117.1	10	2008				

Note: All estimates are generated *by LogLet Lab2* software. For Cambodia, the upper asymptote value in italics - definite overestimation. *Source:* Author's estimates

$_{owerMiddleIncome} = 2007$ (year). This shows that, on average, lower-middle-income countries pass the inflection point on the S-shaped curve 2 years earlier than low-income ones, which is determined by relatively higher dynamics of $MCS_{i,y}$ diffusion in "richer" countries. All estimates are based on rigid assumptions. We arbitrarily foresee that analyzed countries follow the same diffusion pattern and maintain previously achieved diffusion rates. However, the heterogeneity of factors conditioning the future diffusion paths is huge. Technology diffusion needs to contend with institutional regulations, market competition, and societies' ability to assimilate innovations, which depends on education level but also on religious and cultural customs. All factors listed above play a crucial role, especially in developing countries.

Taking into account a fast-changing, and in many cases highly unstable external environment, such an optimistic scenario is not very probable, but it indicates the general trends of ICT diffusion.

2.6 Tracing the Effects of ICT Adoption on Economic Development: A Trial of Quantification

The final part of this chapter summarizes available evidence by extended the study of detecting regularities on the impact of new technologies on economic development. To capture the impact of ICT diffusion on general welfare, we use data on ICT ($FTL_{i,y}$, $MCS_{i,y}$, and $IU_{i,y}$) and economic development ($GDPPPPpc_{i,y}$, $HDI_{i,y}$, and $FLP_{i,y}$). As the $FTL_{i,y}$ variable shows hardly any changes during the analyzed period (see the distributional plots in Fig. 2.3), we exclude the variable from further analysis. Our empirical settings are based on GLM equations,[12] specified as:

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,y} + \delta_2 \ln IU_{i,y} + \varepsilon_{i,y}, \tag{2.6}$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,y} + \delta_2 \ln IU_{i,y} + \varepsilon_{i,y}, \tag{2.7}$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,y} + \delta_2 \ln IU_{i,y} + \varepsilon_{i,y}, \tag{2.8}$$

where $GDPPPPpc_{i,2011}$ denotes the gross domestic product (in PPP) per capita, $HDI_{i,2011}$ denotes the human development index, and $FLP_{i,2011}$ denotes the female labour participation in country i in 2011. Explanatory variables are: $MCS_{i,y}$ shows the share of the population using mobile-cellular telephones in country i in year y; and $IU_{i,y}$ shows the share of the population[13] treated as Internet users country i in year y. Relying on the "delay hypothesis" (David 1990), we assume that the "technological revolution" can take please without causing any straightforward changes in total factor productivity, and the straightforward effects of ICT on development might be revealed with significant time lags. Following this logic, we reformulate (2.6), (2.7), and (2.8) by adding time lag variables. Assuming that y stands for year 2011, the final equations are formalized as:

For economic growth:

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-1)} + \delta_2 \ln IU_{i,(y-1)} + \varepsilon_{i,(y-1)} \tag{2.9}$$

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-2)} + \delta_2 \ln IU_{i,(y-2)} + \varepsilon_{i,(y-2)} \tag{2.10}$$

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-5)} + \delta_2 \ln IU_{i,(y-5)} + \varepsilon_{i,(y-5)} \tag{2.11}$$

$$\ln GDPPPPpc_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-11)} + \delta_2 \ln IU_{i,(y-11)} + \varepsilon_{i,(y-11)} \tag{2.12}$$

[12] We have chosen generalized linear model (GLM) techniques.

[13] Refers to individuals.

Table 2.3 GLM estimates of the impact of ICT on GDP PPP per capita, the human development index, and female labour participation for 46 countries (2000–2011)

