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Interrogating the Impact of ICT Infrastructure Expansion in Francophone West Africa 1993-2005:

A Critical Theory Study using Archival Data and Non-Parametric Research Methods

A
Doctoral Thesis

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To
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By

Felix Afri Bollou
(D.E.S.S., Ing.)

For

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Ph.D. Research Supervisors

Professor Michael Hart

Department of Information Systems
Faculty of Commerce
University of Cape Town

Professor Ojelanki Ngwenyama

Institute for Innovation and Technology Management
Ted Rogers School of Management
Ryerson University, Toronto, Canada

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Declaration

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University of Cape Town
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PhD Thesis Title:

Interrogating the Impact of ICT Infrastructure Expansion in Francophone West Africa 1993-2005: A Critical Theory Study using Archival Data and Non-Parametric Research Methods

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"To GOD be the Glory"

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Dedication

I dedicate this thesis to my father Francois Bollou, who passed away on September 9, 2007.

University of Cape Town

Peer-Reviewed Research Output

Please note that this Doctoral Thesis is not submitted as a collection of the papers below – the page merely lists past research outputs for reference purposes.

O. Ngwenyama, F. Andoh-Baidoo, **F. Bollou**, and O. Morawczynski "Is There A Relationship Between ICT, Health, Education And Development? An Empirical Analysis of five West African Countries from 1997-2003", *Electronic Journal of Information Systems in Developing Countries*, Vol. 23, No. 5, pp. 1-11, 2006.

F. Bollou, "ICT Infrastructure Expansion in Sub-Saharan Africa: An analysis of Six West African Countries from 1995-2002" *Electronic Journal of Information Systems in Developing Countries*, Vol. 26, No. 5, pp. 1-16, 2006

F. Bollou, O. Ngwenyama and O. Morawczynski, "The Impact on Investments in ICT, Health and Education on Development: A DEA analysis of five African Countries from 1993-1999" *Proceedings of the European Conference on Information Systems*, Gothenburg, Sweden, June 11-15, 2006

F. Bollou and O. Ngwenyama "Are ICT investments paying-off in Africa: An analysis Total Factor Productivity of the ICT Sectors of Six West African Countries from 1995-2002" *Journal of Information Technology for Development*, Vol. 14, No 3, 2008

A. Odinma, S. Butakov, E. Grakov and **F. Bollou**, "Planning, Designing and implementing Enterprise Network in a Developing Nation" *International Journal of Enterprise Network Management*, Vol. 2, No. 3, 2008, pp. 301-317

M. Fonkam and **F. Bollou**, "Integration of the Algorithmic & OO Approaches in the Curriculum" *Proceedings of the WorldComp08 Conference*, Las Vegas July 13 – 17 2008.

F. Bollou, S. Tesunbi, and A. Nwokoma, "Impact of ICT on economic freedom: A tobit regression on ICT in Six West African Countries" *Proceedings of SIG GlobDev Workshop, ICIS 2008 Conference in Paris France* December 13-17.

F. Bollou, "Underutilization of Computing power in SSA countries, Is Grid computing a solution for African countries? *Proceedings of the ICT-Africa International Conference Yaoundé Cameroon 2008* (19-21 December 2008 in Cameroon)

F. Bollou, and N. Japari "Introducing SE and CS students to Design rather than Automation" (*Proceedings of the WorldComp09 Conference*, Las Vegas July 13 – 17 2009.

Abstract

This thesis critically investigates the impact of Information and Communication Technology (ICT) infrastructure expansion on Development in Six West African Countries. The problem studied here falls into the general class of problems commonly referred to as the IT productivity paradox. As Robert Solow (1987) once noted, 'You can see the computer age everywhere but in the productivity statistics.' While recent research has shown that ICT has contributed significantly to economic and social transformation in Western developed countries, the same is not necessarily true for less developed countries. After over a decade of heavy investment in ICT infrastructure expansion in Africa, little empirical research on the contribution of ICT to development has been conducted to assess the impact of these investments on the development of these countries. This work is a ground-breaking effort to advance a much needed research program to measure the impact of ICT infrastructure expansion on development in Africa. This research makes a contribution to information systems research methodology and to answering the specific research question. The research also offers a framework and novel approach to using multiple non-parametric methods and archival data to unravel the puzzle of the contribution of ICT to Development. In this research, I set out to answer the following primary research question: "Has ICT infrastructure expansion contributed to economic and social development in Africa?" In order to interrogate and try to answer this question, I use a three-stage strategy: at stage one of the research, I focus on examining the efficiency of ICT infrastructure expansion and sector performance. Following that, stage two involves an investigation of the productivity of the investments in ICT. And finally I examine the impact of investments in ICT on development from different perspectives. Four of the key findings of the research are: (a) although technical efficiency of some ICT infrastructure expansion was observed in some countries in some years, the efficiency is not sustained over time and regular. In addition to that the diffusion of the technology and its utilization are limited by the lack of other civil infrastructure and incentives. (b) There are strong complex complementarities between investments in ICT, health, and education. This finding implies that policy making in one area would impact other sectors. (c) There is no scale efficiency and learning accumulation in the ICT sectors of the countries studied in this thesis. (d) There is no evidence of an impact of the investments in ICT on development in the six West African countries, as measured by the HDI and the different components of this index, namely Income, Education and Health. More in-depth investigation would be useful on this aspect of the research findings.

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Acronyms

ATU	African Telecommunications Union
BF	Basis Function
BCC	Banker, Charnes, and Cooper
CRS	Constant Returns to Scale
CCR	Charnes, Cooper and Rhodes
CST	Critical Social Theory
DRTS	Decreasing Returns to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EC	Efficiency Change
EMS	Efficiency Measurement System
HDI	Human Development Index
ITU	International Telecommunication Union
ICT	Information and Communication Technology
ICT-I	Information and Communication Technology Infrastructure
ICT4D	Information and Communication Technology for Development
ICT4D	Information Technology for Development
IMF	International Monetary Fund
IRTS	Increasing Returns to Scale
OLS	Ordinary Least Squares
LDCs	Least developed countries
LP	Linear programming
MDG	Millennium development goals
MFP	Multi factor productivity
MARS	Multivariate Adaptive Regression Splines
MPI	Malmquist Productivity Index
NIRS	Non-Increasing Returns to Scale
MPSS	Most Productive Scale Size
SFA	Stochastic Frontier Analysis
SSA	Sub-Saharan Africa
SE	Scale Efficiency
TE	Technical Efficiency
TFP	Total factor productivity
UNDP	United Nations Development Program
VRS	Variable Returns to Scale
WDI	World Development Index
WSIS	World Society for Information Systems

Chapter 1: Introduction and Motivation

1.0 Introduction

At the World Summit of Information and Communication Society in Arusha, Tanzania, Nelson Mandela declared that the expectation for the African continent to have a telephone for everyone by the end of this millennium would not be met. (Mandela, 1995). This was not a pessimistic observation; rather it was a wake-up call to the entire technology community that things were not going as well as expected. In an era when information and communication technologies (ICTs) are changing the landscape of the business, government and social life in developed countries, African countries seem to be losing ground. The digital divide is deepening in spite of all the efforts by international agencies and local governments. Unlike the industrial revolution, ICT has been made available to all countries in the world rather quickly, but it has not yielded the same benefits everywhere. In the developed countries, ICT is now an engine for improvement in many sectors. Research by Dewan and Kraemer (2000) showed that for the period 1985-1993 developed countries saw returns from ICT capital investments that are positive and statistically significant. Pohjola (2000) found that ICT played a significant role in macroeconomic growth in 39 developed countries during 1980-1995.

The situation in the least developed countries (LDCs), especially in Africa, is quite different from that of the developed countries. Even though there has been heavy emphasis on ICT expansion in African countries, the impact of investments on their development is largely under-researched. After more than two decades of heavy investments there is no empirical research that demonstrates significant contributions of ICT to development in Africa (Akpan, 2000; Avgerou, 1998; Mwesige, 2004). Recently the United Nations Development Programme (UNDP) declared that there is a need for more research before one can state whether ICT has contributed to development in Africa or not (UNDP, 2004 and 2006). However, some development partners still believe in the potential of ICT (Braga, Kenny, Qiang, Crisafulli, Di Martino, Eskinazi, Schware & Kerr-Smith, 2000; Sein & Harindranath, 2004). The World Summit on the Information Society (WSIS), International Telecommunications Union (ITU) and other

United Nations agencies are pushing African countries to continue investing in ICT infrastructure expansion. ICT expansion is perceived as an opportunity to alleviate poverty.

This research examines the impact of ICT infrastructure expansion on development in six countries in Francophone West Africa over a thirteen-year period, 1993 to 2005. The six countries selected are Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Mali and Senegal. The reason for selecting these countries is that they share a common colonial past and although data on them were difficult to locate in totality, adequate data were available to allow scientific research. The central focus of the thesis research is the interrogation of the Information and Communication Technology for Development (ICT4D) hypothesis which holds that heavy investment in ICT infrastructure expansion will bring social and economic development to Africa as it is believed to have done in Asia. At this point it is important to clarify that my investigation will be narrowed to the investigation of the Information and Communication Technology Infrastructure expansion; which will be designated by the acronym ICT-I in the text. This precision is provided in order to avoid some confusion with the functional definitions of ICT. A general question that is of concern to African policy makers who have embraced the ICT4D hypothesis for almost two decades is: What has been the impact of investments in the ICT sectors and on development of the West African countries studied in the present thesis? This question has been the subject of debate among African policy makers and development specialists for some time, without any clear resolution. The stakes are high - as technological change gathers more speed in the 21st century, there is concern that more research is needed to understand the development potential and challenges that African nations are facing. This research intends to contribute to the debate and understanding of some of the core issues around the ICT4D hypothesis.

1.1 Motivation for the Research

Since the early 1990s, information and communication technology (ICT) has been promoted as an engine of growth that would significantly transform the economic, political, cultural and social conditions of many developing nation states (Färe, Grosskopf, Norris, & Zhang, 1994; Jalavaa & Pohjola, 2002; Deliktas & Kok, 2003). The central argument of the ICT4D hypothesis is that ICT

infrastructure expansion will lead to social and economic development in Africa and other LDCs. True believers in the ICT4D hypothesis encourage heavy investment in ICT infrastructure expansion and praise its potential for increasing the productive capacity of developing nations by creating new work opportunities for their citizens. The 2003 World Summit on the Information Society (WSIS) adopted a declaration of principles in which member states affirmed their commitment to aggressive investment in ICT for social and economic development. The stated goal of WSIS is the creation of an 'Information Society, where everyone can create, access, utilize and share information and knowledge, enabling individuals, communities and people to achieve their full potential in promoting their sustainable development and improving their quality of life' (WSIS, 2004, page 1). It has been argued that the information which these ICTs bring to the residents of developing nations has the capacity to generate new knowledge and bring about unprecedented potential for improvement (Crafts, 2003; Chen & Zhu, 2004). The WSIS plan makes access to technology its main initiative with hopes of reaching half of the world's population by 2015 (WSIS, 2004). Their ambitious program requires that the governments of developing countries funnel significant financial and human resources into ICT infrastructure expansion. International institutions such as the United Nations (UN), World Bank, International Monetary Fund (IMF), and the International Telecommunication Union (ITU), have been pushing governments of developing countries to formulate technology policies and stimulate the development of telecommunications infrastructure. The UN reported that at the end of 2003, more than 90 countries had adopted the strategies (UNDP, 2004). But how appropriate is this course of action from the point of view of the needs of people living in developing countries?

While there is some empirical evidence to suggest that ICT-I expansion can have a dramatic impact on the achievement of social and economical development goals, there are many voices in the international community claiming that governments of developing nations need to divert their focus away from ICT-I initiatives and use their limited financial resources for the development of education and health programs (Sunden & Wicander, 2003). They argue that developing nations need good schools, basic health care, clean water and not telecommunications infrastructure. In spite of these warnings, African countries continue the pursuit of highly expensive ICT infrastructure building

programs. Many initiatives are taking place across the African continent. From acquiring fiber optical cable to building high-tech parks, adopting sophisticated wireless systems to embarking on 3G technologies, African countries are not willing to miss this revolution. A highly ambitious project of this type took place recently with the Nigerian government's telecommunication satellite project. After the successful launch of the satellite by China on May 14 2007, instead of the expected satisfactory comments and encouragements, many critics suggested that the investment of over USD 311 million was clearly a waste in a country where 'the majority of the population live in poverty and the internet can be made redundant by the simple fact that electricity is sporadic at best' (BBC, 2007, page 1). More severe criticism called the whole project 'mismanagement of Nigerian resources' (SciDev.net, 2008, page 1). They argue that since Nigeria had already failed in the utilization of its first satellite which was meant to prevent major disasters in the airline and oil industries, this new telecommunication satellite will also serve no purpose. Solomon Adeniran, Director General of the National Space Research and Development agency, the Nigerian national unit that manages the satellite, expressed skepticism about the quality of the equipment, staff and management of the project (SciDev.net, 2008).

This kind of situation could be avoided if such an important project was supported by research and scientific evidence that could justify and defend the need for this big investment. Clearly, research is needed to provide guidance, reference points and frameworks to African governments in making crucial decisions with regard to their ICT sector. Nevertheless, the situation is not totally hopeless: organizations such as the United Nations remain optimistic about the potential of ICTs. They believe that ICTs are a tool and conduit for adequate development and are encouraging governments of developing nations to formulate national strategies which focus on ICT deployment. The UN's ultimate goal is for these poor countries to establish a dynamic information society which underlies Nelson Mandela's vision about bringing universal access to every village in Africa (Gilhooly & Ocampo, 2005). Some studies have found a positive correlation between investment in ICTs and economic growth in developed nations (Kenny, 1995; Kenny, 2000; Jalavaa & Pohjola, 2002; Molina, 2003). For example, Jalavaa and Pohjola (2002) studied the relationship between ICT diffusion and Gross Domestic

Product (GDP) growth rates in the US (in the 1990s) and concluded that when ICT diffusion was prominent GDP increased (as much as 4.5% at the end of the decade). Following are some examples of the effects of ICTs on development in developing countries. In Nepal, primary school enrollment rose by 5.7% after teachers enrolled in radio-based distance education courses (ITU, 2003a). In Bangladesh, the installation of telephones in rural areas increased the residents' income by 25% over 5 years (ITU, 2003b). In St. Lucia, there was a 143% surge in the use of condoms after a wide broadcast on all digital media warned about the dangers of HIV/AIDS (ITU, 2003b). However, as we move forward into the present century what can be expected from these investments in ICT? The challenges faced by African nations are enormous. The AIDS pandemic, the recurring malaria epidemic, drought, and food shortages among others require attention and investment. The fundamental question for ICT policy makers in Africa is: Should they continue to invest in ICT at current rates, increasing rates or decreasing rates?

1.2 What Exactly is Development?

Many definitions of development can be found in the literature. For the sake of clarity and conciseness, it appears important to adopt one definition that helps set the limits of the present research. In his book *Development Economics*, Raj (1998) provides a simple definition that will be used in this study. The author defines the notion of development as the actions that would move the majority of the people from their current conditions considered *unacceptable* to other conditions that can be seen as *standard* in developing countries. The author clearly states:

'We all have intuitive notions of *development*. When we speak of a developed society, we picture in our minds a society in which people are well fed and well clothed, possess access to a variety of commodities, have the luxury of some leisure and entertainment, and live in a healthy environment. We think of a society free of violent discrimination, with tolerable levels of equality, where the sick receive proper medical care and people do not have to sleep on the sidewalks. In short, most of us would insist that a *minimal* requirement for a *developed* nation is that physical quality of life be high, and be so

uniformly, rather than being restricted to an incongruously affluent minority.' (Raj, 1998, page 8).

Further, the author acknowledges that this view of development emphasizes more the possession of material goods in which high income plays a fundamental role in achieving these goals, but this view is limited and too narrow. Recent definitions of development have incorporated more variables and ask that the multidimensionality of the notion be taken into account. In this thesis I am interested in how Information and Communication Technology can help African populations from their *unacceptable* conditions -as some of them are listed in the citation- in which the majority of the populations live to some standard level where the majority of the population will be provided with the *minimal* commodities they need in order to live in new conditions seen as *acceptable*. In order to set the boundaries of my inquiry into the impact of ICT on development, I have adopted a working definition of development that encompasses the dimensions that are used in the definition of the Human Development Index (HDI) introduced in 1990 by the United Nations. This notion is discussed in detail in section 2.1.

1.3 The African Development Context

Since the early 1990s many African nations have consistently ranked close to the bottom of the HDI scale (UNDP 2003, 2004, 2006). In the 2003 Human Development Report the UNDP warned that the world is facing an 'acute development crisis' (UNDP, 2003, page 12) with many African nations suffering severe socio-economical reversals. The HIV/AIDS pandemic is blamed for the decline, as life expectancy rates continue to fall dramatically (UNDP, 2003). Some researchers blamed the decline on the lack of ICT infrastructure and the emergence of the 'digital divide' (Norris, 2000; Molina, 2003; Gilhooly & Ocampo, 2005). This divide is a quantitative gap in access to ICT and most often exists between developed and developing nations (Molina, 2003). Institutions such as the International Telecommunication Union (ITU) argue that ICT infrastructure is a prerequisite for adequate development. Many scholars have suggested that Information and Communication Technologies (ICT) can make significant contributions to social development in Africa (Akpan, 2000; Avgerou, 1998; Braga

et al., 2000; Hillard, 2002; Mwesige, 2004). Some of these scholars have suggested that ICT will bring 'opportunities of the global digital economy' to remote parts and communities of Africa (Mwesige, 2004, page 91). Hillard (2002) has conjectured that ICT will become integral to the promotion and management of sustainability in many African countries. Others such as Braga et al. (2000) have suggested that ICTs will help Africa 'leap frog' the stages of economic development. This opinion of the potential of ICT to impact development, while not universal, is shared by many key international organizations such as the UN and World Bank.

Despite the fact that there is some evidence of the potential of ICT, the criticism has not been silenced. The main concern is that these new technologies will not be enough to lessen the world's most serious problems of poverty, hunger, and alienation (Obijiofor, Inayatullah and Stevenson, 2000). In Africa, three quarters of the population is illiterate and are living in rural areas which lack basic facilities such as electricity (Obijiofor et al., 2000). In these conditions and until the problems of the basic infrastructure is resolved, it is likely that the effective utilization of communication technologies like the internet would be out of the question. The Economist Intelligence Unit (2002) warns that ICT investment may not bring the same returns in the developing world as it has in the developed. Their analysis of 60 countries found that ICT begins to deliver GDP per head growth only after a certain threshold of ICT development has been reached.

1.4 Can ICT Contribute to Development in Africa?

The question of whether ICT infrastructure expansion is a panacea for African development problems is hotly debated but still undecided. Proponents of the ICT4D hypothesis (Werthner & Klein, 1999; Röller & Waverman, 2001; Zaheer & Manrakhan, 2001; Henderson, Dicken, Hess, Coe, & Yeung, 2002; Carayannis & Sagi, 2002; Antonelli, 2003; Gurumurthy, 2003; Kumar, 2005; Kankaanranta, 2005; Huyer, 2005; Aduwa-Ogiegbaen & Iyamu, 2005; Fielding & Torres, 2009) point to two popular arguments to explain how new ICT technologies can contribute to development in Africa: (a) structural

change; and (b) technical efficiency¹ (TE). The 'structural change' argument contends that new technologies, such as ICT, contribute to economic growth by spawning new economic sectors (new types of businesses or industries) in developed countries (Smith, 2001). In recent times the proponents of the ICT4D hypothesis have pointed to the emergence of the e-commerce sector and outsourcing as examples of the power of ICT to spawn new businesses and industries (Smith, 2001). The 'technical efficiency' argument holds that technology can free up labor and capital for use in other parts of the economy and thus increase total factor productivity² of the economy. With regard to technology in general, this is by far the older argument. In current discourse, the 'productivity growth' argument holds that ICT is a type of capital good, and investment in this good will increase real factor productivity (Smith, 2001). Both arguments have been debated on the microeconomic level (Barua, Kriebel & Mukhopadhyay, 1995; Loveman, 1998) and at the macroeconomic level (Landauer, 1995; Molina, 2003; Sunden & Wicander, 2003). But even in developed countries, empirical evidence of productivity increases from the implementation and use of ICT continues to be contradictory. In 1987 the Nobel laureate economist Robert Solow coined the term 'productivity paradox', to describe this contradictory evidence. His famous words were 'the computer age is everywhere but in productivity statistics' (Solow, 1994, page 46). Some recent research has argued that there is no productivity paradox; the researchers point to inadequacies in research approach and methods for the lack of evidence on productivity improvements (Brynjolfsson, 1993; Dedrick, Gurbaxani & Kraemer, 2003). Other researchers blame mis-measurement of input and output data, and the time lag needed for adjustment to new technologies as the cause of the negative correlations between ICT and productivity (Brynjolfsson & Hitt, 2000; Crafts, 2003). However, the debate continues because there are several studies at both the macroeconomic and microeconomic levels, using a variety of analytical methods that have failed to demonstrate any significant productivity gains from investments in ICT (Barua et al., 1995; Loveman, 1998; Landauer, 1995; Molina, 2003; Sunden & Wicander, 2003).

¹ In economics, **Technical Efficiency** is the effectiveness with which a given set of inputs is used to produce an output. If a firm is producing the maximum output it can, given the resources it employs, such as labor and machinery, and the best technology available, it is said to be technically-efficient.

² **Total Factor Productivity** (TFP) is the portion of output not explained by the amount of inputs used in production. As such, its level is determined by how efficiently and intensely the inputs are utilized in production. TFP can also be determined by learning accumulation.

At the macroeconomic level, economists who studied the US economy in the 1980s failed to see any correlation between large scale ICT infrastructure expansion and overall productivity growth (Landauer, 1995; Rauch, 1995). When the US was investing heavily in the development of their ICT infrastructure, productivity growth consistently declined. Landauer (1995) reported that the decrease of labor productivity grew from 0.7% per year for 1953-1968 to 2.5% per year for 1973-1979. Multi-factor productivity growth declined from 1.75% a year to 0.32%. Rauch (1995) studied the productivity of information workers in a variety of industries. He found that from 1970 to 1986 the number of information workers (white collar) had increased while the number of production workers (blue collar) had declined. However, the output per information worker had decreased by 6.6% while the output per production worker had increased by 16.9%. Recent studies using more sophisticated computer-based analytical techniques have started to unravel some of the puzzles of the productivity paradox. Ko and Osei-Bryson (2004a, b) and Osei-Bryson and Ko (2004), using Multivariate Adaptive Regression Splines (MARS) analysis, found that there is a trade-off point beyond which higher investment in ICT will yield no further productivity improvements. Susiluoto (2003), using data envelopment analysis (DEA), was able to identify effects of ICT on economic efficiency in 83 regions in Finland and 81 regions in Sweden. Sung (2004), using DEA and the Malmquist productivity index, was able to show ICT contributions to productivity in 222 local government regions in Korea from 1999 to 2001. Sophisticated methods such as MARS and DEA have proven successful at unraveling a link between ICT and productivity growth.

1.5 Problems of Measuring ICT-I Impact on Development

The difficulty of measuring the impact of ICT infrastructure expansion on development has been acknowledged by many researchers (Lamberton, 2001; Pohjola, 2001). As stated earlier, inadequacy and lack of research methods have sometimes been pointed to as causes of these difficulties (Brynjolfsson, 1993; Dedrick et al., 2003). Others claim that mis-measurement of input and output data, and the time lag needed for adjustment to new technologies are the cause of the negative correlations between ICT-I and productivity (Brynjolfsson & Hitt, 2000; Crafts, 2003; Gholami, Moshiri, & Lee, 2004:). However, advancement in computer-based analytical techniques is assisting in

unraveling some of the puzzles of ICT impact. However, there is little theory developed to guide researchers investigating this problem (Ngwenyama & Morawczynski 2009). To assist with the problem of analyzing the impact of ICT on development the ITU outlined a framework for developing measurement approaches (Figure 1).

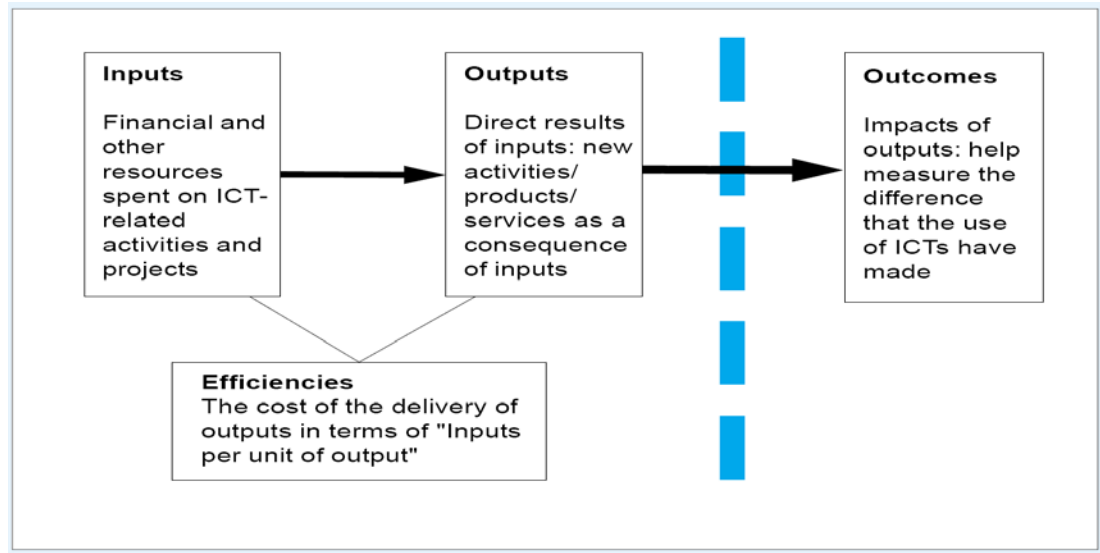


Figure 1: The ITU Framework for Measuring the Impact of ICT on Development (ITU, 2006).

ITU proposes a two phase measuring process: Phase 1 is concerned with the measurement of efficiencies of ICT investments with regard to infrastructure expansion and the cost of providing ICT services; and Phase 2 is concerned with measuring the impact of ICT on specific social indicators. As ITU sees it: 'To understand whether real progress is being made towards the UN Millennium Development Goals (MDGs) with the use of ICTs it is necessary to measure progress at two different levels: (1) at the country level for government policy makers and for comparisons; and (2) at an organizational level for organizations and donors to judge and measure progress' (ITU 2006, page 28). However, the ITU has given no advice on how to operationalize their approach. ITU states simply that 'national governments need to be able to collect the inputs like technology diffusion data and measure their impacts on MDGs' (ITU 2006, page 27). This PhD research shares common interest with ITU in measuring the impact of ICT infrastructure expansion on development in the African context but it differs in some significant ways. First, a core objective of this PhD study is to interrogate the validity claims of the ICT4D hypothesis in the context of developing countries of Francophone West

Africa. Second, this research follows a critical theory approach which is aimed at interrogating the limitations of the ICT4D hypothesis in the context of developing countries of Francophone West Africa. I will outline the critical theory framework, research approach and logic of the inquiry in detail in Chapter 3.

Problem of time lags

In the context of an investment in an economic unit (process, department, business, sector, economy) it takes time to show improvements (due to learning, implementation time, etc); therefore the analyst/researcher needs to figure out what is the time lag between investment and return and build it into the analytical model; this would give a more accurate result from the analysis. The main challenge with analyzing an industry sector (such as ICT) is how to figure out the appropriate lag (should it be 1, 2, 3 or n years). In the case of my research, it is expected that each country (Benin, Cameroon, etc) would have different factors influencing the lag between investment and return. So it is not possible to determine a nominal lag function for a comparative analysis of the countries. Or, to effectively do an ordinary regression model with lags it would require a much larger data set. For example if the lag is deemed to be 2 years I would have to have about 20 years data for a 10 year study, if the lag is 3 years, 30 years data for 10 years study..... Although they don't completely solve the problems with lag effects, I chose the computational methods DEA and MARS because they both provide satisfactory alternative approaches to lagging in ordinary regression analysis.

1.6 Relevance of This Research

This research fills a gap in knowledge concerning the impact of ICT infrastructure expansion in Least Developed Countries (LDCs). While research on ICT in LDCs has been growing, very few attempts have been made to evaluate the impact of ICT expansion on social and economic development. However, many research articles suggest the importance of investing in ICT infrastructure expansion, and many amplify the point of view of the major international organizations that LDCs must heavily invest in ICT infrastructure expansion to achieve higher levels of social and economic development (Avgereou, 1998; Akpan, 2000; Aduwa-Ogiegbaen & Iyamu 2005). Much of the literature comprises wish lists for developing countries. It is not rare to read that African countries should get distance learning, or

developing countries should invest in medical applications of ICT. This discourse, of course, is good, but it does not provide any answer to the fundamental challenges that African (and other LDCs) policy makers face: How to make tough investment decisions on appropriate ICT infrastructure, civil infrastructure, the maintenance and improvement of education systems, or implementation and operation of viable healthcare systems. In the current situation where these countries face decreasing GDP and pandemics such as AIDS, malaria, and tuberculosis, the allocation of limited resources to all the demanding sectors is not an easy task. The need for scientific studies and methods of analysis and policy making would be of great aid to policy makers. Therefore, one of the major objectives in this research is to provide African decision makers not only with answers to the questions, but with methods and techniques to facilitate their decision-making with regard to ICT investments. We believe this research will serve as a reference point for the policy making process. Clearly African policy and telecommunication agencies are the primary target of this research. In addition to that, we believe that researchers, business partners and international organizations interested in the diffusion of the technology in these countries will find valuable information in the findings of this research.

1.7 The Organization of the Thesis

The rest of this thesis will be organized as follows. Chapter 2 provides an overview of the current literature on the topic of ICT expansion and social and economic development. Chapter 3 provides an overview of the philosophy of science which underpins the research and outlines the theoretical framework and the key questions for interrogation. It also lays out the six basic claims of the ICT4D hypothesis which are critically interrogated in this PhD thesis. Chapter 4 provides an overview of the computational methods used in the analysis of the empirical data. Chapters 5, 6 and 7 present findings from the various empirical analyses of the archival data. Chapter 5 presents empirical findings from the analysis of ICT infrastructure expansion efficiency; Chapter 6 presents empirical findings from the analysis of ICT sector revenue performance; and Chapter 7 presents the empirical findings from the analysis of complementarities between investments in ICT, education, and health and their impacts on social and economic development as measured by HDI. Chapter 8 presents a

summary of the findings from the critical analysis of the six basic claims of the ICT4D hypothesis. Finally Chapter 9 presents some remarks, draws conclusions, outlines the contributions of the research and makes suggestions for future work.

University of Cape Town

Chapter 2: Literature Review

2.0 Introduction

Proponents and critics of ICT as an engine for development have been discussing this open question in a debate that has been increasingly topical in the past five years. James George Chacko³ summed up the debate with the following statement during the 2005 World Society for Information Systems (WSIS) summit in Geneva:

'The debate essentially lies in two primary conjectures. On one side, the critics expound on how ICT is not essential in the context of development and is thus dispensable in the fight against world poverty. It is also put forth that a positive relationship between ICT and human development is either weak or absent. The proponents of ICT, however, strongly believe that ICT has the capability to provide developing nations with an unprecedented opportunity to meet vital development goals and thus empower them to 'leapfrog' several stages of their development far more effectively than before. It is argued that those nations that succeed in harnessing the potential of ICT can look forward to greatly expanded economic growth, dramatically improved human welfare, and stronger forms of democratic governance, thus playing a specific role in furthering and enhancing sustainable development. Even the protagonists of ICT for development, however, argue that growth of ICT should not become a "techno-quick-fix" for solving development problems, as these may be unacceptable tradeoffs in less developed countries.' (Chacko, 2005, page 98).

As summarized in the above declaration, the debate surrounding ICT for development is complex and encompasses many determinants and factors that need to be properly taken into account. The complexity resides in the composite nature of development itself; therefore, assessing the impact of ICT on development by focusing on a single variable could be a hazardous undertaking. Consequently, in order to make more meaningful contributions to this debate, most of the literature concerning ICT for development in less developed countries studies the impact of ICT on one specific aspect of development but integrates many variables in the analysis. In the present thesis, I follow the same approach. The literature on the impact of ICT on development is diverse and spans all aspects of

³ James Georges Chacko is the Programme Specialist, UNDP Asia Pacific Development Information Programme.

economic and social development. Many aspects, while raising interesting issues around technology and development, may not be directly relevant to the present thesis and could detract significantly from my main focus. Consequently, in this literature review, for the sake of synthesis and brevity, I regroup the relevant literature into three broad categories that contain many sub-categories. The category 'ICT and Economic Development' regroups all literature related to ICT and economic growth, ICT and productivity growth, ICT and globalization. The second category deals with matters concerning ICT and human capital development and comprises literature pertaining to ICT and education, distance learning, schools, training and all related topics. Finally the last category reports on the literature concerning ICT and social development including ICT in healthcare, ICT and community services, ICT for marginalized groups, ICT and democracy and ICT and digital divide.

Due to the breadth of the literature on ICT and development in the developed countries, and also the growing literature about information and communication technology and development in developing countries on the rise, I have selected a limited number of the most relevant articles related to the three specific categories outlined above. The chapter is organized as follows: first, the literature on development is explored in order to provide a working definition of this notion. The notion of development can be seen from many perspectives and can mean different things to different people in particular circumstances. Since in this research I am investigating the impact of ICT on social and economic development, it is important to clearly state what aspects of development I am concerned with and what the boundaries of this research are according to that definition. Following that, I go through the literature concerning the aspects of interest to ICT and development in general for each of the categories determined and, in each category, I attempt a brief summary of the literature pertaining to Africa specifically. The rest of the chapter is organized as follows: After the section about the definition notion of development, the three subsequent sections report on the literature in this order: a) ICT and human capital development, b) ICT and economic development and c) ICT and social development. The last section regroups all the literature concerning the critics, obstacles and drawbacks of the ICT4D hypothesis. Each section begins with a table summarizing all the literature in that category for reference and traceability.

2.1 Defining Development

The concept of development is multi-faceted and encompasses a wide array of dependent variables. For many years, discussions about development focused on national income and the standard of living of citizens of the country of interest. However, during the late 1980s, the concept was extended to include social factors beyond national income. As the economist David Fielding explains: 'A nation's progress with respect to its material wealth is not independent of its progress in other spheres...economic growth promotes democratic development; education is good for health; and health is good for education' (Fielding, 2002). From this perspective, development is not purely a measure of output (GDP), but involves social measures. GDP and social measures reinforce each other and support the economic success of a nation. Recent research has recognized a strong correlation between economic performance, health, education and political development. And since the late 1980s there has been considerable debate about monitoring other factors of human wellbeing (education, health, political freedom) as aspects of development. An outcome of this and other relevant research is the publication in 1990 of the Human Development Index (UNDP, 1990 - 2004), and subsequent UNDP Human Development Reports published every 2 years since 1990.

The goal of the Human Development Index (HDI) is to assess existing social and economic conditions in all countries. HDI measures three basic aspects of human development: longevity (life expectancy at birth), knowledge (literacy rates and school enrollment ratios) and standard of living (GDP per capita) (UNDP, 1990 - 2004). While there have been arguments about the accuracy of the HDI, this index is the currently accepted approach to conceptualizing and measuring the complex reality of social and economic development (Hicks & Streeten, 1979; Desai, 1991; Sagar & Najam, 1998; Mahlberg & Obersteiner, 2001; Neumayer, 2001). A practical problem with the HDI is that a lack of data causes difficulty in applying it to assess the level of development of many countries. In this research, I use the HDI to contextualize the background conditions of the countries that I am studying. More importantly, I use the various combinations of the components of the index (knowledge, longevity, and standard of living) as targets of some of my models, as I am interested in how various combinations of investments can lead to development.

I will now report what has been written about ICT for development in the three categories that make up development in the sense in which I intend to use it in this study, therefore I will successively report on ICT and Human Capital Development, ICT and Economic Development and finally ICT and Social Development. This does not mean that other aspects that are overlooked in this thesis are not important; they may already be integrated into the HDI in some way or they may be irrelevant for measuring the impact of ICT on development.

2.2 ICT and Human Capital

Literature about ICT and human capital development is dominated by the formal education aspect. Although education is not the only way to develop human capital, it remains the mainstream approach. Nevertheless, many people in developed countries have successfully learned ICT outside the mainstream formal education and this trend is being followed in developing countries now. This means that even people without the formal education background provided by the school system can become ICT literate.

I have grouped the literature of interest regarding ICT and human capital development into four broad categories. The first category is composed of studies that focus on human capital development through the traditional education system. The second category is concerned with literature that focuses on the technology transfer aspect of human capital development. The third category lists literature that studies strategies of adoption of the technology and the way this can help develop human capital. The last category reports studies that focus on research and development and national government involvement in the advancement of the technology. Table 2-1 below summarizes the literature on ICT and human capital.

TABLE 2-1. ICT and Human Capital: Associated Studies and Area(s) of Focus

Topics	Studies	Focus of studies
Human capital development through education and school development	Kankaanranta (2005); Aduwa-Ogiegbaen & Iyamu (2005); Tamura (2002); Noorbakhsh et al. (2001).	Learning enhancement; distance learning facilitation; importance of human capital and foreign direct investments (FDI) in education; creation of new education channels.
Human capital development through technology transfer and local labour training	Xu (2000); Kankaanranta (2005); Papageorgiou (2002); Mayer (2000).	Human capital development through technology transfer, technology adoption and correct acquisition of the technical know-how for local labour.
National education and technology acquisition strategies	Rodríguez-Clare (2001); Noorbakhsh et al. (2001); Papageorgiou (2002); Tamura (2002); Xu (2000).	Adequate strategies for the adoption of the new technologies and fulfilment of prerequisites such as high levels of literacy and political stability. Awareness of complementarities between ICT and other economic sectors.
Knowledge-based societies and research and development	Awang (2004); Vinding (2000).	Knowledge economies require human capital. Focus is on government involvement in education and research and development.

In addition to the supporters of the ICT infrastructure expansion who claim its potential to spur economic development, some researchers have also argued that the impact of ICTs extends well beyond the economic domain, having positive spillover effects on numerous dimensions of social life. For example, these technologies have been harnessed to enhance learning (Kankaanranta, 2005; Aduwa-Ogiegbaen & Iyamu, 2005). In their articles, these authors show how the development of ICT infrastructure creates new channels for education to reach the less privileged in developing

countries. But in the area of ICT and human capital, most research highlights the importance of human capital as a prerequisite to successful technology adoption (Xu, 2000; Mayer, 2000; Rodríguez-Clare, 2001; Noorbakhsh, Paloni, & Youssef, 2001; Papageorgou, 2002). One of the best examples of human capital development is that of Costa Rica. With a very serious and sustained national strategy focused on education and technology-led development, Costa Rica has become the number one Latin American software-producing country (Rodríguez-Clare, 2001). The author acknowledges that a very strong education system, along with political stability and democracy, prompted the multinational and foreign investment companies to believe in the potential of Costa Rica and to begin their collaboration.

Similarly, Noorbakhsh et al. (2001) show that human capital is the most important factor for attracting international investment. In their paper, the authors emphasize the importance of human capital development for any developing country. Furthermore, the authors studied the determinants of the foreign direct investments (FDI) and demonstrated that human capital is the most important factor for FDI distribution in developing countries. After analyzing the investments of the USA multinational companies in 40 of the least developed countries (LDCs), Xu (2000) affirmed that LDCs do not benefit from technology transfer as much as their developed country counterparts. The author concludes that a country needs a minimum level of human capital before it can effectively take advantage of technology transfer.

Papageorgou (2002) demonstrated the importance of human capital, in the form of “continuous knowledge” as the main determinant of rapid growth for developing countries in their adoption of technology. In the same vein, Mayer (2000) suggests that developing countries should concentrate on increasing the skill level of their local labour force. The author suggests that the increase in human capital along with the import of technology will raise the benefits of globalization. Tamura (2002) introduces a model to demonstrate how human capital helped in the transition from agriculture to industry in an empirical analysis of firms in the UK. In his model, the author uses human capital as a variable of total factor productivity (TFP). It is also well established that governments have an essential role to play in the development of human capital. For example, Awang (2004) demonstrates

how Malaysia became an ICT-driven and knowledge-based society with important and rising government spending in schools, research and development and training. Vinding (2000) points out that collaboration between internal research and human resource management and the acquisition of knowledge from external partners is essential for human capital development. The author concludes that the increase of internal capacity is the way to assimilate and absorb knowledge provided by increasing external knowledge.

2.2.1 ICT and Human Capital in Africa

With the exception of a few reports concerning developing countries such as Costa Rica and Malaysia, most of the literature reported above studied ICT and human capital in developed countries. The few articles that concern ICT and Africa express pessimism on the success of the adoption of the technology. Very often it is suggested that the adoption of the technology is not benefiting African countries largely due to the lack of human capital (Xu, 2000; Mayer, 2000). Consequently, what is reported in the literature about ICT and Africa are wish lists of things that African countries ought to do in order to enhance the benefits of the use of ICT in this area. Nonetheless, there are no clear guidelines as to how many engineers need to be educated annually, how many schools need to be built or what specialties are needed in the context of the African countries. These are the guidelines that can help policy makers.

2.3 ICT and Economic Development

More overwhelming is the literature that praises the capacity of ICT to increase national income, spur economic development and reduce poverty. Proponents of the ICT4D hypothesis perceive ICT as the new engine for development. In this regard, there is increasing literature reporting positive effects of ICT implementation throughout the world. Although most success stories come from the western developed world, there are a few reports of positive impact of ICT implementation in the developing world too. These reports focus in general on the following key aspects reported in the table below: ICT

as an accelerator of economic development, ICT and productivity growth, ICT and its effects on globalization, ICT and new business enabler is also reported in this section.

Table 2-2 ICT and Economic Development studies and Area(s) of focus

Topics	Studies	Focus of studies
ICT and acceleration of economic development	Cronin et al. (1993); Dholakia & Harlam (1994); Jukka & Pohjola (2002); Madon (2005); Pohjola (2001); Röller & Waverman (2001); Colecchia & Schreyer (2002); Piatkowski (2003); Oliner & Sichel (2002).	Evidence of ICT and economic development. The adoption of ICT spurs GDP growth, accelerates economic development and contributes to the growth of the national economy.
ICT and productivity growth	Dulton (2004); Mahomy & Vecchi (2003); Van Ark et. al. (2002); Pohjola (2001); Piatkowski (2003); Jalava & Pohjola (2007); Martinez, Rodriguez & Torres (2008).	Use of ICT can free up labor that can be used elsewhere. In addition, enhancement of business processes and automation have positive impact on productivity
ICT and positive effects on globalization	Akpan (2003); Piatkowski (2004); Darley (2003).	ICT permits the notion of globalization. Business can be done everywhere in the world. Physical barriers materialized by frontiers and distances are overcome by ICT.
Enabler of new business opportunities	Darley (2003); Overa (2006); Akpan (2003); Limam & Miller (2004); Mbarika & Mbarika (2006).	ICT is viewed as the engine for new businesses and the new economic sector for the future – especially in the area of mobile phones, direct and indirect job creation.