	$GDPPPPpc_{AllCountries,2011}$	$HDI_{AllCountries,2011}$	$FLP_{AllCountries,2011}$
$MCS_{i,(y-1)}$	$\boldsymbol{\delta_1 = 0.672}$	$\boldsymbol{\delta_1 = 0.241}$	$\delta_1 = 0.130$
$IU_{i,(y-1)}$	$\boldsymbol{\delta_2 = 0.270}$	$\boldsymbol{\delta_2 = 0.09}$	$\delta_2 = (-0.13)$
$MCS_{i,(y-2)}$	$\boldsymbol{\delta_1 = 0.729}$	$\boldsymbol{\delta_1 = 0.241}$	$\delta_1 = 0.064$
$IU_{i,(y-2)}$	$\boldsymbol{\delta_2 = 0.184}$	$\boldsymbol{\delta_2 = 0.071}$	$\delta_2 = (-0.11)$
$MCS_{i,(y-5)}$	$\boldsymbol{\delta_1 = 0.588}$	$\boldsymbol{\delta_1 = 0.151}$	$\delta_1 = (-0.07)$
$IU_{i,(y-5)}$	$\delta_2 = 0.077$	$\boldsymbol{\delta_2 = 0.063}$	$\delta_2 = (-0.03)$
$MCS_{i,(y-11)}$	$\delta_1 = 0.088$	$\delta_1 = 0.031$	$\delta_1 = (0.59)$
$IU_{i,(y-11)}$	$\boldsymbol{\delta_2 = 0.26}$	$\boldsymbol{\delta_2 = 0.097}$	$\delta_2 = (-0.11)$

Note: All estimates have a 5 % significance level. All data are log transformed. Boldfaced entries are parameters that are statistically significant. Constant reported—not included. *Source:* Author's own estimates

For the human development index:

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-1)} + \delta_2 \ln IU_{i,(y-1)} + \varepsilon_{i,(y-1)} \tag{2.13}$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-2)} + \delta_2 \ln IU_{i,(y-2)} + \varepsilon_{i,(y-2)} \tag{2.14}$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-5)} + \delta_2 \ln IU_{i,(y-5)} + \varepsilon_{i,(y-5)} \tag{2.15}$$

$$\ln HDI_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-11)} + \delta_2 \ln IU_{i,(y-11)} + \varepsilon_{i,(y-11)} \tag{2.16}$$

For female labour participation:

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-1)} + \delta_2 \ln IU_{i,(y-1)} + \varepsilon_{i,(y-1)} \tag{2.17}$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-2)} + \delta_2 \ln IU_{i,(y-2)} + \varepsilon_{i,(y-2)} \tag{2.18}$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-5)} + \delta_2 \ln IU_{i,(y-5)} + \varepsilon_{i,(y-5)} \tag{2.19}$$

$$\ln FLP_{i,2011} = \alpha + \delta_1 \ln MCS_{i,(y-11)} + \delta_2 \ln IU_{i,(y-11)} + \varepsilon_{i,(y-11)} \tag{2.20}$$

Table 2.3 summarizes estimation results of (2.9)–(2.12). The δ_1 and δ_2 parameters report on the positive or negative impact, respectively, of ICT adoption on economic growth, human development, and the participation of women in the labour market. We see that the relationship between ICT adoption and female labour participation is neither strongly positive nor statistically significant as in each case the δ_2 is negative. This suggests that broader usage of the Internet by individuals negatively impacts women's empowerment in the labour market, but these results are at odds with elementary logic. Having in mind that ICTs give people better access to education, economic resources (including finance), jobs creation, and many other benefits, we would expect the influence of ICT to be both high and positive. One possible explanation for these results is that ICT requires more time to significantly impact changes in labour market structures. Contrary to the results previously discussed, the picture that follows from the regression estimates in (2.9)–(2.16) is remarkable. The results confirm the hypothesis about existing technology-driven growth and development. Positive links are revealed even from a short-term perspective (i.e., 1- and 2-year lags). Values of δ_1 for 1- and 2-year lags suggest that the impact of mobile telephony on gross domestic product (in PPP per capita) is strong, positive, and statistically significant. The highest impact—explained by the highest values of δ_1—is reported for $MCS_{i,(y-2)}$, and states for ($\delta_1 = 0.729$). For the 1-year lag, $\delta_1 = 0.672$, and for the 5-year lag, $\delta_1 = 0/588$. The statistically insignificant relationship is also reported for the 11-year lag.