Many researchers argue that the development of information and communication technology (ICT) infrastructure is vital to drive rapid development of less developed countries (Cronin, Parker, Colleran, & Gold, 1993; Dholakia & Harlam, 1994; Pohjola, 2001; Röller & Waverman, 2001) Jukka & Pohjola, 2002; Madon, 2005). It is further believed that investments in ICT can visibly make possible macro-economic growth in developing countries (OECD, 2005), by contributing to an increase in GDP and labor productivity rates (Piatkowski, 2003; Jalava & Pohjola, 2007). These beliefs are based on studies that have shown that ICT had positive impacts on the US economy and a number of European countries' economies as well (Colecchia & Schreyer, 2002; Oliner & Sichel, 2002; Stiroh, 2002; van Ark, Melka, Mulder, Timmer & Ypma, 2002; Daveri, 2002; Jalava & Pohjola, 2002).

The successful impact of ICT infrastructure on development and economic growth has been regularly reported in the literature but much of the literature is largely devoted to developed countries. For example, studying nine Organization for Economic Cooperation and Development (OECD) countries over 2 decades, Colecchia and Schreyer were able to conclude from their empirical evidence that investments in ICT had contributed between 0.2 and 0.5 percentage points per year to economic growth depending on the countries. The countries studied included the United Kingdom, USA, Australia, France, Italy, the Netherlands, Finland, Germany, Japan and Canada. Likewise, the Commission of the European Communities (2001) reported that, during the second half of the 1990s, apart from the United States, some European Union (EU) member countries (particularly Ireland, the Netherlands, and Finland) plus other OECD countries such as the United States of America, Australia and Canada, have recorded stimulation of economic growth and of productivity. Furthermore, the studies affirm that their unemployment and inflation rates have been stable or falling after massive deployment of ICT. More recently, Piatkowski (2003) analyzed empirical data of ICT investments in Poland between 1995 and 2000. The empirical findings of the study show that about 8.9% of the GDP growth is attributed to the contribution of the investments in ICT. Moreover, the findings show that ICT also induced an increase of 12.7% of the labour productivity between 1995 and 2000. ICT's contribution to GDP growth and labour productivity is clearly demonstrated by a study conducted by Jalava and Pohjola (2007), on the ICT industry in Finland. The authors showed evidence of substantial GDP growth

and significant labour productivity in Finland attributed to the tremendous development of the telecommunication sector.

There is also the belief that globalization is going to be beneficial to developing countries. Although this claim is still premature and not fully supported, there are conjectures that developing countries will be admitted into the global world economy through ICT. The main argument of the proponents of this thesis is that globalization will enlarge and diversify the business environment of all countries. For example, Akpan (2003) questions the importance of ICT in the globalization movement. In her paper investigating the basic needs for globalization, the author analyses the relationship between ICT and globalization in the context of developing countries. The paper concludes that globalization is important for development but LDCs should find their own ways to move towards globalization without abandoning the daunting problems of basic developmental needs. The paper further suggests that ICT, if not properly managed, will concentrate in the hands of the well-off, hence creating a greater divide and increased poverty.

Another argument put forward by supporters of the ICT4D hypothesis is that the ICT sector is a new contributor to the national economy which provides the opportunity for new businesses creation (Darley, 2003; Mbarika & Mbarika, 2006). These researchers view the adoption of ICT in the developing world from a business opportunity perspective. For example, Darley (2003), exploring the internet environment of sub-Saharan African countries, claims that the internet is a good enabler for new business. He claims that the use of the internet will establish closer links with customers and open these countries to the global market. The author further suggests that in this era of internet dominance, it is necessary to link business and government. Similarly, in a study of African countries, Mbarika and Mbarika (2006) found out that the boom of mobile phones is creating a viable and vibrant business environment in African countries. The authors remarked that the direct or indirect job creation linked to the development of mobile phones constitutes a structural change in the job market in these African countries. ICT is also perceived as a support for business that enhances the service

and offers alternatives to the traditional business environment. In her study of the impact of cellular phones on the trade business, Overa (2006) posits that the adoption of ICT has enhanced trust building in the trade and reduced the cost of communication and transportation hence creating higher profit potential. Most of the research conducted in developed countries demonstrates that there is sustained total factor productivity (TFP) growth in the ICT sector and that the growth of the sector is positively impacting the growth of economies in North America and Europe. For example, Oulton's (2004) work on ICT and productivity growth in England reveals that the growth of ICT output has contributed about a fifth of GDP growth from 1989 to 1998. Others such as Mahomy and Vecchi (2003) demonstrate that there is a positive impact of the investments in ICT on TFP in the US and the UK. Limam and Miller (2004) performed a comprehensive study on TFP measures for the Hong Kong telephone company. Their findings show that TFP growth changed substantially under different regulatory regimes and revealed that the importance of the scale effect diminished relative to technological change.

2.3.1 ICT and Economic Development in Africa

Apart from a few isolated ICT success stories – and most of them reporting on the good standing of the ICT sector in South Africa – it is rare to find literature reporting economic growth of African countries due to the adoption of the technology. Although there are conjectures that African countries will benefit from globalization (Akpan, 2000; Darley, 2003), the only domain that is believed to be advancing the economies of African countries is the introduction of mobile telephony. Real or imagined, gains in the mobile phones industry in Africa has been largely echoed by research in recent years (Mbarika & Mbarika, 2006). The current dynamism of the mobile phone business is perceived as the sector reviving African economies. But in the absence of substantive empirical evidence for these claims, the interpretations of the findings are rather controversial.

2.4 ICT and Social Development

This can be considered one of the areas where the proponents of the ICT4D hypothesis have produced the most conjectures. There are a large number of research articles that see the potential of ICT in the domain of health and other social advancements such as the reduction of discrimination against minorities or marginalized groups. Numerous researchers speculate on the immense possibilities the new technology can bring to the developing countries in terms of health care and other social development areas. Some of this literature is summarized in the table below.

Table 2-3 ICT and other social areas studies and Area(s) of focus

Topics	Studies	Focus of the studies
Enabling telemedicine	Von Lubitz & Wickramasinghe, (2006); Branko, Lovell, & Basilakis (2003).	ICT infrastructure development will enable developing countries to experience the benefits of telemedicine.
Empowering marginalized groups	Huyer (2005); Gurumurthy (2003); Jain (2006).	ICT creates spaces for marginalized groups to express themselves. For example, women use this medium to free themselves from oppression.
Promoting good governance and democracy	Meso, Datta, & Mbarika (2005); Fuchs & Horak. (2008); Diaz Andrade & Urquhart. (2009).	Studies in this category conjecture that through the use of ICT, some of the endemic problems are going to find a solution. For example, use of ICT can lead to the promotion of democracy, reduce the digital divide and reinforce social networks.

2.4.1 ICT and other Social Benefits

A growing number of researchers argue that some of the most important spillover effects of the implantation and expansion of ICT infrastructure is the improvement of healthcare (Von Lubitz & Wickramasinghe, 2006; Branko, Lovell, & Basilakis, 2003), the empowerment of marginalized women (Huyer, 2005; Gurumurthy, 2003), the promotion of indigenous knowledge (Jain, 2006), and the maintenance of good governance (Meso, Datta, & Mbarika, 2005; Fuchs & Horak, 2008). The reduction of the digital divide is another solution to the social problem related to access to ICT that has been identified as one of the major drawbacks of the developing countries. But it is believed that, if not properly handled, the adoption of the new technology will increase the divide in the developing countries rather than reducing it. For example, Fuchs and Horak (2008) propose six strategies to overcome the digital divide and suggest that a redistribution of the resources of the countries is a precondition for reducing the divide. Further, the authors suggest that the digital divide is not only the lack of access to computers but is part of other social and economic divides; hence the solution to closing it begins by closing the other social divides of which it is a part.

ICT is also viewed as an enabler of social networks. The use of email and social networks has proven efficient in connecting people around the world every day. These technologies, together with the explosion of the use of mobile phones, are considered new instruments of human network enablement. ICT has facilitated the networking of people in many ways, and social network applications that have sprouted on the web are among the most used applications today. Research by Díaz Andrade and Urquhart (2009) of two villages in rural Peru shows how the use of mobile phones has created a sense of connection among communities.

2.5 Critiques of the ICT4D Hypothesis

But dissenting voices have been heard recently in research with regard to the ICT4D hypothesis. A number of researchers have started critiquing the different claims that make the ICT4D hypothesis. These critiques usually challenge the ICT4D hypothesis on the basis that it is an incomplete argument that does not address the key issues that are holding back the less developed countries such as lack of basic infrastructure, illiteracy and cultural barriers. Most of the critiques consider the hypothesis as mere conjectures not properly supported by evidence from the developing world (Mbarika, Okoli, Byrd, & Datta, 2005; Bollou & Ngwenyama, 2008). Most critical arguments are targeted against the claim that the adoption of ICT is going to develop human capital. Another area of weakness of the argument is the claim for economic development. This argument appears as a wish; no serious analysis was conducted from the developing countries to support it. Most conjectures about the impact of ICT on economic development are based on findings of studies conducted in developed countries.

2.5.1 Critiques of ICT for Development and Human capital

One of the aspects most criticized in the ICT4D hypothesis is that relating to human capital. It seems implicit in the claim that ICT will positively impact developing nations and there is also the postulation that the fact that there is not enough human capital to implement and manage the technology can be easily overcome. Knowing that the lack of human capital has generally been the problem in technology transfer, proponents of ICT4D were not well inspired to bring this issue to the forefront of the debate. And so, in the recent literature, we have seen many critics in the research community challenging the ideology of the benefits and the potential of ICT for development of human capital. Most of them underline the lack of a plan to bring the human capital of developing countries to the level where usage of the technology can become really meaningful, and hence beneficial to the larger population of the LDCs; others point out the low level of literacy that hinders significantly the adoption of the new technology. In this body of literature, the studies relevant to the current research address the following key aspects grouped under four categories: Illiteracy, Technical aspects of the technology,

Lack of complementarities of the investments and the digital divide or societal organization. Table 2-4 below gives an overview of the literature.

Table 2-4 Barriers to ICT adoption in developing countries

Topics	Studies	Focus of the studies
Illiteracy as an obstacle to the adoption of ICT	Osborn (2006); Pinkett (2003); Huerta & Sandoval-Almazan, (2007); Etta & Parvyn-Wamahiu (2003)	The lack of literacy in general in developing countries is the greatest barrier to the adoption of ICT.
Obstacles due to technical aspects of the technology	Songan, Khairuddin, Yeo, Gnanih & Zen (2004); Gurstein (2001); Bahuman Bahuman, Baru, Duttagupta & Ramamritham (2007); Soriano (2007).	The lack of diversity of internet language and the lack of local content for most of the less developed countries constitute obstacles to its quick adoption.
Lack of complementary investments, low human capital	Williams (2005); Taylor & Marshall (2002); Ngwenyama & Morawczynski (2009); Samoilenko & Ngwenyama (2008); Kwasi-Fosu (2007).	The low level of human capital development and the lack of complementary investments in other sectors can hinder the development of the ICT sector.
Digital divide and the organization of the communities are barriers to the adoption of ICT	Gigler (2004); Harris (2001); De Moor, (2005); Bhatnagar, 2003; Pinkett (2003); Stoecker (2005); Romm & Taylor (2001); Fuchs & Horak (2008); Van Dijk & Hacker (2003).	The habits in the communities, the local organizations and community participation and initiatives constitute barriers to the adoption of ICT. So do the digital divide and the lack of incentives.

Some researchers have recently pointed out illiteracy as one of the main obstacles to economic and social development through adoption of ICT in the developing countries. Although this view is widely admitted in the research community, Osborn (2006) notes that the problems pertaining to literacy and languages are yet to be investigated. In addition to the lack of literacy, some research articles

have found out that other factors such as the unavailability of local content of the internet plus the domination of the English language in most internet documents are hindrances to the use of telecentres and other internet applications. They claim that local content and easy access to the internet through local languages could be a factor of engagement of the users of the community. Pinkett (2003) and Huerta and Sandoval-Almazan (2007) observed that since English literacy is very low in most developing countries, and most internet content is delivered in that language, most users in developing countries are kept away from accessing these contents, which further creates digital divide. Similarly, Gurstein (2001), and Songan, Khairuddin, Yeo, Gnaniah and Zen (2004) suggest that limited knowledge of the English language constitutes a challenge for a large population of developing countries who wish to take advantage of the technology but do not have sufficient knowledge of the language. In a survey conducted on the usage of telecentres in Sri Lanka, Gamage and Halpin (2007) noted that most respondents that were not familiar with the English language couldn't benefit from the internet. They then concluded that the most important factor of the usage of telecentres in this country is language. A similar experiment conducted among farmers in rural India, to assess a knowledge-sharing project revealed that the main barrier to the usage of the telecentres was both the content and the English language. (Bahuman et al., 2007). Likewise, Sorinao (2007) reported that the availability of local content is the major source of motivation for people to use telecentres in rural China. After conducting a survey in some African countries, Etta and Parvyn-Wamahiu (2003) were able to demonstrate that users of telecentres were rather young and literate. They draw the conclusion that literacy level had an influence on the usage of telecentres.

Other important factors were also acknowledged to be obstacles to the adoption of ICTs in developing countries. In this regard, the capabilities and goals of the communities were identified as one of the major factors. In the developed countries, for example, one of the goals of the community is to acquire knowledge through their own means. The technology and internet address this need. Secondly, the communities in the developed countries have the capacity to use the technology. The literacy rate is high, and the community is also accustomed to the usage of technology. Some researchers suggest that the impact of ICT on development be also studied from the perspective of

the capabilities of the communities. For example, Gigler (2004) argues that some researchers assessing the impact of information and communication technologies on development focus only on technology rather than the capabilities of the communities. He suggests that the method proposed by Harris (2001) be adopted. In Harris' approach, the community's goals are the primary focus; therefore the impact is measured from the perspective of the community. In his findings, it appeared clearly that the goals and capabilities of the community is a major determinant of the impact of ICT on development. With regards to community informatics, more and more researchers have suggested that there is a need to develop a body of theory to address the particular issue of ICT and communities. (Romm & Taylor, 2001; Pinkett, 2003; Bhatnagar, 2003; De Moor, 2005 & Stoecker, 2005). They argue that this area should not rely on anecdotes but evidence.

Research has also found that social ties and social networks are important factors that push forward the use of the Internet. The level of importance of such networks and ties is a major determinant of the impact of ICT on social development. Interesting work by Williams demonstrates that social ties and social capital influence the use of ICTs for social development (Williams, 2005). Similarly, Taylor and Marshall (2002) posit that social networks and social capital are important in the adoption of the Internet for development purposes.

The digital divide has also been identified as one of the factors that slow the adoption of ICT in developing countries. Among the researchers who share this point of view are Fuchs and Horak (2008). In their article on ICT and the digital divide in Africa, the authors suggest that the digital divide is not only a question of access to the internet but also a question of its usage and the benefits of the usage. According to them, it does not suffice to just try to bridge the gap between developed countries and less developed countries by creating more infrastructures allowing more internet connectivity in the developing country. The fundamental problem is the usage and the benefit of that usage. There must be a total change in the society to trigger global interest and yield more benefit from the usage of the Internet. Van Dijk and Hacker (2003) went further and identified four types of

digital divide. They argue that there is a need to address the four areas identified as digital divide simultaneously in order to bridge the divide. They laid out the four divides as follows:

- The lack of 'mental access': refers to a lack of elementary digital experience.
- The lack of 'material access': means a lack of possession of computers and network connections.
- The lack of 'skill access': is a lack of digital skills.
- The lack of 'usage access': signifies the lack of meaningful usage opportunities'.

(Van Dijk and Hacker, 2003).

More recent literature has pointed out the lack of coordinated action from the developing countries to develop simultaneously their human capital along with the implementation of the adoption of the ICT infrastructure. Ngwenyama and Morawczynski (2009) have demonstrated the equal importance of investments in ICT infrastructure-building and investments in education in a study of five Latin American countries. Similarly, Samolienko and Ngwenyama (2008) demonstrated how the lack of technologically skilled workers can hinder the adoption of the technology and advised on the need for complementarities in the investments in ICT and education in transition economies. Recently, UN researcher Kwasi-Fosu (2007) has insisted that money saved from international debt rescheduling or canceling should be invested in education. In his analysis of West African countries, the author discovered the desire of countries to increase their national budget shares for education but pointed out that they are constrained by international debt services.

For many years, research has been praising the advent of the adoption and implementation of ICT in developing countries. In order to accompany this initiative, many articles relaying the achievements of this experience were published; until recently when some scholars started interrogating the relevance and opportunity of these investments, particularly at a time of financial crisis where scarce resources need to be assigned to projects more carefully. These dissenting voices have been growing stronger and stronger and merit careful attention. I have assembled some of the references to these critiques in Table 2-5-2 below and subsequently summarized some of the critic's arguments.

2.5.2 Critiques of ICT for Development and Income studies and focus of the studies

Topics	Studies	Focus of the studies
Level of investments in the ICT sector	Oliner and Sichel (2002); Jorgenson (2001); Jorgenson & Stiroh (2000).	There is a threshold that the investments in ICT must attain before they become beneficial to the developing countries. The low level of investments in the ICT sector hinders its impact on development.
Lack of complementary investments	Black & Lynch, (2000); Devaraj & Kohli (2003); Brynjolfsson & Hitt (2000); Ramirez (2003); Arvanitis (2003); OECD (2003); Fielding (2002); Kneller (2005); Lamberton (2001); Von Lubitz & Wickramasinghe, (2006).	The lack of success of investments in ICT is due to the lack of complementary sectors which prevents ICT from producing the expected benefits.
Relationships between ICT and other sectors	Dewan and Kraemer (2000); Ngwenyama, Andoh-Baidoo, Bollou, & Morawczynski (2006); Bollou (2006).	Studies highlight the importance of the relationships between investments in ICT and other sectors for optimum impact on development.

Early researchers had already suggested that that there exist two factors which affect the relationship between investments in ICT and economic outcomes (Dewan & Kraemer 2000). The first factor is the size of the ICT investment and overall accumulated ICT capital. The authors suggest that it should be above a certain threshold before it can have a detectable effect (Jorgenson & Stiroh, 2000; Jorgenson, 2001; Oliner & Sichel, 2002). The other factor is that ICT investments need complementary investments in other sectors before the outcomes produced by ICT can significantly increase and have an effect on the national economy (Black & Lynch, 2000; Brynjolfsson & Hitt, 2000; Devaraj & Kohli, 2003; Ramirez, 2003; Arvanitis, 2003; OECD, 2003).

Other researchers make the argument that too large parts of national budgets are allocated to ICT-I expansion as an engine of growth while little consideration is now given to other development sectors and basic infrastructure (for example, roads constructions, continuous electricity and water provision) (Lamberton, 2001; Fielding, 2002; Kneller, 2005; Bollou, 2006; Von Lubitz & Wickramasinghe, 2006).

In order to harness benefits from the ICT investments, these investments must be combined with investments in other sectors (Dewan & Kraemer, 2000; Ngwenyama et al., 2006; Ngwenyama & Morawczynski, 2009). In an investigation of investments in West African countries and similar analysis of Latin American countries, Ngwenyama et al., (2006 and 2009) demonstrated that there is a complex relationship between investments in ICT-I and investments in education and health. The authors further showed that the correct combinations of these investments had a positive impact on the HDI, whereas bad combinations had the reverse effect. In their study on Latin American countries, the authors further demonstrated that investments in basic civil infrastructure along with the investments in ICT-I has a positive impact on development whereas the absence of investments in basic civil infrastructure showed no sign of development even though massive investments had been conveyed in ICT-I development.

2.6 Conclusions

There seems to be agreement that the huge potential of ICT-I to influence economic and social development in developing countries is undeniable, when one reads all the reports on what has been done in the developed world and recognizes the improvement of the capabilities of the technology over time. But how the technology is going to deliver the miracle still remains a question with no definite answer. Walsham and Sahay (2006), in a survey of IS literature concerned with developing countries, were able to come to the following conclusion:

‘There had been some debate as to whether information and communication technologies (ICTs) were relevant to developing countries, but this debate has been resolved with a clear yes answer. The question has become not whether, but how ICTs can be beneficial’. (Walsham & Sahay, 2006, page 7).

Most research in support of the ICT4D hypothesis makes the claim that developing countries are going to reap the same benefits that developed countries have already gained from their utilization of the new technology. Their statements assume a quasi automatic and linear, cause and effect type of phenomenon. On the other hand, critics of the ICT4D hypothesis try to challenge the correctness of the hypothesis by analyzing the discourse from qualitative and quantitative approaches. Their argument is that, in spite of the examples of rapid economic growth in the past decades quickly attributed to ICT, one has to be careful when assessing the exact role of ICT in this development and not confuse the tool and the effect. As a general observation, it becomes easy to conclude that since the new element introduced in an economy is the ICT sector all new developments are automatically attributed to that new element. As a matter of fact, some developing countries have had tremendous economic development lately and the temptation to credit ICT for all of that improvement is what some authors are cautioning us against. When considering ICT, the situation of developed countries is quite different from the developing ones and one should be careful in assessing ICT and development because of the many accumulated factors capable of triggering economic growth at any moment. For example, Soeftestad and Sein (2003) are a little sceptical about the hope of developing countries achieving accelerating development due to ICT. They claim that, so far, studies show limited correlation between investments in ICT and traditional economic growth in spite of the rapid adoption and the huge investments conveyed in the sector by developing countries. Similarly, Heeks (2002) cautions that the realities of development are more complex and should be assessed with caution. He remarks that too many researchers draw quick conclusions and make quick associations between ICT and development. The author acknowledges that these researchers' conclusions are influenced by those of business consultants, international organizations, vendors and other development partners who have interest in positive outcomes of the huge investments in the ICT sector.

After two decades of ICT adoption in developing countries, a sparkle of benefits should begin to show. I believe that a way to interrogate the ICT4D hypothesis is to verify its veracity by analyzing the results of its adoption over two decades. In order to critically analyze the discourse of the proponents of

ICT4D, I will conduct an empirical investigation of the claims that are found in the literature and were reported in this literature review. The investigation will interrogate the truth, sincerity and legitimacy of the claims.

University of Cape Town

Chapter 3: Philosophical Foundations and Theoretical Framework

3.0 Introduction

The fundamental objective of this research is a critical interrogation of the ICT for Development (ICT4D) hypothesis in the context of Francophone West Africa. In the field of information systems (IS) there is a long tradition of critical studies that dates back to the early 1980's (Mingers, 1980; Lyytinen & Klein, 1985; Ngwenyama & Lee, 1997). Much of this critical IS research has been conducted from the point of view of Habermas' critical social theory, but there are some studies that are informed by other critical social theorists, such as Foucault and Bourdeu (cf. Heeks, 2008; Richardson, Tapia & Kvasny, 2006). Further, while the Habermasian tradition of critical theory research accommodates multiple epistemic orientations and methods (Habermas, 1962, 1981; Ngwenyama, 1991; Ngwenyama & Lee, 1997) most of the critical studies of IS use qualitative methods for analyzing communicative (text and pictures) data to derive empirical observations (Cukier, Ngwenyama & Nesselroth-Woyzbun, 2008). This study, however, uses quantitative data coupled with non-parametric statistical methods to derive empirical observations for critical analysis.

The choice of critical social theory (CST) as the philosophical foundation for this PhD research is motivated by my interest in developing a critical understanding of the potential and limitations of the African ICT for Development (ICT4D) project. During the late 1990s I enthusiastically embraced and supported the ICT4D project in West Africa and worked in the sector implementing new infrastructure for 'Voice Over IP' telephony. I very much believed ICT to be an important vehicle for social and economic development. During that time, when I was closely involved in ICT infrastructure development, I encountered a range of difficulties not only around the lack of national ICT policy in the countries, but health, education and other civil infrastructure. Through the years of working in the field I became more and more concerned about the rise of strong ideological positions and strong uncritical support for ICT as an engine of development and the contradictions of the social realities in many of the African countries. One decade later, in spite of a few achievements made here and there,

progress in social and economic development has not met the level of expectation of the African people and policy makers. On this account I set out on a PhD research project which has as its objective the conduct of a systematic critical interrogation of the ICT4D hypothesis.

The objective of this chapter is to outline the philosophical foundations and theoretical framework upon which this PhD research project was designed. The rest of the chapter is organized as follows. Section 3.1 situates this research project within Burrell and Morgan's four sociological paradigms (Burrell & Morgan, 1985), and outlines the basic assumptions of the critical theory approach that is followed. Section 3.2 outlines the philosophical perspective of critical theory upon which this research is based. Section 3.3 presents an overview of the theoretical underpinnings of the central claim of the ICT4D hypothesis. Section 3.4 outlines the principles and strategy for the critical interrogation of the underlying arguments of the ICT4D hypothesis. And Section 3.5 ends the chapter with a summary of the procedure for generating the empirical observations for the critical theory analysis of the claims of the ICT4D hypothesis.

3.1 Situating the Research Project

To situate this research project I will briefly discuss the four-paradigm framework of Burrell and Morgan (1985)⁴. While there are other frameworks outlining assumptions of research paradigms this framework is well established and accepted in the field of IS (Klein & Hirschheim, 1993). The Burrell and Morgan (1985) framework is an analytical tool for examining the ontological and epistemological assumptions and value orientations of IS and other social science research approaches. The framework (Figure 3.1) classifies social science theories and research along two dimensions: assumptions about social reality and assumptions about human nature and social systems. The dimension that concerns assumptions about social reality encompasses two extreme perspectives on the nature of social reality: *subjective* and *objective*. At the subjective extreme the fundamental structures of social systems are viewed as historical constructions of the involved actors that they

⁴ A detailed discussion of the framework is beyond the scope of this thesis. For a comprehensive view the reader is referred to the original text: Burrell, G; and G. Morgan; Sociological Paradigms in Organizational Analysis, Gower, 1985.

can change, and on the objective extreme the fundamental structures of social systems are viewed as given, preexisting, to which human actors must conform. The other dimension of the framework concerns assumptions about the dynamics of social systems of which the two extremes are movement towards 'stability and regulation' and 'instability and change'.

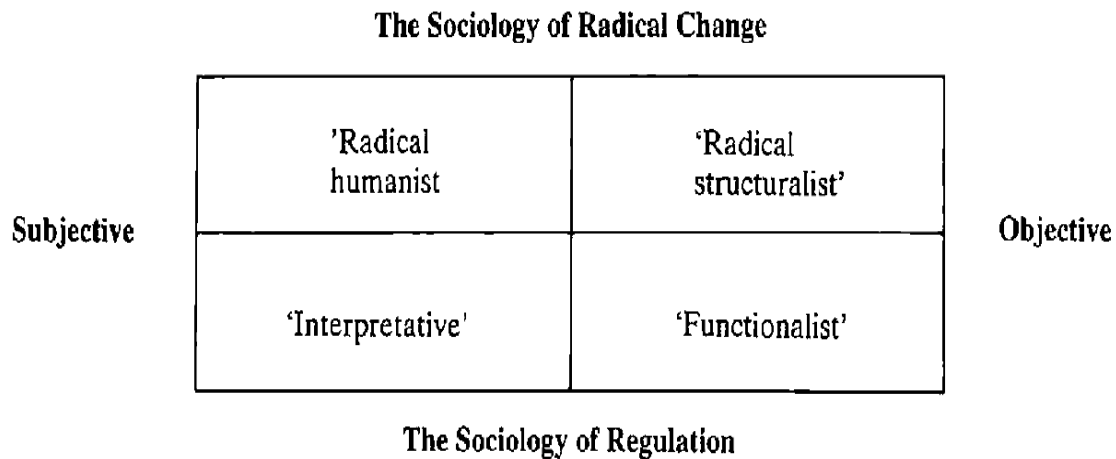


Figure 3.1 Four Paradigms of Research (Burrell and Morgan, 1985, page 22)

Social theories at these two extremes are characterized as sociology of regulation and sociology of change respectively. Each of the four quadrants of this framework represents a distinct set of assumptions about the ontology of social structures, social systems and the nature of human action, and the appropriate epistemologies for inquiry and concomitant methodologies. Social scientists working within each of these paradigms hold different assumptions about the ontology and epistemology of social organizations and the nature of human action. In that sense the knowledge interest and methods of inquiry differ. Paradigm choices are subjective judgments that researchers make based on their orientations and interests. The Radical Humanist paradigm views social systems (rules and structures) as the products of social actions of the participants that are continually emerging. The radical humanist researcher is interested in the unhindered development of people within their social worlds, and seeks to achieve this through individual and social system improvements. Hence research from the radical humanist perspective is not limited to description of social rules (or the status quo), but focuses on a critical analysis of the social structures and rules that impinge on human development in order to transform them. The radical humanist believes

that human actors can improve and transform social arrangements in society when they become oppressive or are co-opted by powerful stakeholders. One class of theories that falls within this paradigm is critical social theory, the foundations of this PhD research. The interpretive paradigm assumes a subjectivist epistemology but regulative assumptions of human behavior and social systems. As such, research from this perspective focuses on interpretation and description of the status quo, instead of critical interrogation for transformation. While the interpretivist views human systems as socially constructed and having specific meaning to the participants, she is not concerned with changing anything. The interpretive research focus is to achieve understanding of social actions within the social context while being sensitive to the lifeworlds of the actors.

The functionalist paradigm holds to an objectivist epistemology and regulative ideals of social systems and human behaviour. While a strict functionalist may accept that social systems are created by human actions, she does believe that there is an ideal design that will bring equilibrium and order to the social system. In this regard the functionalist is preoccupied with uncovering those theories and explanations that lead to the maintenance of social order and system equilibrium. Unlike the interpretivist, the functionalist believes that there exist enduring universal social rules/laws upon which well ordered social systems can be built. The ICT4D hypothesis is an example of a theory that falls within these paradigmatic assumptions. The functionalist ICT4D researcher assumes the universal applicability of her prescriptions and the efficacy of these paradigms in bringing about development in every social setting, if they are applied correctly. The radical structuralist, like the functionalist, also holds to an objectivist epistemology, but she believes that social systems are tending towards chaos and anarchy. The radical structuralist emphasizes that structural conditions of conflict, contradiction, deprivation and modes of domination of the more powerful will eventually lead to radical change and emancipation of the oppressed. Researchers from this paradigm, for example Marxists, are focused on the dialectical analysis of social structures and forces in order to understand how they undermine human potentiality and lead to radical change.

3.2 The Philosophical Perspective of Critical Social Theory

The philosophical perspective of this research is the critical social theory (CST) of Jürgen Habermas which falls within the radical humanist paradigm. The basic objective of CST is the improvement of the human condition (Habermas, 1962, 1981; Ngwenyama, 1991; Klein & Hirschheim, 1993). While traditional social theory focuses on analyzing and understanding the status quo, critical social theory focuses on critiquing and unearthing limitations of existing social conditions and social processes and finding alternatives which can more adequately address human needs. CST considers the link between theory and practice as essential to its research program which is concerned with the design and implementation of social structures and processes for the development of people in society. The general approach is to critically examine prevailing ideologies and conditions of social life to reveal distortions, contradictions and barriers to human development and freedom. In this regard a key concern of CST is the interrogation of concrete problems of contemporary social organization in order to transform conditions of domination and control and emancipate social actors. The primary strategy of empirical analysis in CST research is the interrogation of arguments implicitly or explicitly embedded in communication in the public sphere and structural conditions of social life (Cukier, Ngwenyama, Bauer, & Middleton, 2009). Here communication includes all forms of speech intended to influence, coordinate or implement social actions. CST views systematically distorted and strategic communication as the central mechanism for implementing régimes of coercion and domination in social affairs. It also views 'Ideal Speech' as the primary vehicle by which actors can communicate, achieve understanding and come to agreement on how to construct and implement solutions to their everyday social problems (Habermas, 1979, 1984, 2006; Forester, 1989). CST also posits that all arguments can be interrogated from the perspective of four basic claims to validity - *truth*, *sincerity*, *legitimacy* and *comprehensibility* - summarized in Table 3.1 below (Ngwenyama & Lee, 1997; Cukier et al., 2009).

Validity Claim	Criteria for Ideal Communication	Potential Distortion	Validity Test
Truth	The propositional content of what is said is factual or true.	Misrepresentation	Is empirical evidence sufficient (to support the truth claim)? Is the reasoning provided sufficient (to support the truth claim)?
Sincerity	The speaker is honest (or sincere) in what she says.	False Assurance	Is what is said consistent with how it is said?
Legitimacy	What the speaker says (and hence does) is right or appropriate in the light of existing norms or values.	Illegitimacy	Are competing 'logics' (e.g. stakeholders) equally represented?
Comprehensibility	What is said is audible (or legible) and intelligible.	Confusion	Is the communication intelligible? Is the communication complete? Is the level of detail too burdensome for the reader or hearer?

Table 3.1: The Four Basic Claims of Arguments (adopted from Ngwenyama and Lee, 1997)

While the analytical method for interrogating the validity claims in communication is critical interpretivism, different methods of empirical analysis can be used to derive empirical observations about the claims from the data (Cukier et al., 2009). In general, most CST research conducted in information systems has so far been limited to textual data and qualitative methods (Ngwenyama & Lee, 1997; Cecez-Kecmanovic, 2001; Cecez Kecmanovic & Janson, 2001; Cukier et al., 2009). Further, most of the still growing critical theory research on the idea of ICT4D is also largely qualitative (Schech, 2002; Thompson, 2003; Klecun & Cornford, 2005; Heeks, 2008;). This research, however, uses non-parametric statistical analysis to interrogate archival data and draw empirical observations for critical interrogation.

The use of quantitative data and analysis methods is not contradictory to CST research. As Ngwenyama (1991) has pointed out, Habermas' CST adopts multiple epistemologies as the basis for critical investigation. In the pursuit of its critical and transformatory objective CST adopts three knowledge interests - *instrumental*, *communicative* and *emancipatory* - and appropriate empirical methods from both objectivist and subjectivist traditions of social science (cf. Table 3.2). Instrumental

knowledge interest is concerned with the design and implementation of efficient and effective alternatives to the status quo that could support the development of the social actors. The communicative knowledge interest is concerned with achieving mutual understanding about social structures, action and relations that are important to the transformation of the social world of the actors. Emancipatory knowledge interest is concerned with uncovering ideological positions, systematically distorted communication and other obstacles to human development and finding and implementing legitimate alternatives to the status quo.

KNOWLEDGE INTEREST	KNOWLEDGE ORIENTATION	EPISTEMIC ORIENTATION And METHODS	PHENOMENA OF INTEREST	KNOWLEDGE CLAIMS
Instrumental	Prediction Control	Objectivist Constructivist	Social Systems Social Actions and Social Structures	Efficiency, Effectiveness, Legitimacy
Communicative	Mutual Understanding	Subjectivist Interpretative and Critical Interpretative	Social Action and Social Relations	Truth, Comprehensibility, Sincerity and Clarity
Emancipatory	Critical Understanding	Objectivist and Subjectivist Interpretative and Critical Interpretative	Social Structures and Social Relations	Comprehensibility and Legitimacy

Table 3.2: Epistemological Orientation of Critical Theory Research (Ngwenyama, 1991)

The central strategy of empirical research in CST is the analysis of arguments (Cukier et al., 2009). To contest and reveal the constraints and distortions of ideology, the critical theorist must interrogate the underlying logic of the arguments and subject them to the four validity claims tests. Consequently, the critical theorist must analyze the logic and empirical evidence upon which the arguments of interest are based. This is why Habermas includes empirical methods necessary to investigate the logic of arguments and social programs based on both subjectivist and objectivist social theories (Habermas, 1971, 1988). The nature of the argument and the claim under interrogation will determine the epistemic orientation and the method of analysis (Cukier et al., 2009). This PhD research aims to interrogate and challenge the central claim that 'ICT infrastructure expansion is an engine for social and economic development', the central argument of the ICT4D ideology, which is

rooted in the neoclassical growth accounting theory. Consequently, in deconstructing the arguments of this ideology it is necessary to use quantitative methods to analyze the data in order to derive empirical observations from the perspective of growth accounting theory which can be then subjected to critical interpretive analysis.

3.3 Theoretical Underpinnings of the ICT4D Hypothesis

In this research I set out to outline the structure of the argument underpinning the ICT4D hypothesis. The reader will recall that ICT4D hypothesis claims that heavy investment in ICT infrastructure expansion is an effective strategy for achieving social and economic development in underdeveloped countries. The central claim of the ICT4D hypothesis is that 'ICT is an Engine of growth and development which would free people in less developed countries from poverty and other factors of underdevelopment'. The theoretical models upon which this claim is based are the neo-classical economic theory and the neo-classical growth accounting model (Young, 1928; Solow, 1956, 1957, 1994; Cobb & Douglas, 1928) which has seen a reemergence in recent research (Lucas, 1988; Romer, 1986, 1990; Colecchia & Schreyer, 2002). The neo-classical economic theory and growth accounting model (also called the Solow growth model) attributes advances in social and economic development in the social systems to improvements in technical efficiency and technological change (i.e. learning accumulation in the social system). Technical efficiency frees up resources which can then be allocated to other parts of the social system. Technological change is the result of learning accumulation and spillovers of knowledge and innovation to other parts of the social system. Measurement in the growth accounting model highlights the relative importance of capital accumulation and technological change. The early work of Solow (1957) demonstrated that technological change accounted for almost 90 percent of economic growth in the U.S. economy during late 19th and early 20th centuries.

Proponents of the ICT4D hypothesis base their argument on this theory and point to more recent findings on the impact of ICT on the developed countries. They argue that high quality ICT infrastructure is a necessary precondition for participation in global markets, facilitating services,

capital movement, investment, coordinating of distant production and transportation of goods to consumers (Werthner & Klein, 1999; Röller & Waverman, 2001; Zaheer & Manrakhan, 2001; Carayannis & Sagi, 2002; Henderson et al, 2002; Antonelli, 2003; Kumar, 2005). Some ICT4D proponents have also argued that the impact of ICT infrastructure expansion extends well beyond the economic domain, having spillover effects on all dimensions of social life. For example, they argue that ICT technologies will enhance learning (Kankaanranta, 2005; Aduwa-Ogiegbaen & Iyamu, 2005), promote indigenous knowledge (Jain, 2006), improve healthcare delivery (Branko et al., 2003; Von Lubitz & Wickramasinghe, 2006), empower marginalized women (Gurumurthy, 2003; Huyer, 2005), and improve governance (Meso et al., 2005). In recent times the proponents of this argument have pointed to the emergence of the e-commerce sector and outsourcing as examples of the power of ICT to spawn new businesses and industries (Henderson, et al., 2002; Jukka & Pohjola, 2002; Susiluoto, 2003).

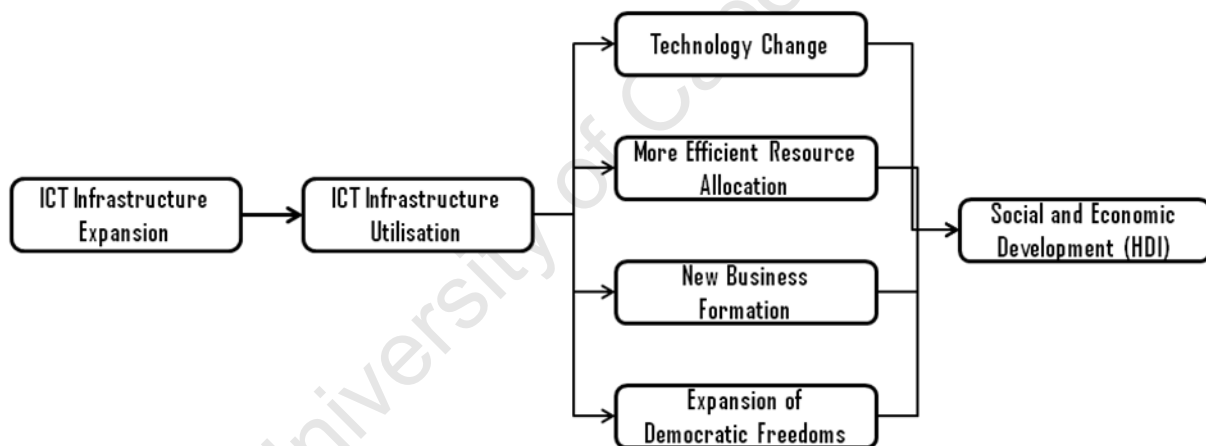


Figure 3.2 Conceptual Structure of the ICT4D Argument

The conceptual structure of the ICT4D argument for how ICT infrastructure expansion can contribute to social and economic development is mapped in Figure 3.2. ICT infrastructure expansion directly contributes to total factor productivity (TFP) of the society and also gives rise to ICT utilization which in turn influences: (1) learning accumulation and spillovers (the technology change argument); (2) improves the allocation of scarce resources (the technical efficiency argument); (3) leads new business formation (the network externalities argument)⁵; and (4) influences the expansion of

⁵ Network Externalities of ICT are the indirect effects of the usage of ICTs on other sectors of the economy.

democratic freedoms (the network externalities argument). Finally, the outcomes of efficient ICT utilization (1, 2, 3, and 4) influence social and economic development. It is important to note here that many researchers have argued that technical efficiency and technology change are the most important drivers of social and economic growth in a social system because of the result in TFP growth (Young, 1928; Solow, 1994; Romer, 1986, 1990; Carayannis & Sagi, 2002; Fielding & Torres, 2009). Consequently, TFP (also called multifactor productivity, (MFP)) is one of the most measured factors of economies. I will now outline the basic concepts of the analytical model of neoclassical growth accounting upon which the ICT4D hypothesis is based.

3.3.1 The Analytical Model of Growth Accounting

The most common representation of the neo-classical economic growth accounting model upon which the ICT4D hypothesis is based is the Cobb-Douglas production function. This is also the most common analytical approach used by researchers conducting empirical analysis of input-output statistical data to derive empirical observations about technical efficiency and technology change in a social system (where the social system can be a company, a sector, or an economy). The Cobb-Douglas production function provides an analytical strategy for assessing a social system to determine: (a) its technical efficiency; (b) its TFP; and (c) its level of learning accumulation (technology change). The basic mathematical model for the Cobb-Douglas production function is defined as follows:

$$Y = A L^{\alpha} K^{\beta}, \quad \text{Equation 1}$$

Where:

Y = output of the system

L = labor input to the system

K = capital input to the system

A = Total Factor Productivity of the system

α and β are constants determined by the production technology

The term production technology is meant in the broadest possible sense and includes all knowledge, methods and techniques that are used by the system to transform the inputs into outputs. The exponents α and β are output elasticities for measuring the responsiveness of output to changes in labor and capital, respectively, used in production of the output (*ceteris paribus*). When $\alpha + \beta = 1$, the system/economy is operating at constant returns to scale. Thus if inputs L and K are each increased by 20%, the output Y should increase by 20%. When $\alpha + \beta < 1$, returns to scale are decreasing, and when $\alpha + \beta > 1$ returns to scale are increasing. Assuming that competition is perfect, α and β can be shown to be labor and capital's share of output. In equation 1, Y represents total output as a function of TFP represented by A . A key limitation of the Cobb-Douglas production function (as well as other production functions) is that it cannot measure network externalities, that is, impacts outside of the system. Impacts external to the system under analysis are deduced by inferential statistical methods such as regression analysis. The technical details of how I analyze the input-output data of the ICT sectors of the countries for technical efficiency and technology change are discussed in the next chapter. There I outline the key concepts of the primary mathematical methods for the production function analysis, DEA and MARS used in this study. What follows here is an outline of the general strategy for critical interrogation of the ICT4D hypothesis used in this research.