Considering the impact of Internet use on growth, the estimates report similar relationships; however, they are weaker in all cases. Estimates for $HDI_{i,2011}$ as a dependent variable gave analogous results. The potential impact on human development of $MCS_{i,y}$ (with 1-, 2-, and 5-year lags imposed) is positive and significant, as $\delta_1 = 0.241$ (1-year lag), $\delta_1 = 0.241$ (2-year lag), and $\delta_1 = 0.151$ (5-year lag). In the case of estimates for 11-year lags, the δ_1 and δ_2 show similar tendencies. Despite the fact that the effects of $MCS_{i,y}$ and $IU_{i,y}$ adoption on economic development are as hypothesized, the impact is weaker than it is for GDP.

To provide more clarity to our estimates, and to reveal existing relationships between ICT and economic development, we draw 24 scatterplots. Figures 2.4 and 2.5 plot statistical relationships between $MCS_{i,y}$ and $IU_{i,y}$ adoption and gross domestic product ($GDPPPPpc_{i,2011}$) per capita in 2011 (Fig. 2.4), and $IU_{i,y}$ and the same dependent variable (Fig. 2.5).

Next, Figs. 2.6–2.9 extrapolate relationships between the same ICT variables against the human development index in 2011 (Figs. 2.6 and 2.7), and female labour participation in 2011 (Figs. 2.8 and 2.9). Empirical evidence clearly shows that the level of adoption of new technologies correlates strongly and positively with economic growth and development. The results also claim that many of the least developed countries managed to take huge strides on the path toward development. Not all countries' economic performance was equally good, but in almost every one of the 46 studied countries, the diffusion of ICT was unprecedentedly dynamic, which is a good reason for boosting growth further.

For developing nations, new technologies can be important drivers of social, political, and economic changes. Adoption of ICTs create conditions for education and skills improvement, and empower disadvantaged groups to overcome barriers and to tap the global market for goods and services. ICTs enhance a shift from traditional to modern forms of running businesses, leading countries to become more industrialized and to create service-based economies. Above all, new technologies allow for declines of asymmetries, and by eliminating market failure, they better engage in the labour market, increase job creation, foster national competition among producers, and create a friendly environment for "going abroad" and starting to trade internationally. All these behaviors rely on national policies that should be

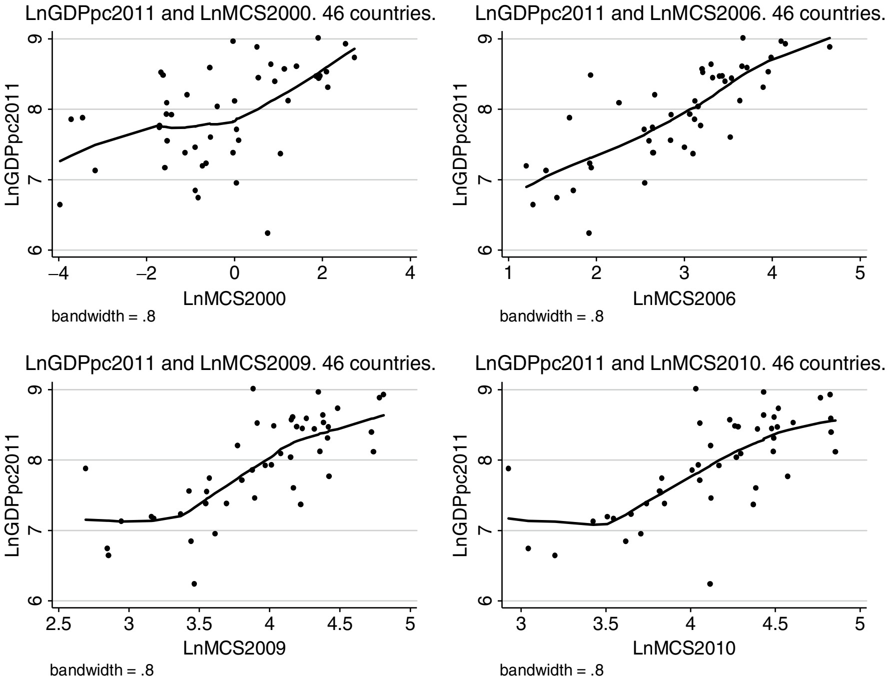

Fig. 2.4 Relationships among MCS adoptions for 46 countries in 2000, 2006, 2009, and 2010, and GDP PPP per capita in 2011