3.4 The Critical Theory Interrogation Strategy

The strategy for critical theory analysis of the ICT4D hypothesis is adopted from Ngwenyama and Lee (1997) and Cukier et al. (2009). Both of these critical theory approaches to the analysis of arguments have used Toulmin's model for the analysis of arguments (Toulmin, 1958; Toulmin, Rieke, & Janik, 1978). The basic strategy is to interrogate arguments by challenging key aspects of the conceptual structures upon which the argument is built. Figure 3.3 is Toulmin's schematic representation of the general structure of a scientific argument. According to Toulmin (1958), and Toulmin, Rieke, & Janik, (1978) a scientific argument is composed of some *claim* which is a logical conclusion from reasoning about some set of *evidence* from the perspective of a given *theory or model*. The key point is that the scientific claim is an interpretation of a set of empirical evidence from the point of view of a specific

theory. Consequently, any researcher critically interrogating a given scientific claim must of necessity examine the argument structure of the claim.

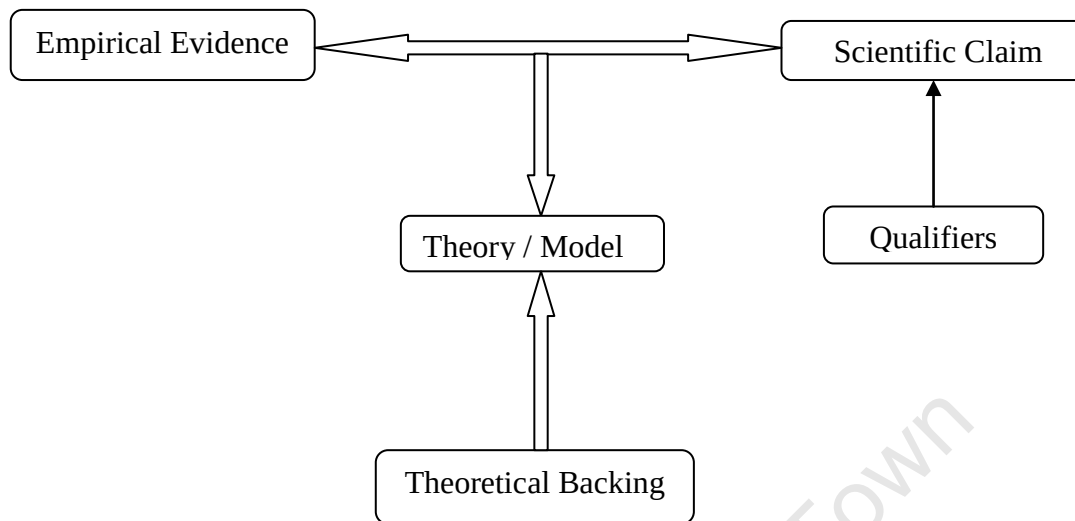


Figure 3.3 Toulmin's Model For Analysis of Scientific Arguments (cf. Toulmin, Rieke, & Janik, 1978)

To systematically interrogate a scientific claim the researcher must:

1. Interrogate the appropriateness of the theory/model to the espoused scientific claim.
2. Interrogate the validity of empirical evidence upon which the claim is based
3. Interrogate the appropriateness of the empirical evidence for the espoused claim
4. Interrogate the qualifiers and quantifiers of the espoused scientific claim

The appropriateness criteria are subtle issues that require some elaboration. A key concern for any researcher challenging an argument is examining the appropriateness of the empirical evidence and theory used to argue the claim. The researcher must make sure that the empirical evidence used to interrogate the claim is that which is appropriate for making the claim (Toulmin et al., 1978). The other subtle point is that it is incumbent on the researcher to stay within the paradigmatic constraints when generating empirical evidence for challenging the argumentation of the claim. In other words, the interrogator must, when possible, use the same theory or model for generating empirical evidence and analyzing the claim upon which the original argument was made (Toulmin et al., 1978). This helps to avoid problems of incommensurability resulting from using different paradigmatic

assumptions for challenging the claims that may already be antithetical to the argument under interrogation.

Foci of analysis	Specific Claims of the ICT4D Hypothesis	Validity Test	Interrogation Questions
ICT Infrastructure Expansion	1. ICT expansion will have direct contribution to TFP growth in the society	Truth	Does the empirical evidence support the claim? Is the reasoning provided in the ICT4D hypothesis sufficient to support the claim?
		Legitimacy	Are there competing explanations of the development dynamics not represented in the ICT4D hypothesis?
ICT Infrastructure Utilization	2. ICT Infrastructure utilization will lead to learning accumulation and spillovers in the society that will increase TFP growth 3. ICT utilization will lead to more efficient resource allocation in the society that will increase TFP growth 4. ICT utilization will lead to new business formation in the society that will increase TFP growth 5. ICT utilization will lead to expansion of democratic freedoms which in turn will increase TFP growth	Truth	Does the empirical evidence support the claim? Is the reasoning provided in the ICT4D hypothesis sufficient to support the claim?
		Legitimacy	Are there competing explanations of the development dynamics not represented in the ICT4D hypothesis?
Investments in ICT Infrastructure Expansion	6. Heavy investment in ICT infrastructure expansion will lead to rapid Social and Economic Development	Truth	Does the empirical evidence support the claim? Is the reasoning provided in the ICT4D hypothesis sufficient to support the claim?
		Legitimacy	Are there competing explanations of the development dynamics not represented in the ICT4D hypothesis?

Table 3.3 Summary of Critical Theory Validity Test of the Core Claims of the ICT4D Hypothesis

It is now important to restate the basic claims of the ICT4D hypothesis and the critical theory validity tests which will form the basis for their interrogation. Table 3.3 provides a summary of the key claims of the ICT4D hypothesis and the critical theory validity test they will be subjected to in my analysis. The reader will recall that Figure 3.2 outlined the basic conceptual structure of the ICT4D hypothesis as containing a set of interdependent outcomes. To achieve social and economic growth from ICT infrastructure expansion, there must be a sufficient level of ICT utilization to result in some or all of the following: (a) more efficient allocation of resources in the society; (b) learning accumulation and spillovers; (c) new business formation; and finally (d) expansion in democratic freedoms, all of which are believed to positively influence social and economic development. A critical theory analysis of these claims of the ICT4D hypothesis would interrogate the truth and legitimacy of the claims by subjecting them to systematic interrogation.

The basic validity claims test of the core claims can be operationalized by examining each claim from the perspective of two basic questions: (1) Is the empirical evidence and reasoning provided sufficient to support the claim? (2) Are competing explanations of the development dynamics not represented in the ICT4D hypothesis? To systematically investigate these questions empirical observations of the output (effects) as the consequence of the input will be needed on each of the three focal points of the present analysis: (1) ICT infrastructure expansion; (2) ICT infrastructure utilization; and (3) Investments in ICT infrastructure expansion. The set of empirical observations required for the analysis are as follows:

1. The level of efficiency of ICT infrastructure expansion:

The empirical analysis of ICT-I expansion efficiency is concerned with finding out if the ICT sectors are efficiently utilizing ICT investments and staff in building the infrastructure. Rapid ICT infrastructure expansion is one of the key arguments of the ICT4D hypothesis; so efficient and effective expansion of ICT infrastructure is a prerequisite to achieving any development gains. An important question here is: What factors affect the efficiency of ICT expansion? Identifying these factors could help to develop synergistic strategies to achieve optimum outcomes.

2. The level of efficiency of utilization of the ICT infrastructure:

The second part of the analysis concerns making empirical observations about the utilization of the ICT infrastructure. Efficient utilization of the infrastructure could lead to optimum contributions to revenue returns for the sector, which in turn contributes to gross domestic product (GDP) and TFP growth. Here again we are interested in whether there is learning accumulation about utilization of the infrastructure that could lead to sustained TFP growth.

3. The level of learning accumulation in the ICT sectors:

In analyzing ICT infrastructure expansion I am also interested in the nature of productivity gains. A key question is: Are the ICT sectors achieving any learning accumulation? If the sectors do not achieve learning any gains would be lost over time, with adverse consequences to development.

4. The level of effective utilization of the investments in the expansion of ICT infrastructure:

I need to generate a set of empirical observations to critically analyze the utilization of investment for ICT infrastructure expansion. Two questions are important here: Is there over investment in ICT expansion? And, is the investment in ICT infrastructure properly utilized? A core issue of social and economic development is the allocation of scarce resources. Consequently it is important to know if there are other resource allocation strategies that could achieve a higher level of development for the society.

5. The level of contribution to TFP of the ICT sectors.

As a new economic sector, the ICT sector is expected to contribute to the national economy growth through its contribution to the production factors such as TFP. In this thesis, I assess the productivity of the ICT sectors over the years in order to determine the level of contribution of the ICT sectors to the growth of the national economy. Two observations emerge from this assessment: number one; the analysis helps to determine if the sector is productive and self

sustainable. And following that, I evaluate if the growth is large enough to positively impact the national economy.

6. The impact of investments in ICT infrastructure expansion on key development indicators:

Finally, the last focal point requires the development of a set of empirical observations about the impact of investment in ICT infrastructure expansion on key development indicators such as health, education, and per capita GDP, which are measures of social and economic growth.

To generate the empirical observations for the critical theory analysis of the ICT4D claims I use the Cobb-Douglas function with DEA and MARS computational models to analyze the input-output archival data from the six countries. Figure 3.4 below gives a graphical illustration of the key components of the critical analytical approach following Toulmin's model as described by Ngwenyama and Lee (1997) and Cukier et al. (2009). In this approach the claims are interrogated using empirical observations generated using the Cobb-Douglas production function. The empirical observations are used to test the truth and legitimacy validity claims of the ICT4D hypothesis.

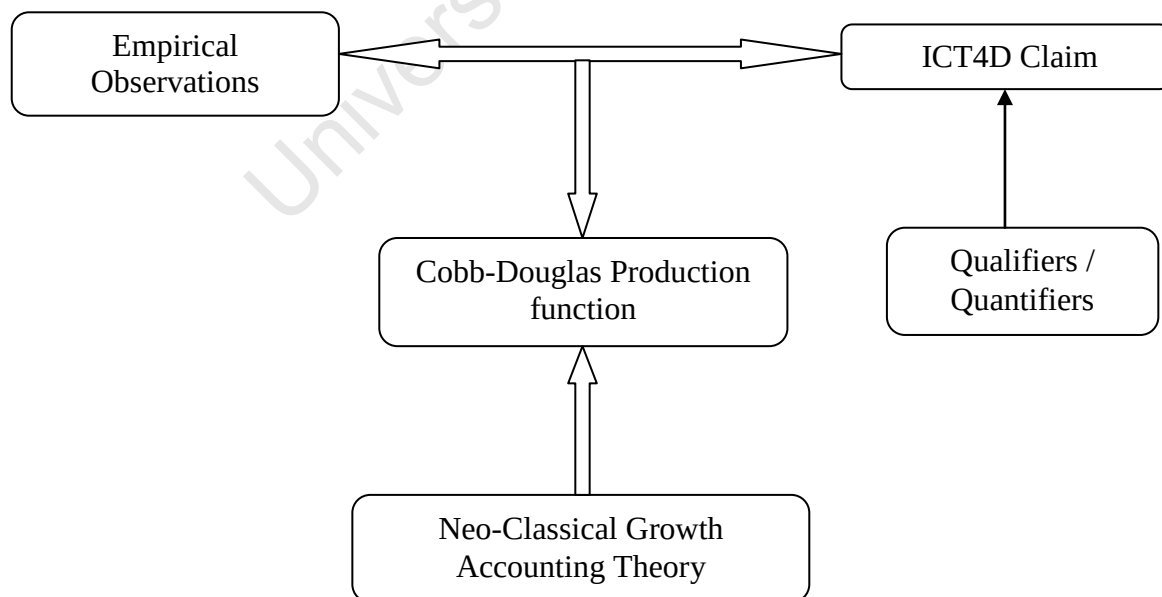


Figure 3.4 General Framework of the Critical Interrogation

3.5 Summary of the Empirical Analysis Procedure

I will now summarize the key steps of the empirical analysis procedure that I will follow. It is understood that empirical analysis is conducted on input-output data from the ICT sectors of the six West African countries and some national level statistics, namely HDI components that measure the level of development of the countries. Figure 3.4 provides a general illustration of the framework of the analysis. The primary model for analyzing the empirical data to generate the empirical observation is the Cobb-Douglas production function, the same neo-classical growth accounting model upon which the ICT4D hypothesis is based. The DEA and MARS computational methods are used to conduct the Cobb-Douglas analysis of the data to derive the following empirical observations about the ICT sectors and economies of the six countries:

Step 1 of the analysis uses DEA models to derive the following efficiency observations:

- 1.1 The relative technical efficiency of ICT infrastructure expansion
- 1.2 The inefficiencies in the utilizations of the inputs for ICT infrastructure expansion
- 1.3 Key factors that are affecting the technical efficiency of ICT infrastructure expansion
- 1.4 The multifactor productivity and learning accumulation in ICT infrastructure expansion

Step 2 of the analysis uses DEA models to derive the following empirical observations:

- 2.1 The relative technical efficiency of ICT infrastructure utilization
- 2.2 The relationship between the inputs to ICT sectors and revenue outputs
- 2.3 The multifactor productivity and learning accumulation in ICT infrastructure utilization

Step 3 of the analysis uses MARS to analyze the impact of investments in ICT infrastructure expansion on key social and economic indicators: education, health and per capita GDP.

There are two limitations of this empirical analysis. First the challenges of developing systematic empirical observations for assessing network externalities (see ICT Infrastructure utilization in Figure 3.2) resulting from ICT expansion in the context of these developing six countries is beyond the scope of this PhD thesis. The data necessary for such an analysis do not exist. Second, the decision was

taken not to include an empirical analysis of the impact of ICT utilization on democratic freedoms. A systematic analysis of those issues could be the subject of another PhD thesis. A limited investigation here would not do justice to the issues.

University of Cape Town

Chapter 4: Research Methods and Empirical Data

4.0 Introduction

This research utilizes a multi-method approach for the empirical analysis. The reason for the multi-method approach to the empirical analysis is the need to investigate: (a) the relative and scale efficiencies⁶ of the ICT sectors; (b) total factor productivity and learning accumulation of the ICT sectors; and (c) the relationships between various independent and dependent variables. In this regard the efficiency measurement system (EMS) of Data Envelopment Analysis (DEA) is used for the empirical analysis of relative and scale efficiencies; the Malmquist Productivity Index (MPI) is used for the empirical analysis of TFP and learning accumulation; and Multivariate Adaptive Regression Splines (MARS) is used to analyze and unravel the relationships among relevant variables. MARS helps in the investigation of impact between dependent and independent variables. Ordinary Least Square regression is also used in some cases to establish the impact of independent variables on dependent variables when the relationship is linear. In following sections of this chapter I will describe these empirical analysis methods then describe the archival data for analysis.

4.1 Data Envelopment Analysis⁷

Data Envelopment Analysis (DEA) is a nonparametric method of measuring the efficiency of input-output production systems (also called decision-making unit or DMU). A DMU can be a process, department, company, and industry sector, a region or an entire country. In this research the DMUs are the ICT sectors of the six countries under study. DEA is a nonparametric method comprising a collection of models and techniques for analyzing the efficiency of DMUs that uses observed input-output data. An important feature of DEA is that the measuring of relative efficiency can be done with unknown or unavailable price values for data inputs and outputs (Sengupta, 1995). Another important feature of DEA is the flexibility it offers the researcher to choose from a number of models and

⁶ **Scale efficiency** is the potential productivity gain from achieving optimal size of a firm. In other term, the reduction in unit cost available to a firm when producing at a higher output.

⁷ The description of DEA was adapted from Charnes, Cooper, Lewin and Seiford's book (1994) on DEA and the OnFront Software Reference guide 1998-2000.

orientations to conduct the most appropriate empirical analysis (Dulá, 2002). The theoretical foundations of DEA are rooted in Neoclassical Growth Accounting theory (briefly described in Chapter 3). While a discussion of the development of DEA is beyond the scope of this chapter⁸, I provide an overview of the theoretical concepts behind the DEA computations used in empirical analysis.

4.2.1 DEA Models and Orientations

The three commonly mentioned orientations of the DEA model are: input-oriented, output oriented, or base-oriented (Charnes, Cooper, Lewin & Seiford, 1994). An input-oriented model would be concerned with the minimization of the use of the inputs for achieving a given level of the output. Thus, it deals with the efficiency of the input utilization and inputs within the model are controllable. In my research I will employ the input-oriented model in order to approach the issue of efficiency from the perspective of the policy maker, who would probably be interested in how efficiently the allocated investment resources are being utilized to build ICT infrastructure. This model will also be used to assess relative efficiency of the investments in the ICT sectors to benchmark best performing countries compared to the others in order to inspire policy makers in less performing countries to follow good examples.

An output-oriented DEA model, on the other hand, would be concerned with the maximization of the level of the outputs per given level of the inputs. Thus, it deals with the efficiency of the output production where outputs are controllable. In this study I will also use the output-oriented model, for it appears reasonable to expect that the macroeconomic goal of any economy is maximization of the output. My goals are manifold; using this model I will perform simulations of the output maximization of the ICT infrastructure such as landlines, internet connections, but also the maximization of economic factors such as GDP; other simulations will concern the various combinations of the input factors. The base-oriented model, unlike the first two, has dual orientation and would be concerned with the optimal combination of the inputs and outputs. Therefore, this type of DEA model deals with

⁸ The interested reader might benefit from an excellent summary of the theoretical underpinnings of DEA in Dulá 2002.

the efficiency of the input utilization and efficiency of the output production, having control over both inputs and outputs within the model.

As a result, definition of the efficiency would depend on the orientation of the model. In the case of an input-oriented model, no DMU would be considered efficient if it is possible to decrease any of its inputs without affecting any other inputs and without decreasing level of the outputs. While in the case of an output-oriented model, a DMU could not be considered efficient if it is possible to increase the level of any of its outputs without affecting other outputs or increasing level of any of its inputs (Charnes, Cooper & Rhodes, 1978). The empirical foundation of DEA eliminates the need for some of the assumptions and limitations of traditional efficiency measurement approaches (Bowlín, 1998). As a result, DEA could be used in cases where the relationships between the multiple inputs and multiple outputs involved in DMUs are complex or unknown (Cooper, Seiford & Zhu, 2004).

The original DEA model was introduced in 1978 by Charnes, Cooper and Rhodes and it is commonly called CCR (an abbreviation consisting of first letters of the authors' names). This model allowed representing multiple inputs and outputs of each DMU as a single abstract 'meta input' and 'meta output.' Consequently, the efficiency of each DMU could be represented as a ratio of the abstract input to the abstract output, and the resulting efficiency value could then be used for comparison with other DMUs in the set. Mathematically, this ratio could be expressed as following objective function:

$$\max h_o(u,v) = \sum_r u_r y_{ro} / \sum_i v_i x_{io}$$

where:

the u_r 's and the v_i 's are the observed output values and

the y_{ro} 's and x_{io} 's are the observed input values of DMU_o (the evaluated DMU).

Adding the normalizing constraint, according to which the ratio of virtual input to virtual output for each DMU must be less than or equal to one, the following linear programming (LP) problem could be formulated:

$$\max h_o(u,v) = \sum_r u_r y_{ro} / \sum_i v_i x_{io}$$

Subject to:

$$\sum_r \mu_r y_{rj} / \sum_j v_j x_{ij} \leq 1 \text{ for } j = 1, \dots, n$$

$$\mu_r, v_j \geq 0 \text{ for all } i \text{ and } r$$

However, the formulation given above yields an infinite number of solutions, thus, transformation of the formulation has been developed by Charnes and Cooper (1962), which changes (μ, v) variables to (μ, v) and yields the equivalent linear programming problem to the one above. Following is a Charnes-Cooper transformation

$$\max z = \sum_{r=1}^s \mu_r y_{r0}$$

Subject to

$$\sum_{r=1}^s \mu_r y_{r0} - \sum_{i=1}^m v_i x_{ij} \leq 0$$

$$\sum_{i=1}^m v_i x_{ij} = 1$$

$$\mu_r, v_i \geq 0$$

The LP Dual for this linear problem, which sometimes referred to as the 'Farrell model,' could be formulated in its 'relaxed' form (i.e., having $\mu_r, v_j \geq 0$, rather than $\mu_r, v_j > 0$) as

$$\Theta^* = \min \Theta$$

Subject to

$$\sum_{j=1}^n x_{ij} \lambda_j \leq \Theta x_{i0} \quad i = 1, 2, \dots, m;$$

$$\sum_{j=1}^n y_{rj} \lambda_j \geq y_{r0} \quad r = 1, 2, \dots, s;$$

$$\lambda_j \geq 0 \quad j = 1, 2, \dots, n;$$

The optimal solution to this problem, Θ^* , yields the efficiency score for a particular DMU, which implies that $\Theta^* \leq 1$. As a result, all DMUs for which $\Theta^* < 1$ are inefficient, while those for which $\Theta^* = 1$ are considered to be 100 percent efficient. Similarly to the above formulation of the input-oriented model an output-based formulation could be offered as follows:

$$\begin{aligned} \Theta^* &= \max \Theta \\ \text{Subject to} \\ \sum_{j=1}^J z_j x_{jn} &\geq \Theta u_{jm} \quad m = 1, 2, \dots, M; \\ \sum_{j=1}^J z_j x_{jn} &\leq x_{jn} \quad n = 1, 2, \dots, N; \\ z_j &\geq 0 \quad j = 1, 2, \dots, J; \end{aligned}$$

Where:

Θ = output technical efficiency measure,

u_{jm} = quantity of output m produced by DMU j ,

x_{jn} = quantity of input n produced by DMU j , and

z_j = intensity variable for DMU j .