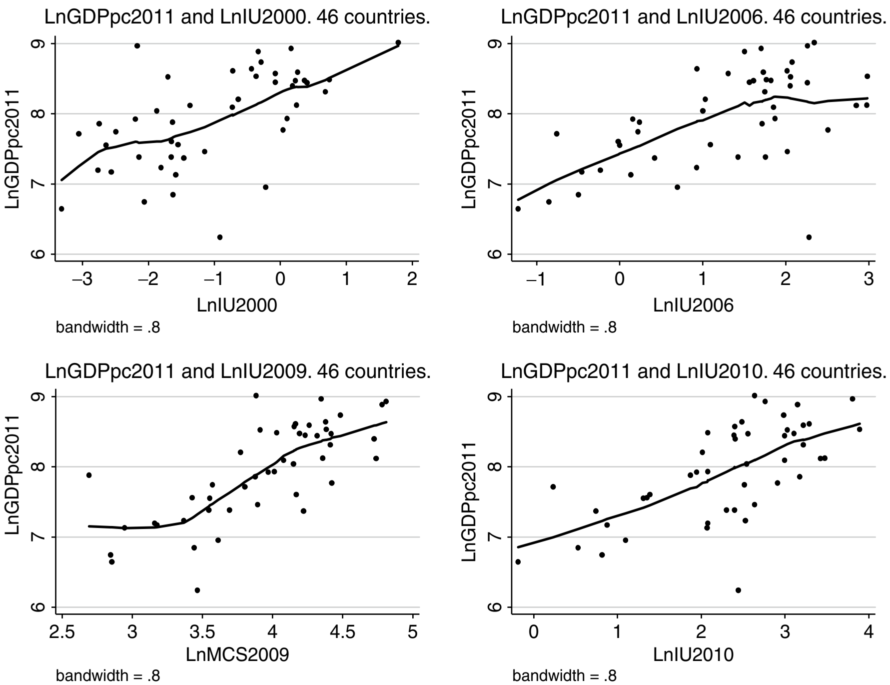

Fig. 2.5 Relationships among IUs for 46 countries in 2000, 2006, 2009, and 2010, and GDP PPP per capita in 2011

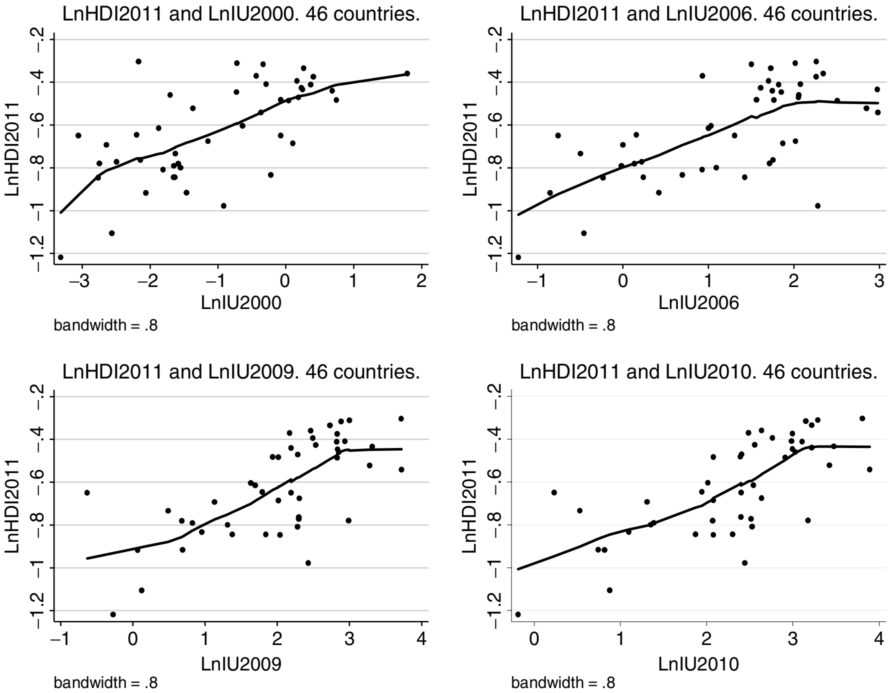

Fig. 2.6 Nonparametric plots showing relationships among IUs for 46 countries in 2000, 2006, 2009, and 2010, and HDI in 2011

designed to be “pro-poor,” providing legal conditions for full and effective use of the new technologies.