In simple terms, in the case of 'non-relaxed' LP, a score less than one means that some other unit(s) from the sample could produce the given level of outputs using less inputs (in output-oriented model), or, could utilize the given level of the inputs more efficiently by producing higher level of the outputs (in the case of input-oriented model). In the case of the 'relaxed' LP, however, a DMU receiving a score of less than 1 could still be considered 'weakly' efficient. This 'weak' efficiency could take place in the case if the optimal solution with positive slacks exists and there is no other DMU which is better in every input or output. Thus, by using the techniques of LP, this comparison results in efficiency ranking of each DMU in the given set, where the highest ranking DMU is considered to be 100% efficient (Sengupta, 1996). Because multiple DMUs could receive the same score, there could be

multiple 100% efficient DMUs in the given set. As a result, DEA 'envelops' the data set with the boundary points represented by the 100% efficient DMUs.

According to Charnes et al. (1994), the basic concepts and methods of DEA are now incorporated into four models: CCR, BCC, Multiplicative, and Additive. The authors summarize the interpretive possibilities of each of these models as follows:

1. The CCR (Charnes, Cooper and Rhodes, 1978) ratio model yields an objective evaluation of overall efficiency and identifies the sources and estimates the amounts of the identified inefficiencies.
2. The BCC (Banker, Charnes, and Cooper, 1984) model distinguishes between technical and scale inefficiencies by estimating pure technical efficiency at the given scale of operation and identifies situations of increasing, decreasing, or constant returns of the DMU.
3. The Multiplicative model provides a log-linear piecewise approach to the Cobb-Douglas production function (Charnes, Gallegos and Li, 1996).
4. The Additive model and the extended Additive model express the efficiency results in terms of Pareto optimality (Charnes et al. 1994). Both these models can be seen as extensions of the Charnes-Cooper (1962) inefficiency analysis.

DEA models with different assumptions regarding their returns-to-scale would, naturally, produce different interpretations of the data. As a result, the models with the different returns-to-scale assumptions would produce different efficiency frontiers consisting of the set of the 100% efficient DMUs. In this regard, based on the created efficiency frontier, the results of DEA could provide descriptive, as well as prescriptive information to each DMU. Descriptively, results of the analysis could yield the relative efficiency of each DMU in comparison to the rest of the set and in comparison to the efficiency frontier. While prescriptively, DEA could provide some suggestion regarding improvement of the inefficient DMUs. Specifically, it could suggest how much a given DMU must alter its outputs and inputs in order to become more efficient (Soteriou & Zenios, 1998). More details on the scale efficiency models used in this study are provided later.

DEA, BCC model

The BCC model introduced by Banker, Charnes, and Cooper (1984) is a commonly used model for DEA analysis. The main difference between the CCR model and the model of Banker, Charnes, and Cooper lies in how the returns to scale are handled. While the CCR model assumes constant returns to scale, the BCC model is more flexible in that it allows for variable returns to scale. Hence, a given DMU is considered to be efficient by the CCR model only if it is both scale⁹ and technically¹⁰ efficient, while for the same DMU to be considered efficient by the BCC model it must only be technically efficient (Bowlin, 1998). Thus, if a DMU is considered to be efficient by the CCR model, it will also be considered as such by the BCC model, while the reverse is not necessarily true.

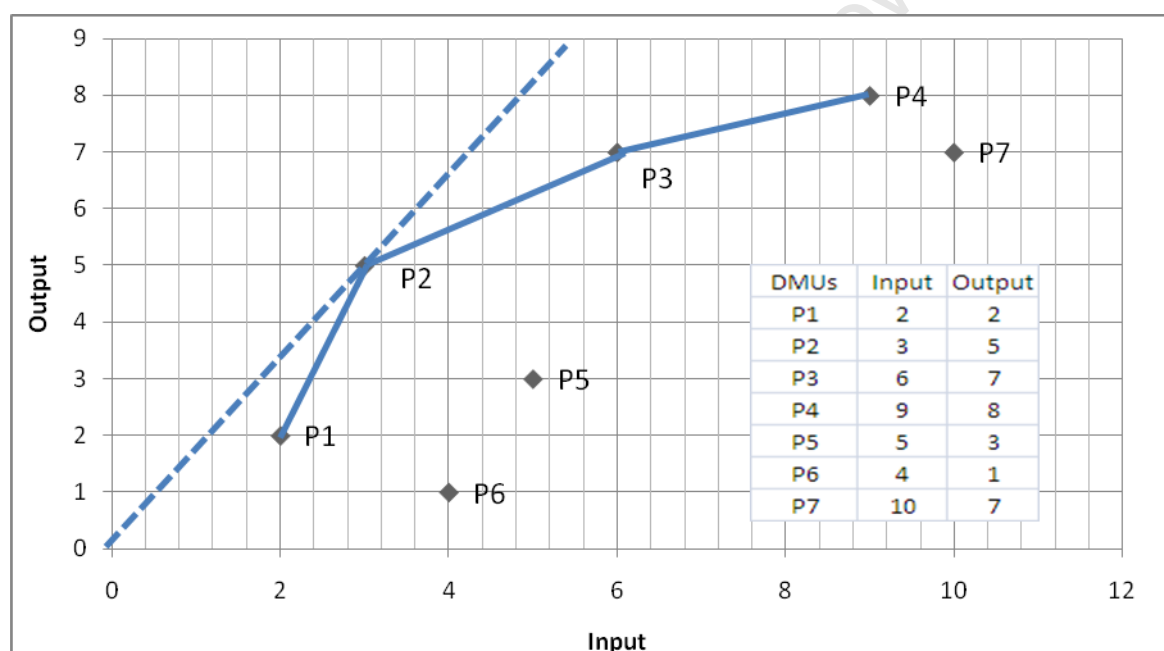


Figure 4-1 DEA: CCR (Dashed line) and BCC (Solid line) Models

In a similar way to the CCR model, BCC makes the efficiency of a given DMU to be contingent on two conditions: the value of proportional reduction being equal to one and all slacks being equal to zero. This, of course, is equivalent to zero distance from the efficiency frontier. Thus, all the sources on

⁹ In DEA, Scale efficiency is a measure of the deviation from the constant return to scale

¹⁰ In DEA, a DMU is said to be **Technically Efficient** if it presents the greatest proportion of the maximum potential output to the actual or observed output in the case of output-oriented model, or the greatest proportion of the minimal feasible input usage to the actual or observed input usage for input-oriented model (from OnFront Reference guide 1998-2000).

inefficiency stem from nonzero slacks and value of proportional reduction being less than one. Similarly to the CCR model, for a given DMU to be qualified as efficient under the input oriented model of BCC, it must simultaneously qualify as efficient under the output oriented model and vice versa. Figure 4.1 illustrates the differences in the enveloping surfaces produced by the CCR and BCC models for a set of 7 DMUs with a single input and a single output.

In Figure 4-1 the dashed line represents the frontier of the CCR model, with constant returns to scale, while the solid line depicts the enveloping surface produced by the BCC model with the variable returns to scale. As we could see, the CCR model produces an efficiency frontier defined by the single DMU (P2), while the efficiency frontier of the BCC model is produced by the four DMUs (P1, P2, P3 and P4). The DMUs that do not belong to this envelopment surface (or efficient frontier) are operating inefficiently. In both cases, whether one uses the CCR or BCC model, the use of DEA allows for producing of the efficiency frontier consisting of the efficient countries. The efficiency of the countries in this research is determined by how well the set of inputs, one of which is the investment in ICT, is transformed in the output, represented by the ICT infrastructure. Another important productivity measurement analysis functionality of DEA, namely scale efficiency, is used in the present study. A complete description of this functionality is provided next.

Evaluating Efficiency

Let me quickly remind the reader of the advanced notion of efficiency briefly described earlier that will help me introduce the notions and description of the scale efficiency analysis that I intend to do in this section. The DEA approach of efficiency is decomposed into two components: technical and allocative (Deliktas and Kok, 2003). Technical efficiency measures the ability of a DMU to produce maximum outputs from a given set of inputs for a determined period of time. Allocative efficiency measures the ability of a DMU to optimize the use of its inputs given its existing production technologies. A DMU is fully efficient if it cannot produce any more of an output without decreasing another output or increasing an input (Deliktas and Kok, 2003). A DMU is said to be technically efficient when it operates on the efficient production frontier, and technically inefficient when it

operates below the efficient production frontier. The efficient production frontier (BC in Figure 4-2) is the set of all technologically feasible production plans (development policies) with the highest efficiency. A technically efficient DMU may still attain a higher level of productivity by moving upward along the efficient production frontier. Such improvements in productivity can result from improvements in technical efficiency, scale efficiencies, or change in production technology.

Scale Efficiency

Technical efficiency (TE) can be seen as a complex notion if not properly defined. For example if an ICT sector is declared inefficient, it would be good for the decision makers to know the perspective from which the inefficiency occurs. In other words, questions like: has the ICT sector spent too much for too little output? Or is the sector inefficient because there is too little investment to enable it to reach the productivity threshold? In order to be able to answer these questions, an empirical analysis of scale efficiency is needed to complement the analysis of technical efficiency. The details of the scale efficiency analysis models are now discussed. Figure 4-2 below depicts the regions of the scale efficiency referred to in the discussion.

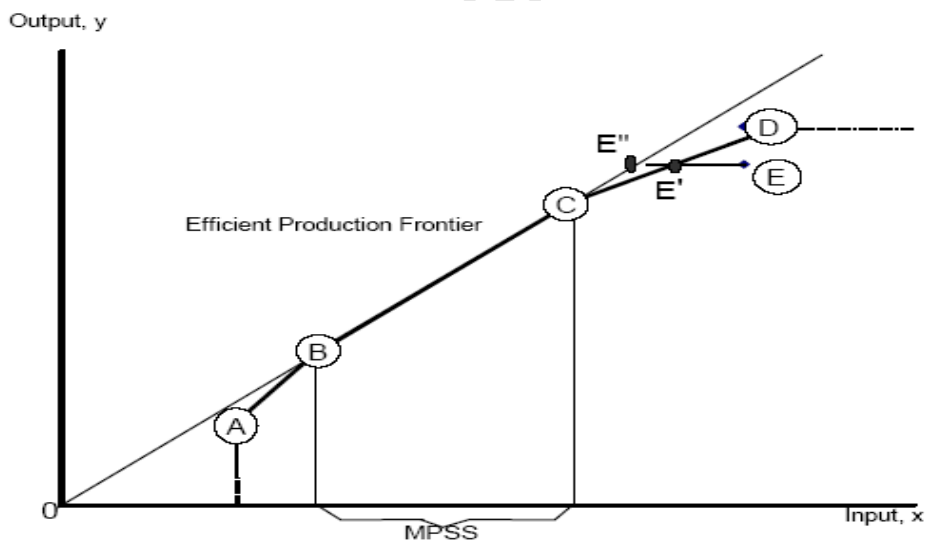


Figure 4-2: Scale Efficiencies and the Efficient Production Frontier (source Banker et al. 1984)

Banker et al. (1984) provide some DEA models for assessing scale efficiency of DMUs: constant returns to scale model (CRS); variable returns to scale model (VRS); and, the non-increasing returns (NIRS) model. The CRS model can assess if an ICT sector is operating on the production frontier (the line through the origin in Figure 4-2). It assumes one unit of input will result in one unit of output (broadly defined). This assumption is not unusual and is in fact implied in ratio analysis. When an ICT sector is technically efficient it will have a CRS (TE_{CRS}) score of 1 (or 100%). When it is not technically efficient it will have a $TE_{CRS} < 1$ and fall below the production frontier. The VRS model assumes one unit of input can result in output ranging from less than one unit to more than one unit. This model computes the improvement outputs needed to reach the efficiency frontier based on the slacks of input variables. When an ICT sector is operating at VRS technical efficiency (TE_{VRS}) it will have a score of 1 (or 100%). This means that no changes in inputs will improve its outputs. When VRS technical efficiency is $TE_{VRS} > 1$ (or 100%), we can infer that the ICT sector has the potential to achieve higher levels of outputs by rearranging the inputs. Finally, the non-increasing returns to scale (NIRS) model tells the analyst the point beyond which any additional inputs would not achieve an increase in outputs for that ICT sector. A TE_{NIRS} score of 1 (or 100%) tells the analyst that the ICT sector is operating at NIRS.

An important aspect of efficiency analysis in this research is the determination of the scale efficiency of the ICT sectors. An ICT sector is Scale Efficient (SE) when $TE_{CRS} = TE_{VRS}$, but when $TE_{CRS}/TE_{VRS} < 1$ the ICT sector is scale inefficient. When an ICT sector is found to be scale inefficient, I compare the NIRS technical efficiency (TE_{NIRS}) to TE_{CRS} to determine the nature of the scale inefficiency. If an ICT sector is scale inefficient, that is $TE_{CRS} < TE_{VRS}$ from an input orientation and $TE_{NIRS} = TE_{CRS}$, the ICT sector is operating at an inefficiently small scale (increasing returns to scale, IRS). On the other hand, when $TE_{CRS} < TE_{VRS}$ from an input orientation and $TE_{NIRS} > TE_{CRS}$, the DMU is operating at an inefficiently large scale (or decreasing returns to scale, DRS). Further, if a DMU scores 100% on both CRS and VRS, we can conclude that the ICT sector is operating at the most productive scale size (MPSS). Figure 4-2 above shows three different regions of the efficient production frontier that are relevant to our analysis: (1) the segment AB represents increasing returns to scale (IRS); (2) the segment BC

represents scale efficiency SE and MPSS; and, (3) the segment CD represents decreasing returns to scale (DRS). These concepts are important to my analysis as they can help me understand where the countries in my study are operating on the efficient production frontier and what kinds of adjustments they can make to improve their performance. This will help me provide alternative combinations to the investments policies if necessary.

Next, the objective of another aspect of my empirical analysis is to isolate yearly changes in the implementation of the ICT infrastructure, or revenues generated from the ICT sector as these values change from year-to-year. This is accomplished by means of using the Malmquist index, covered in the following section.

4.2 DEA Based Malmquist Index

As described in Chapter 3 the neoclassical growth accounting theory claims that economic growth could be determined by two factors. The first factor, resource accumulation, could lead to high rates of growth, albeit, due to the law of diminishing return, only for a limited period of time. Thus it is the second factor, growth in productivity which is necessary for sustained economic growth. Productivity in neoclassical growth accounting is commonly referred to as Total Factor Productivity (TFP) and its growth. One approach to measuring TFP growth is the Malmquist index developed by Caves, Christensen and Diewert (1982) based on a set of ideas originally suggested by Malmquist (1953). Later, Färe, Grosskopf, Norris, and Zhang (1994) developed a Malmquist index model based on the DEA. Essentially, the approach is based on performing DEA analysis in two points in time; let us say T1 and T2. For illustration let us again consider a set of 7 DMUs (P1..P7), each with single input and a single output. Figure 4-3 below shows the constructed efficiency frontier at the time T1, and, designated by a dashed line, inefficiency of the DMU P5 relative to the frontier.

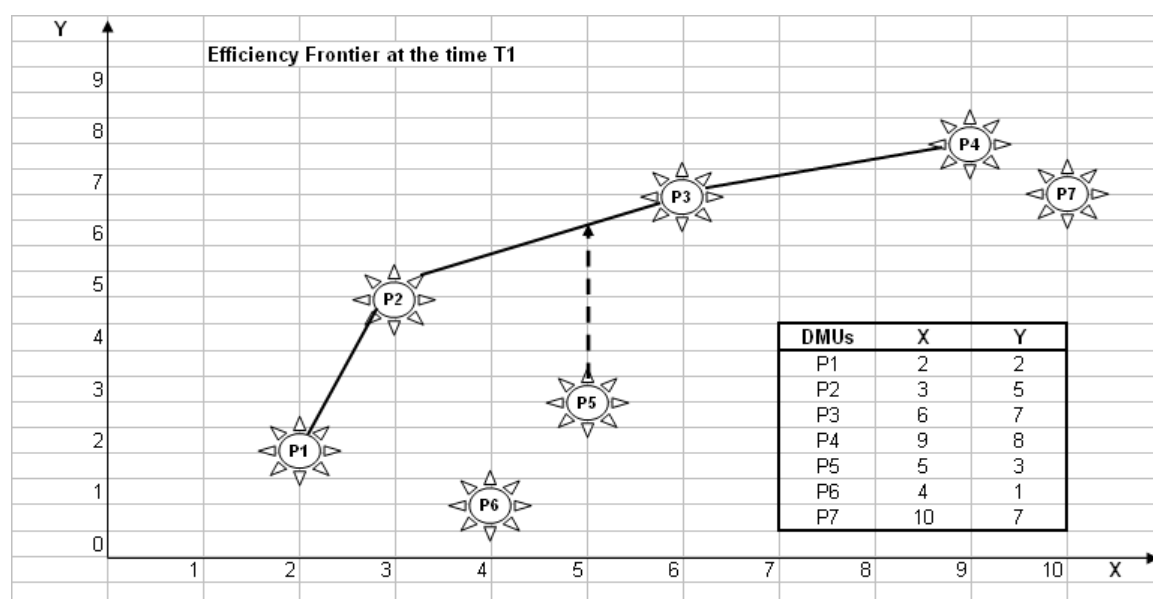


Figure 4-3 Efficiency Frontier, Efficient and Inefficient DMUs

Then, for a given DMU, the period of time ($T_2 - T_1$) could be represented by the distance between the data point at the time T_1 and the data point at the time T_2 . For each DMU the distance between these data points would be reflective of the change in this DMU's TFP, which is represented by the Malmquist index. In the case of economic growth it would be expected that the efficiency frontier for a given set of DMUs would change its position over a period of time. Let us suppose that three DMUs, P2, P3 and P5, have changed their position over the period of time $T_2 - T_1$ (as depicted in the Figure 4.4). Such change is reflected by the new positions of these DMUs, as well as a new position of the efficiency frontier (represented by dashed line). As a result, for a given period in time, change in the position of each DMU could be perceived as consisting of the two components. The first component is the change in distance between a given DMU and the efficient frontier, which reflects the changes in technical efficiency, and the second is the change in position of the efficient frontier itself, reflective of the technological change that took place over ($T_2 - T_1$) period of time.

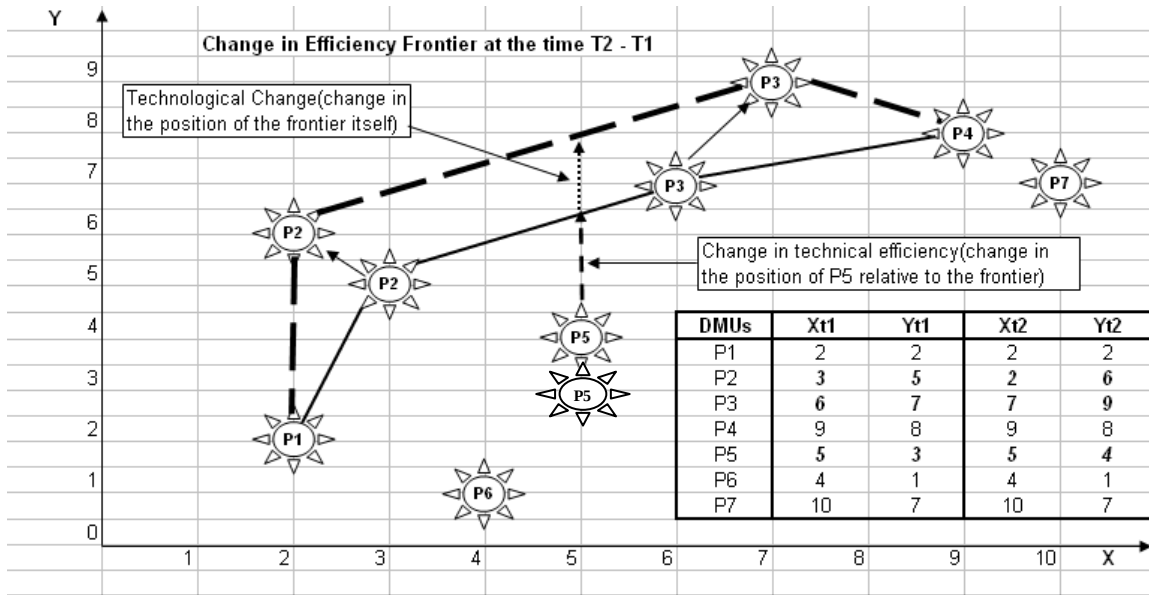


Figure 4-4 Components of Malmquist Index: TC and EC

Figure 4-4 depicts such changes in the frontier, as well as the change in the position of the DMU P5 relative to the frontier. In this case change in the position of DMU P5 relative to the frontier, less the change in the position of the frontier itself, would be represented by a particular value of the Malmquist index for DMU P5. Formally, the Malmquist (output-oriented) TFP change index between period 0 (the base period) and period 1 could be defined by using the concept of distance functions $d^t(x, y)^{11}$ and is given by following (cf. Milana & Zeli 2002):

$$TFP_m(y_0, x_0, y_1, x_1) \equiv \left[\frac{d^0(y_1, x_1)}{d^0(y_0, x_0)} * \frac{d^1(y_1, x_1)}{d^1(y_0, x_0)} \right]^{1/2}$$

Which is equivalent to:

$$TFP_m(y_0, x_0, y_1, x_1) = EC * TC = \frac{d^1(y_1, x_1)}{d^0(y_0, x_0)} \left[\frac{d^0(y_1, x_1)}{d^1(y_1, x_1)} * \frac{d^0(y_0, x_0)}{d^1(y_0, x_0)} \right]^{1/2}$$

¹¹ In the case of output-orientation distance function is defined as $d^t(x, y) = \min \{d : (y/d) \in A^t(x)\}$, where $A^t(x)$ is the set of all possible levels of the output y for a given technology t and the input level x (Milana and Zeli 2002)

Where EC is an index of efficiency change between periods 0 and 1

$$EC \equiv \frac{d^1(y_1, x_1)}{d^0(y_0, x_0)}$$

And TC is an index of technological change between periods 0 and 1

$$TC \equiv \left[\frac{d^0(y_1, x_1)}{d^1(y_1, x_1)} * \frac{d^0(y_0, x_0)}{d^1(y_0, x_0)} \right]^{1/2}$$

DEA, Summary

I have described how by using DEA I am able to assess the technical efficiency, the scale efficiency and obtain the indexes of productivity values changes (called TFP) over the years for each country's ICT sector in this research. The choice of DEA is warranted, for this technique has been widely used in the research investigating technical efficiency of firms, nations and sectors. More specifically DEA has been used by researchers at international development institutions (such as the UNDP and World Bank) for decades. There are many advantages to using DEA, but it has some weaknesses. Thus, for example, it would appear that DEA would require homogeneity of the DMU within a given sample, for this type of analysis makes sense only if one determines relative efficiency of similar DMUs. It is also quite obvious that the presence of any outliers within a set of DMUs would be detrimental to analysis due to inevitable distortion of the enveloping surface. In these two cases the problems lie not within the technique of DEA itself, but are inherent to the data set that is the subject of analysis. Thus, to maximize the benefits offered by DEA I analyze the data set that I use with the purpose of determining whether or not it contains any obvious outliers and whether the data of the West African countries under study are homogenous. In the case of obvious differences in the results being interpreted, the differences will be outlined during the discussion of the results of the DEA analysis. In order to analyze more complex relationships between input and output and the variables in general, MARS is used, an overview of which is presented next.