An individual country’s development strategy can both aid and hinder their entering a path of sustainable development which might have been initiated by the adoption of ICTs. However, we suppose that the evidence may not be robust. Final results are probably highly sensitive for exclusion or inclusion of outliers. The time horizon and number of countries included in the sample are also of crucial importance. The analyzed period 2000–2011 is unique from a historical perspective. In those 12 years, the rates of ICT adoption were extraordinarily high, and such dynamic changes were definitely unprecedented. That is why, taking into account the complexity of structural changes in national economies, we are not fully convinced about drawing rigid conclusions about long-term macroeconomic regularities in the growth and development conditioned by diffusion of ICTs. The existence of dynamic links between technological progress, and growth and development, surely cannot be neglected; however, we claim that these links are rather two-way, instead of going in one fixed direction.

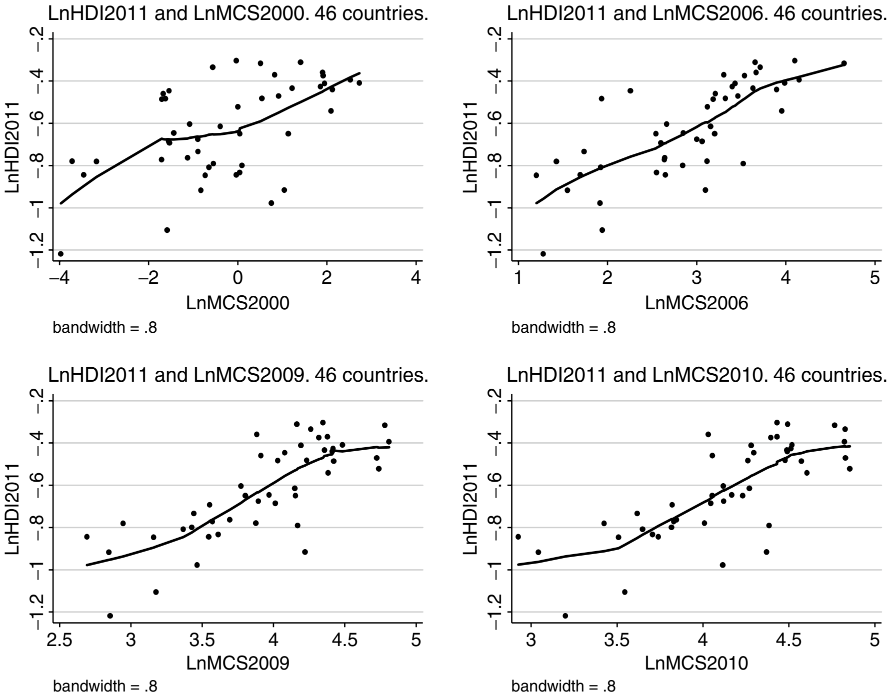

Fig. 2.7 Nonparametric plots showing relationships among MCS adoptions for 46 countries in 2000, 2006, 2009, and 2010, and HDI in 2011

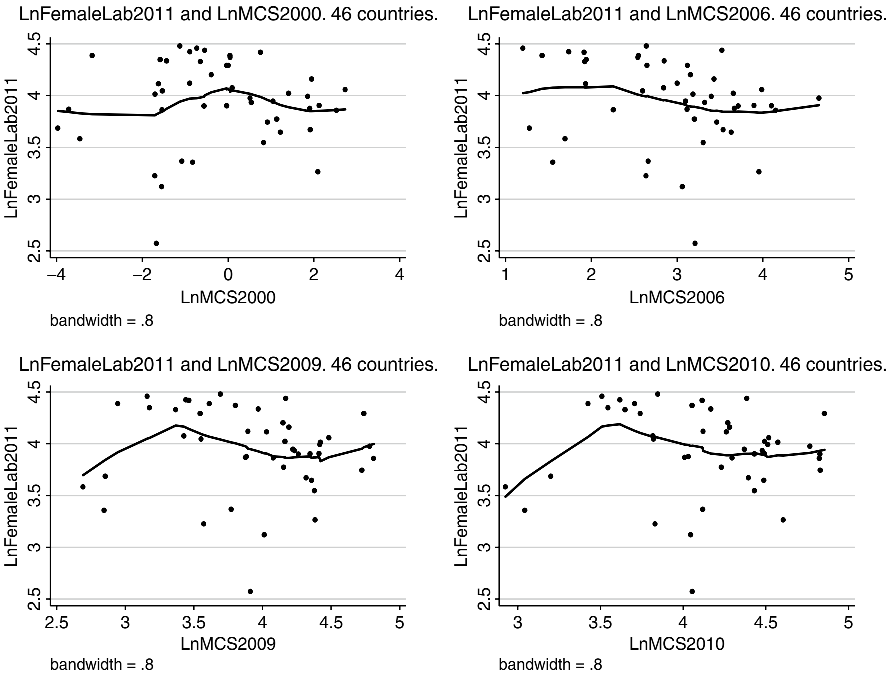

Fig. 2.8 Nonparametric plots showing relationships among MCS adoptions for 46 countries in 2000, 2006, 2009, and 2010, and FLP in 2011

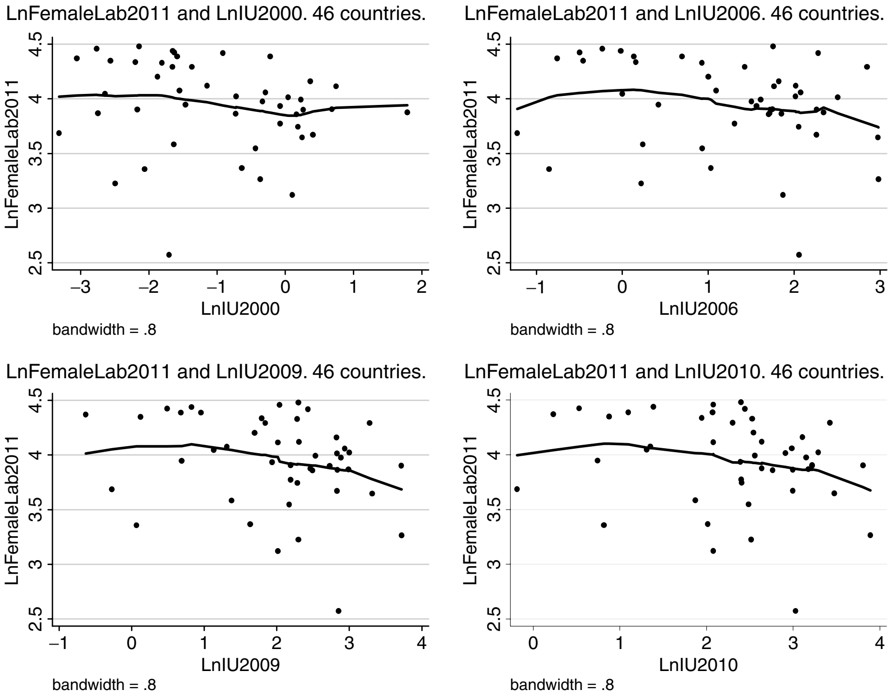

Fig. 2.9 Nonparametric plots showing relationships among IUs for 46 countries in 2000, 2006, 2009, and 2010 and FLP in 2011

2.7 Conclusions

In the unique period 2000–2011, an unprecedented dynamic of diffusion of new ICTs took place in each of the countries we studied. For many of them, we discovered that the ICT diffusion path could be approximated by a complete S-shaped trajectory. For the variable $IU_{i,y}$, it is reported that most countries are located in the early phases of the diffusion process; however, the estimated average annual growth rates are high. Additionally, we have identified the quantitative links between levels of ICT adoption and economic growth, and between economic development and female labour participation.

It is important to keep in mind that the real impact of ICTs on the performance of a country's economy can only be seen with a long-term perspective. Their direct impact is limited and hardly quantifiable, and the visible impact of ICT on developing countries can only be confirmed when it is converted into human development.

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