4.3 Multivariate Adaptive Regression Splines

The Regression Splines approach is used in this research because of its flexibility for modeling complex relationships and interactions among the variables of this study and the Cobb-Douglas production function upon which some of my analysis is based. Ordinary Least Squares regression attempts to model the relationship between outcome and predictor variables using a single function (e.g. linear, log linear) of the predictor variables. It describes the contribution of each predictor (independent) variable with a single coefficient. To capture any relevant non-linearity, higher order terms (x^2 , x^3 , etc.) may be introduced but the coefficients of these terms will be estimated using the data globally and thus, local features of the true function might not be captured (Hastie & Tibshirani, 1990). A Regression Splines (RS) approach models the relationship between outcome and predictor variables as a piecewise polynomial function $f(x)$ which can be obtained by dividing the range of each predictor variable into one or more intervals and representing f by a separate polynomial in each interval (Hastie, Tibshirani, & Friedman, 2001). A regression spline function can be expressed as a linear combination of piecewise polynomial *basis functions* (BF) that are joined together smoothly at the knots (Figure 4-5), where a *knot* specifies the end of one region of data and the beginning of another (Steinberg, Colla, & Martin, 1999).

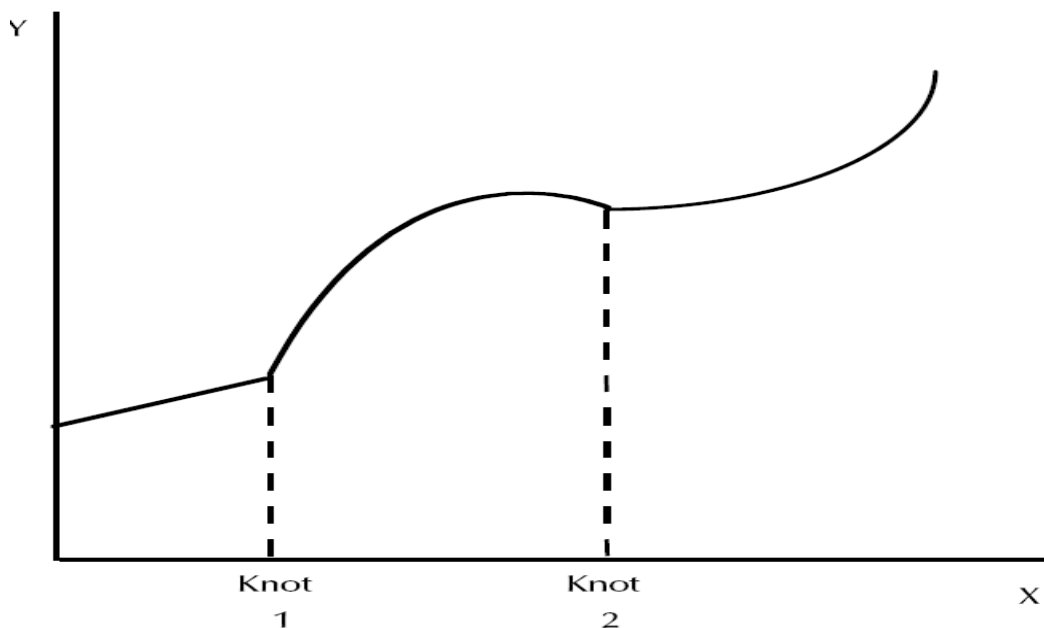


Figure 4-5: Illustration of Knots in a Regression Splines plot

The coefficient of each basis function is estimated by minimizing the sum of square errors, which is similar to the estimation process of regression, but involving local data for the given region. Basis functions are defined in pairs of the form $(x - t)_+$ and $(t - x)_+$ where t is the knot. The '+' represents positive part, thus, $(x - t)_+$ means $x - t$ if $x > t$ or 0 if otherwise and $(t - x)_+$ means $t - x$ if $x < t$ or 0 if otherwise (Hastie and Tibshirani, 1990; Hastie et al., 2001). The MARS approach builds a model in a two-phase process, using a forward stepwise regression selection and backwards-stepwise deletion strategy. In the forward phase, MARS builds an overfitted model by adding basis functions. In the backward phase, basis functions that have the least contribution to the model are deleted and the model is optimized (Steinberg et al, 1999). In the forward phase, MARS starts with just a constant in the Initial model and then begins the search for a Variable-Knot combination that would result in the best improvement in the model, where improvement is measured by the change in the mean squared error (MSE). Adding a BF always improves the MSE. This search process is then repeated in order to identify the best Variable-Knot combination to add given the BFs already in the model. This forward search process continues until a user-specified limit on the number of BFs (i.e. Maximum Number of BFs) is reached. In the Backward Phase, Starting with the largest Forward Phase model, MARS determines the BF which, using a residual sum of squares criteria hurts the model the least if dropped. After refitting the now-pruned model, MARS again identifies the next BF to drop (using a residual sum of squares criteria). This process is repeated until all BFs have been eliminated. The end result of this deletion procedure is a unique sequence of candidate models.

Similar to OLS regression, larger forward stage models will have higher R^2 values than smaller forward stage models but will also be more complex. Thus a complexity measure, called the GCV, is used to penalize larger models in a manner that is similar to the role of the AIC (Akaike Information Criterion) for regression models. This penalty is based on the degrees-of-freedom (df) charged per knot, which can be specified manually or determined automatically using methods such as random selection of a portion of the data for testing, or 10-fold cross validation. In this work I use 10-fold

cross validation, which is a well known data mining technique (Hastie, Tibshirani and Friedman, 2001). It should be noted that both regression and regression splines can identify the order of importance of the independent variables in a predictive model, and estimate the value of the coefficient for each independent variable. However, if the impact of an independent variable on the dependent variable is conditional¹², then regression splines can identify such conditions while OLS regression cannot. Thus, the regression splines approach provides the means for exploring issues relevant to this research that OLS regression cannot.

4.4 The Data of this Research

To investigate my research question I collected data from the UN, ITU and World Bank for the period of 1993-2005, and did various empirical analyses on the data in order to address the concerns stated in the specific research questions. The selection of the sample of the countries to investigate was guided by the usual approach for any economic or social investigation of the African countries. In some of the reports released by the UN and other development agencies, Africa is studied by geographic regions namely North Africa including Algeria, Morocco, Mauritania, Tunisia, Libya, and Egypt. The second subgroup is southern Africa comprising the Republic of South African, Mozambique, Botswana, Angola and Lesotho. The Central African region is composed of Gabon, Congo, Zaire, Republic of Central Africa, Tchad and Burundi. The Eastern Africa comprises Tanzania, Somalia, and Uganda, which is sometimes studied along with the central African region. West Africa is by far the largest region with regards to the number of its countries. Benin, Burkina, Cameroon¹³, Cote d'Ivoire, Mali, Niger, Nigeria, Ghana, Sierra Leone, Liberia, Gambia and Senegal compose this group. I began my research with the intention of systematically analyzing a large number of African countries. I had to quickly change my mind when I started putting together the data for analysis. First of all, the data set is not homogeneous. There were many holes and discrepancies. As an example, some countries yielded five years of data whereas others yielded ten. In some countries, statistical data about education is readily available, while it is almost impossible to find such information for other

¹² The impact of a variable is conditional because depending on its value, it can be either negative or positive

¹³ Although Cameroon is geographically situated in central Africa, it has usually been studied along with western African countries in UN reports.

countries. Finally, I decided to build a small but more homogenous set of data. In that sense, I subdivided the West African group into two subgroups: one identified as English-speaking and the other as French-speaking based on the heritage from their colonial past. The sample in question in the present study is the French-speaking West African countries. Table 4-1 below summarizes the background of these countries.

Countries	Population (millions)	% Living In urban area	Land Area (Sq km)	Life Expectancy (years)	GDP per Capita 2005 Constant US\$	Literacy rate %	HDI	HDI Rank 2006
Benin	8.6	40	110620	61	513.3	56	0.411	163
Burkina	15.2	19	274122	52	389.4	53	0.342	174
Cameroon	19.0	56	465400	51	932.2	75	0.499	144
Cote d'Ivoire	20.5	48	318000	57	880	60	0.396	164
Mali	12.7	31	1240000	48	472.5	46	0.338	175
Senegal	12.2	42	192530	55	739.8	39	0.43	156

Table 4-1 Demographic Background of the countries. Source UNDP 2006

4.5 Limitations of Data Set

ICT is a relatively new technology for all the countries of interest in this research. Therefore statistics or archived data is not readily available at one source. Thus collecting all the necessary data and compiling them in a homogeneous manner was the biggest challenge of this work. Fortunately, I was able to compile data from various sources to build an understandable set of variables capable of explaining the objects of my inquiry. In addition to the ITU yearbook and World Development Index (WDI) published by the World Bank along with the UN database, which provided most of the data used in this study, complementary information was drawn from the UNDP database, national statistical institutes, various scientific publications, and the Toronto Public Library. In order to comply with the methodology and to harmonize some data sets, certain variables have been computed.

4.6 Sources of Data

As stated above the dataset was compiled from data collected from the ITU, UN and World Bank. The ITU is one of the UN agencies which specializes in the telecommunication sector, and is the most reliable source of data for the ICT sector for its telecoms aspect. The database released each year includes data for all countries in the world. The ITU yearbook released each year is a complete source of relevant information for research in the area of telecommunications. In addition to that, ITU publishes research papers and defines frameworks for researchers interested in the sector. As stated earlier, the yearbook is limited to the telecoms aspects of ICT, therefore, other sources were identified to provide other proxies and variables which were needed in my study. The United Nations Millennium Development Goals put together a good source of inspiration and also a reference for this kind of study. In several publications, the UN provides frameworks for studies on development. The UN releases several development indices against which one can measure the impact of the sector being studied. Variables such as the Human Development Index, Literacy rate, GDP, and many others were pulled from the UN's statistical databases. Thirdly, the World Bank Development Group which also compiles statistical profiles of countries is by far the most complete in terms of variety of indices. It offers a database that is very well organized including all countries in the world, presented in several dimensions, including data related to the millennium goals of the UN, the development indices, education, health, and agriculture, ICT, basic infrastructure, etc.

4.7 The variables

The diverse origin of the variables used in combination in order to conduct this research obliges me to give more details about the origin of the variables and a clear definition for the understanding of their real content and relevance to the study. Some variables were computed because they were not available at one source in the form in which they were needed for this research. In the table below, I provide the computational method and the origin of the variables which they are derived from if necessary. Here is the complete list of databases and programs from which the data for the analysis was drawn:

1. UNDP (United Nations Development Program)

2. WDI (World Development Index)
3. ITU (International Telecommunication Union)
4. WB (World Bank)
5. NS (National Statistics Institute)
6. DR (Derived from other variables)
7. TPL (Toronto Public Library)

Variable name	Definition	Source
ICT-INVEST	Total investments in telecommunication sector	ITU
ICT-STAFF	Total Staff in telecommunication sector	ITU
ICT-REVENUE	Total revenue from the ICT sector	ITU
LANDLINES	Number of fixed telephones lines	ITU
CELLULAR	Number of mobile phones	ITU
INTERNET	Number of estimated internet users	ITU
TRAFFIC	Total number of outgoing telephones minutes	ITU
POPULATION	Total population	ITU
HOUSEHOLDS	Total number of households	ITU
Variable name	Definition	Source
ICT/GDP	ICT Investments as a percentage of GDP = Investments in ICT/GDP * 100	DR
HH/Tel	Percentage of households with a telephone = Number of landlines / total number of households * 100	DR
PAYPHONE	Number of public payphones	ITU
GDP	Gross Domestic Product	UNDP
GDP PPP	Gross Domestic Product purchasing power	UNDP
LITERACY	Literacy rate	WDI and TPL
PRIMARY	Enrollment in primary school as a percentage of total	WDI
SECONDARY	Enrollment in secondary school as a percentage of total	WDI
TERTIARY	Enrollment in tertiary school as a percentage of total	WDI
HDI	Human development index	UNDP
ECONDFREE	Economic freedom index	TPL
TFP (TOTAL FACTOR PRODUCTIVITY)	This index measures the residual growth of the sector as an aggregate output to aggregate input	DR
HEALTH	Annual public investments in the health sector	WDI
EDUCATION	Annual public investments in the education sector	WDI
LIFEXPECT	Life expectancy index	UNDP and TPL
LAND	Land area of the country	TPL
ROAD	Total Length of roads in the country	TPL

AIRPORTS	Number of airports in the country	TPL
SEAPORTS	Number of seaports in the country	TPL
ROAD/LAND	Percentage of roads relative to the land area = $(ROAD / LAND) * 100$	DR
RAIL/LAND	Percentage of railways relative to the land area = $(RAILWAY / LAND) * 100$	DR
RAILWAY	Total length of railways in the country	DR
RMONTHCHG	Residential telephone monthly charges	ITU
BMONTHCHG	Business telephone monthly charges	ITU
RCONCHG	Residential telephone hook up charges	ITU
BCONCHG	Business telephone hookup charges	ITU

Table 4.2 Variables used in this study

Conclusion

Collecting data and putting together a homogeneous dataset for the study of the ICT sector in Sub-Saharan African (SSA) countries is a big challenge. In spite of the availability of most ICT related data on the ITU database released each year, the data released is not homogeneous. For some countries data is released as early as 1993 whereas for others, data is only available from 1995 and even later. It is also important to note that there are many gaps in the dataset and alternative sources were consulted to fill these gaps.

4.8 Procedure for the Empirical Analysis

The empirical analysis for this research follows a three step procedure: In Step 1, an analysis of the efficiency of the ICT sectors is conducted. Step 2 is an analysis of ICT sector productivity; finally Step 3 is an analysis of the impact of investments in ICT on social and economic development (as measured by HDI) in the six countries. The following is a description of the details of each step in the procedure:

Step 1: Assessment of Efficiencies

The evaluation of relative efficiencies of the ICT sectors is concerned with finding out the level of efficiency and the scale efficiency of the sectors. If a certain amount is invested, a corresponding level of output is expected, (put in simple terms). An added dimension to this is that the assessment can be made for individual countries, but for comparison many countries can be analysed together to

determine efficient firms and inefficient ones. In chapter five where this topic is addressed, in stage one, technical efficiency of all the countries is computed using the DEA BBC model. Rankings and discussions of benchmarks and less performing countries are presented. Later in the chapter, stages two and three discuss the sustainability and scale efficiency of the ICT sector respectively.

Step 2: Assessment of Productivity

In chapter six, I address the issue of the productivity of the ICT infrastructure. If the investments assessed in chapter five have been efficient, then it could be expected that the ICT infrastructure sector be productive enough to advance the national economy and sustain itself. The productivity analysis starts with an inquiry of the intensity of use of the ICT infrastructure that is built. In the second stage of productivity inquiry, the investment in ICT is compared to GDP over the years to demonstrate the importance and the trend of ICT investments at the national level. The same thing is done with the outcomes as measured by revenue of the ICT sector relative to GDP. The two results are compared to find out if this trend of productivity was sustainable over time. The last two stages include the notion of time lag (productivity index) and scale efficiency measures in the productivity analysis. The DEA-based Malmquist Productivity is used at this stage as the computational model.

Step 3: Impact of ICT

The third step of my inquiry presented in chapter seven deals with the impacts of ICT on development. Different aspects of development are considered here. I investigate the effects of ICT investments on HDI in stage one, then in stage two, I investigate the impact on economic development as measured by GDP and also on social development as measured by Life expectancy and Education. MARS is the computational method used to uncover the relationships among the variables.

Chapter 5: Analysis of ICT Infrastructure Expansion Efficiency

5.0 Introduction

Chapter 5 deals with the Efficiency of ICT Infrastructure Expansion. The reader will recall that a key research question is: How well have the ICT sectors performed with regard to ICT infrastructure expansion which is central to the ICT as an engine of growth argument? To interrogate this question I focus on deriving empirical observations from the data on three critical issues of ICT expansion following a three steps model depicted in Figure 5-1 below. This figure illustrates the logic of the analysis undertaken in the chapter. According to this model, I will respectively assess the technical efficiency, the total factor productivity (TFP) and the scale efficiency.

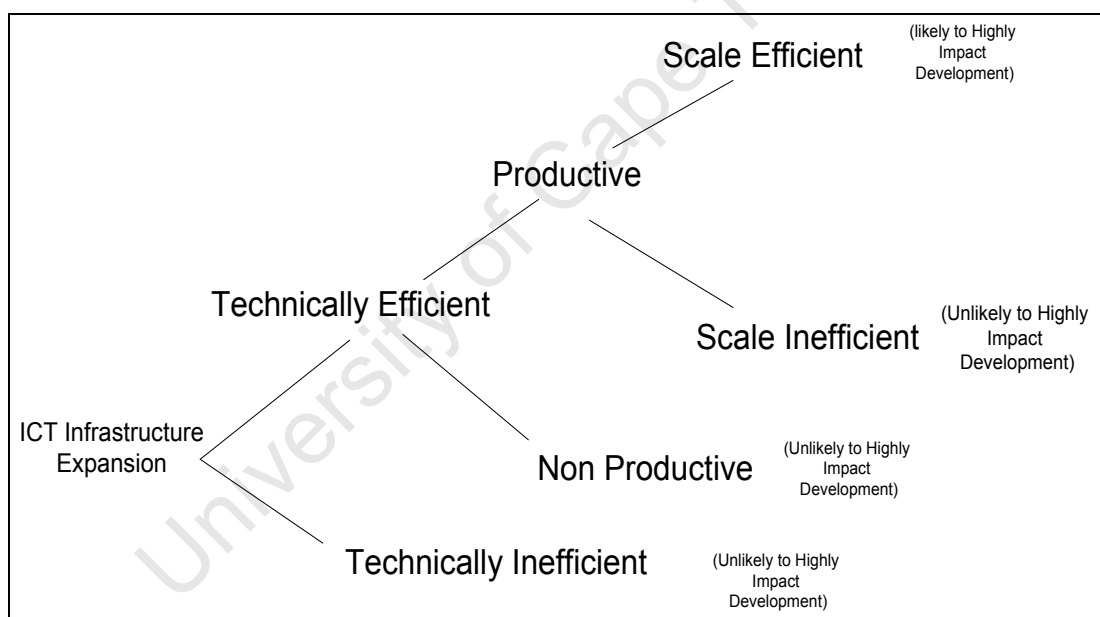


Figure 5-1: Model for studying the impact of ICT for Development

This model lays out the approach to the efficiency analysis of ICT infrastructure expansion. The investigation unfolds as follows: I start by assessing the technical efficiency of the ICT infrastructure expansion. If the ICT infrastructure expansion is not showing any technical efficiency, it is an indication that the ICT infrastructure expansion is unlikely to have high impact on development. Conversely, if there is technical efficiency of the expansion, it is the sign that the ICT infrastructure expansion is likely to spur development but I still need to assess the productive capacity and the scale

efficiency. In any case, in the second step, I interrogate the productive capacity of the sector. If the sector is productive, it is an indication that the sector is likely to sustain itself and grow, hence the possibility to participate in the development of the national economy. The absence of productivity suggests that the sector will not grow without additional investments in its current configuration. The third step is to assess the scale efficiency of the sector. A sector that is scale efficient is likely to impact the national economy without additional investments because this situation shows the maturity of the sector. In this situation, the sector is likely to have lasting impact on the national economy, therefore stimulate development. The primary method used for this empirical analysis is DEA. The variables for this analysis are listed in Table 5-1 below.

Input Variables	Output Variables
Investment in telecommunications ICT	Number of Main Telephone Lines
Number of ICT Staff in telecoms	Number of Cellular Phones
	Percentage of Households with a Telephone
Non-discretionary variables	
Population	
Number of households	

Table 5-1: List of variables used in DEA and Productivity Analysis

After liberalization of the telecommunication sectors in African countries, the development of ICT was characterized by the spending of huge sums of money in building new telecommunication infrastructure as part of the backbone of their ICT sector. In the present analysis of ICT infrastructure expansion, the objective is to assess how the investments of capital and the staff (used as the input variables) have contributed to the expansion of ICT infrastructure (main telephone lines and mobile phones used as the output variables); hence the choice of variables. Population and Number of households are non-discretionary variables only used to put in perspective the results but are not used in the computation. Parts of the ICT artifacts are fiber optic acquisition, applications development, ICT capacity building to list a few, but these variables were not available to me at the time of this analysis.

The chapter is organized as follows. Section 5.1 starts with a descriptive statistical analysis of ICT infrastructure expansion in the countries in this study. Section 5.2 provides a short discussion of the models used in the analysis. Section 5.3 presents the analysis of technical efficiency of expansion. Section 5.4 presents the scale efficiency analysis of ICT expansion. Section 5.5 presents an analysis of total factor productivity of ICT expansion. And finally, Section 5.6 presents an analysis of relative ranking of the ICT sectors with regard to the best performing countries relative to the others in this analysis referred to as 'Best Practice'.

5.1 Descriptive Statistics on ICT Infrastructure Expansion

The statistical results discussed in the present section are intended to assess the progress made by each country in the study with regards to their ICT infrastructure expansion over the period of study. Of all the elements that compose the ICT infrastructures, attention has been especially given to two in the present analysis: the development of landlines and mobile phones. Therefore, the following discussion is going to be exclusively about these two aspects of the ICT infrastructure expansion. There was not enough consistent available information about the other components of the ICT infrastructure to include them in the present discussion at the time of this research, as said earlier. It is conceivable that elements such as cybercafés and fiber optic cable developments could have been included in the current discussion if they were available. For ease of presentation, I have presented the results in two different figures. The figure below (Figure 5-1) presents the results for Cameroon, Cote d'Ivoire and Senegal. This will be called Group 1 in the discussion. Results for Group 2 composed of Benin, Burkina Faso and Mali will follow in Figure 5-2.

The ICT infrastructure expansion performance of the countries varies widely. Three of them – Côte d'Ivoire, Senegal and Cameroon have been more successful than the others (Figure 5-2). However, Côte d'Ivoire stands out for its explosive growth in the number of cellular telephones and considerable expansion in the area of landline capacity. Starting from zero cellular telephones in 1993, this segment grew gradually to just under 100,000 in 1998 then skyrocketed to just over 1 million in 2002, and then doubled in only 2 years to 2 million cellular phones in 2004. The number of

cellular phones is still rapidly growing in this country, numbering close to 2.5 million units in 2005, making Côte d'Ivoire the largest cellular telephone market of the six countries. Côte d'Ivoire also led progress in the area of telephone land lines, increasing from just above 100,000 in 1993 to above 350,000 in 2002. Since 1993 the number of telephone mainlines has been increasing at an average rate of 1.2% each year and outgoing telephone traffic has been almost doubling every 3 years.

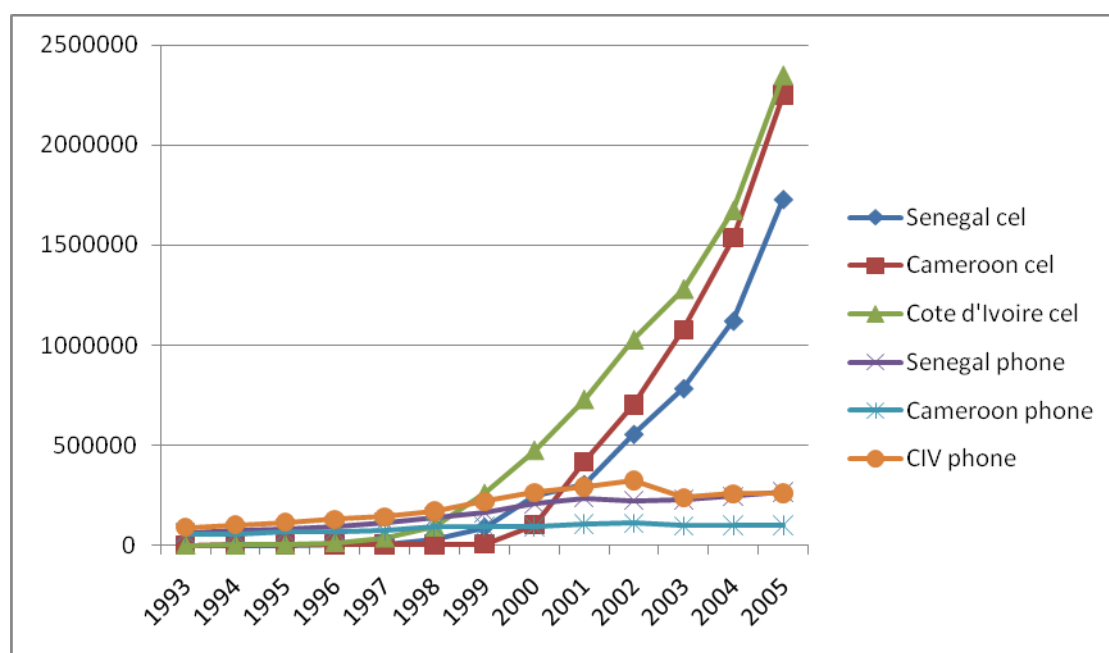


Figure 5-2: Landline and Mobile Phone ownership in Côte d'Ivoire, Cameroon and Senegal

As clearly showed in Figure 5-2, all countries in this study seem to have abandoned their landline expansion after 2002 and shifted their effort to an unprecedented development of Mobile Phones.

Cameroon, the country with the second most rapid expansion in cellular telephones, had very low numbers of Mobile Phones between 1993 and 1999. In 1999 this subsector started a growth spurt that resulted in an increase to about 100,000 in 2000, then a more rapid rise to around 700,000 cellular phones in 2001. Cameroon reached 1 million cellular phones in 2002 and more than doubled this capacity in 2005 with over 2.3 million cellular phones. However, Cameroon has not done as well in the area of landline expansion. Up until 1995 it had only 65,597 landlines. Over the thirteen years investigated in this study, it almost doubled that number to reach 110,881 landlines in 2002. It is important to note that of all the countries in our study, Cameroon has the highest urban population

and the highest GDP per capita (USD 932.2 in 2005). Consequently the slow rate of landline expansion seems counterintuitive; however an investigation of this issue is beyond the scope of this research. Senegal has the second most rapid expansion of telephone landlines, behind Côte d'Ivoire. In 1993, Senegal, the last of this high performing group, had just under 100,000 landlines but increased slowly, doubling its capacity by 2000 when it leveled off. It has also managed explosive expansion of the cellular telephone segment, from zero in 1993 to approximately 450,000 in 2002. Senegal reached 1 million cellular phones in 2004. This sector is pursuing its steady growth with over 1.5 million units in 2005. When one considers that the 2005 GDP of Senegal is just over USD 8 billion, compared to that of Côte d'Ivoire and Cameroon with double this amount in that same year, such expansion is remarkable.

I will now start the discussion about the other three countries in this investigation (Group 2). Before doing so, I will present in Figure 5-3 the result of the analysis of landline and Mobile Phone ownership of the countries in this group.

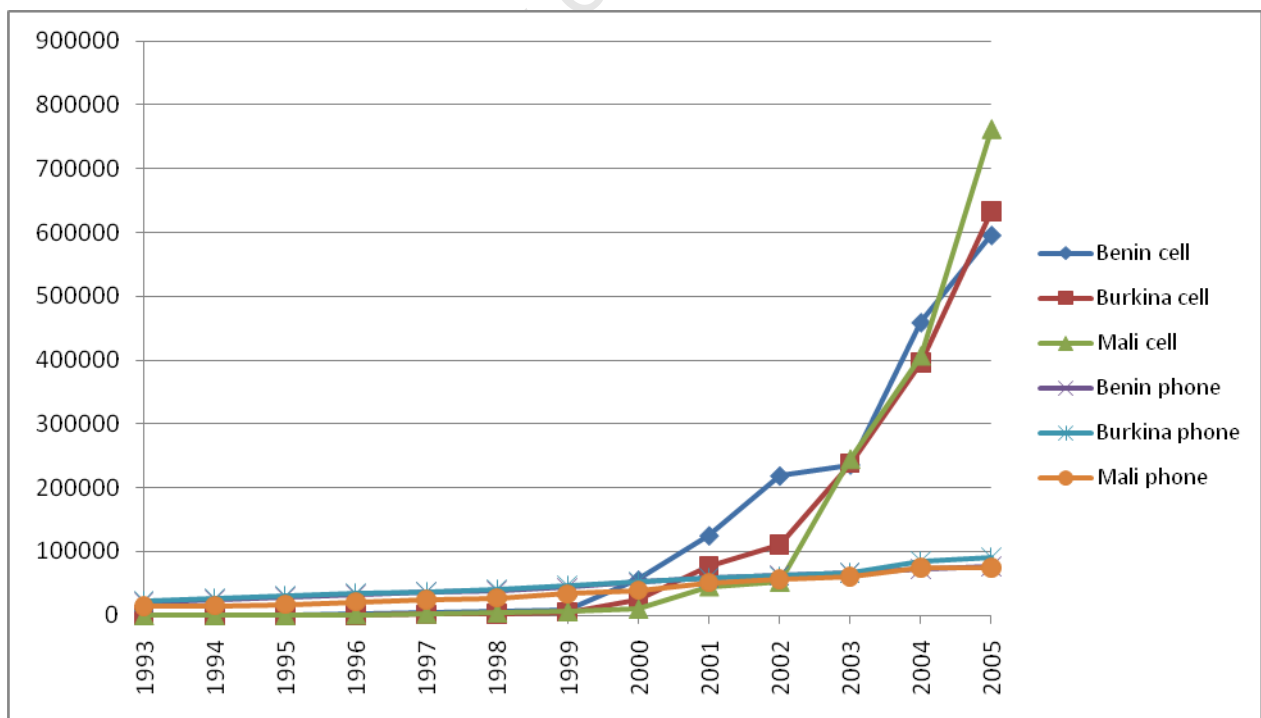


Figure 5-3: Landlines and Mobile Phones ownership in Benin, Mali and Burkina Faso

The second group of countries called Group 2 is composed of Benin, Burkina Faso and Mali, as stated earlier. This group realized modest expansion in their ICT infrastructure for the period of the study compared to the first. In the area of cellular telephones Mali is the leader in this group. Like the other two countries in this group, Mali's cellular phone units remained under a few thousand up until 1999. But expansion took off in 2003 resulting in a rapid rise to about 244,000 cellular telephones in 2003. In the following year, 2004 it reached the 500,000 mark in cellular phone units before its exceptional cellular phone sector development in 2005 with 761,986 cellular phones, the highest in this group. Mali had a more rapid growth in telephone landlines than Benin and Burkina Faso, but started lower with just under 20,000 in 1995, jumped to about 55,000 landlines in 2002 and leveled off. Mali also has the fourth highest population at 12.7 million, the second lowest GDP per capita (USD 472.5) in 2005 of Group 2 behind Benin and the largest land mass, about three times that of Cameroon which has the second largest land mass. Benin and Burkina Faso follow similar patterns in their infrastructure development. Although Benin's cellular phone expansion commenced earlier than that of Burkina Faso in 2002 with over 200,000 units, it resulted in 600,000 cellular phones similar to Burkina Faso in 2005. It is important to note here that Benin has about a third of the population and about two third of the GDP per capita of Côte d'Ivoire. In 1995, Benin had fewer than 30,000 telephone landlines and achieved a limited expansion to about 52,000 by 2005. Concerning Burkina Faso, one would have expected a higher rate of cellular telephone expansion. Although Burkina Faso had the lowest GDP per capita (USD 389.4) of this group in 2005, it has the third highest population behind Côte d'Ivoire and Cameroon, and the lowest urban population. Burkina Faso just doubled its landline capacity, moving from about 31,000 landlines in 1995 to about 60,000 in 2005.

5.2 Models for Analyzing ICT Infrastructure Expansion

For the analysis of ICT infrastructure expansion I utilize four DEA models. I used the Efficiency Measurement System (EMS) and the Onfront software for my DEA models. The four DEA models used here are: constant returns to scale (CRS), variable returns to scale (VRS), non increasing returns to scale (NIRS) and the Malmquist index. The constant return to scale model is concerned with assessing

the pure technical efficiency (TE_{CRS}) of ICT expansion. For TE_{CRS} , I use the maximum average input oriented (CRS_MAX_IN) model to investigate the relative technical efficiencies of the ICT sectors with regard to their utilization of inputs to achieve infrastructure expansion (cf. Table 5-1 for the list of the variables used in the analysis).

Further, I use the VRS model to determine if there is a potential for higher (or lower) levels of ICT expansion efficiencies while holding the inputs constant. The reader will recall that the variable returns to scale (VRS) model assumes one unit of input can result in output ranging from less than one unit to more than one unit. The analysis of the data followed a two step procedure. (1) First, I ran an input oriented CRS model on the data to determine which of the countries were operating at maximum relative efficiency. (2) I then ran an output oriented VRS model to determine if there might be other policy regimes that could help inefficient countries to achieve higher levels of efficiency. Further, I also included the efficient countries as a test to determine which, if any, were operating at most productive scale size (MPSS). For the VRS analysis I ran the maximum average output oriented (VRS_MAX_OUT) model. When VRS technical efficiency TE_{VRS} is larger than 100% it is an indicator that a sector has the potential to achieve higher levels of infrastructure expansion by re-arranging the inputs. The VRS_MAX_OUT model computes the possible improvement factors of the output variables based on the slacks of input variables in order to attain the determined efficiency frontier. Since the CRS analysis alone cannot help to evaluate the scale efficiencies of the ICT sectors, I complement it with VRS analysis. The results of the three models can be read as follows: an ICT sector is scale efficient (SE) when $TE_{CRS} = TE_{VRS}$. However, when a sector is scale inefficient I compare the non-increasing returns to scale (NIRS) technical efficiency (TE_{NIRS}) to TE_{CRS} to determine the nature of the scale inefficiency (Banker et al., 1984). Now if an ICT sector is scale inefficient, that is $SE < 1$ from an input orientation and $TE_{NIRS} = TE_{CRS}$, the sector is operating at an inefficiently small scale (increasing returns to scale). On the other hand, if $SE < 1$ from an input orientation and $TE_{NIRS} > TE_{CRS}$, the sector is operating at an inefficiently large scale (or decreasing returns to scale DRS). Further, if $TE_{CRS} = TE_{VRS} = TE_{NIRS}$, it can be concluded that the sector is operating at most productive scale size (MPSS). This means that under the prevailing structural conditions it cannot achieve a higher level of infrastructure expansion.

Finally, I use the Malmquist Index model to analyze total factor productivity of ICT expansion. In doing this, I am primarily interested in finding out if any of the gains in productivity from investments in ICT are as a result of learning. Specifically I want to know if knowledge accumulation is occurring or whether the ICT sectors are achieving their efficiency gains only from expansion of ICT staff. A full description of the models was provided in Chapter 4.

5.2.1 DEA Empirical Observations of Technical Efficiency

As stated above, I use the scores obtained from the CRS input oriented model to rank the countries from the best performing country to the least performing country with regard to efficiency of ICT investments for infrastructure expansion. In fact, the goal of this analysis is to determine the efficiency of the investment in ICT relative to the infrastructure development over the 13-years period 1993 to 2005 of my investigation in the countries concerned and to compare the performances of the countries in the sample in order to learn from each other's experience; Hence helping in future ICT-I investments decision making. Table 5-2 below summarizes the relative efficiency scores.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	AVG
Senegal	66	73.9	76.8	76	87	83.9	85.6	94.3	100	92.6	91.8	100	100	86.7
Côte d'Ivoire	62	68.5	71.4	71.2	73.8	75.8	72.7	83.7	84.5	88.1	100	100	91.4	80.2
Cameroon	68.9	65.8	65.1	65.6	66.7	73.4	72.6	62.7	73.5	71.3	75.0	82.1	100	72.5
Mali	62.8	100	56.7	56.1	55.7	59	64	65.9	69.8	70.6	76.3	86.7	100	71.06
Benin	59.1	63.8	64.1	71.2	67.4	64.1	63.2	66.1	70.6	72.9	61.5	79.7	100	69.5
Burkina Faso	57.7	64.2	66	62.3	61.6	68.2	70.4	69.7	71.6	70.9	63.3	63.8	69.3	66.0

Table 5-2: DEA CRS Technical Efficiency Scores and Ranking

As shown in Table 5-2, Senegal is by far the most efficient country in the group. It can be considered the 'best practice' country, with an average efficiency score of 86.7% for the entire period of the

study. It is important to note that Senegal has ranked first in ten of the 13 years of the study. It has attained 100% efficiency 3 times, in the years 2001, 2004 and 2005 and has been the benchmark¹⁴ over 78 times in the model. It was cited as the benchmark in almost all the observations in the model. Côte d'Ivoire ranks second with an overall average of 80.2%. Côte d'Ivoire's performance was sustained and progressed as time went on. This country attained 100% efficiency in 2003 and 2004. Mali, which has a small rate of investments in ICT-I relative to the others, surprisingly ranks fourth in the CRS analysis with an average technical efficiency score of 71.06% for the period of the study. Mali operated at 100% efficiency in 1994 and 2004 and was cited as a benchmark six times for its exceptional performance in 2005.

Cameroon, Benin and Burkina Faso, rank respectively Third, fifth and sixth with an average score of 72.5% for Cameroon, 69.5% for Benin and 66% for Burkina Faso. Of these last three countries, Cameroon and Benin only attained 100% technical efficiency in 2005. Apart from that relatively high performance, the scores of the three countries remain relatively modest ranging from 57.73% to 84.16%. According to this model, all of the countries could have been more efficient in the use of their ICT-I investments. More in depth analysis would be needed to determine how exactly these countries could have changed their strategies to optimize ICT-I expansion. One such investigation is to find out what factors affect technical efficiency. This problem is addressed in the next section.

5.2.2 DEA Empirical Observations of Technical Inefficiencies

Although some of the countries attained the efficiency frontier during the period of study, most of them are operating largely below technical efficiency level. In normal circumstances, the countries are expected to operate at 100% efficiency level after a few years of adjustment. In fact, based on the results in Table 5-2, some of the countries under investigation are not showing that they are

¹⁴ A benchmark is a country with such a good performance in a model that its data is used as an example to enhance other countries' scores in the simulation model proposed by DEA. A benchmark can be referenced to several times for each variable in the same year by other DMUs.

moving in that direction. The average technical efficiency score ranges from 66.08% for Burkina Faso to 86% for Senegal. The most salient remark in the performance of these countries is the unusual trends of their results. For example, Mali is 100% efficient in 1994 but falls back into inefficiency until 2004. Another example, Burkina Faso attains 70% efficiency in 1999 and ends at 63% efficiency in the latter years. To recapitulate, apart from a few years out of 13 where some countries operated at efficiency level, the countries are mostly operating below efficiency level. This technical inefficiency has consequences for productivity, the scale efficiency of which is going to be discussed later in this chapter.

5.3 Analyzing Factors Affecting Technical Efficiency

The present section aims to explain the factors affecting technical efficiency. A number of researchers have debated the possible factors that influence technical efficiency. For example, Gholami et al. (2004); and Ngwenyama and Morawczynski (2009) discuss the importance of human capital and ICT capital in the determination of TE_{CRS} . Other factors are also identified as possible predictors of TE_{CRS} , including the economy, the cost structure of the service and other civil infrastructure. In the present investigation, the Technical Efficiency Variable (TE_{CRS}) was used as the dependent variable and several other variables were used as independent variables, including GPDPPP, LITERACY, telecommunication service costs¹⁵, and other civil infrastructure variables such as (ROAD/LAND, RAILWAY/LAND, AIRPORTS and SEAPORTS ref. Table 4-2). Before running any regression for the current model, I decided to run a correlation analysis to have a better appreciation of the nature of relationships between the predictor variables in question and identify potential autocorrelations. Table 5-3 below summarizes the results of the correlation analysis of the selected variables.

¹⁵ Telecommunication Service Costs or COST for short is the average of all the telephone service charges including Business and Residential hook up charges, Business and Residential telephone monthly charges listed in Table 4-2.

To investigate these regression models I selected a set of candidate explanatory variables for this analysis from the same ITU and UN databases from which I drew the rest of the data. In the economic factors category, I use GDP per capita and usage fees and tariffs (computed as an average of residential and business connection charges plus business and residential monthly charges of the telephone services). In the human capital category, I consider the literacy rate of adults aged 15 and older. I would have liked to use annual university graduation rates and many other variables but I could not obtain these data for all the countries in question. Consequently I was limited to use the following variables for the present analysis: For the geography and infrastructure category, I consider: (1) land area; (2) kilometers of highway; (3) kilometers of railway; and (4) the number of airports and seaports as candidate explanatory variables. I am not suggesting that this is the complete set of factors that affect ICT-I expansion. There are clearly other variables such as social capital which were not available to me at this time.

	COSTS	GDP	LITERACY	ROADS/LAND	RAIL/LAND	AIRPORTS	SEAPORTS
COSTS	1						
GDP	-.236(*)	1					
LITERACY	-.167	.727(**)	1				
ROADS/LAND	-.116	.698(**)	.334(**)	1			
RAIL/LAND	.618(**)	.013	-.116	.132	1		
AIRPORTS	-.706(**)	.461(**)	.434(**)	-.669(**)	-.669(**)	1	
SEAPORTS	-.134	.751(**)	.483(**)	.450(**)	.450(**)	.339	1

Table 5-3: Pearson Correlation Matrix (78 observations; * denotes significant at 0.05 level, ** 0.01 level 2-tailed test)

From the correlation analysis results (Table 5-3 above), it can already be concluded that there are some strong correlations worth commenting on. The analysis shows strong positive correlations between: Literacy and GDP; Roads/Land and GDP; Rail/Land and COSTS; Seaports and GDP. There are also strong negative correlations between: Airports and Costs; Airports and Roads/Land; Airports and Rail/Land. Finally, there is a moderate negative correlation between COSTS and GDP. I would like to further comment on this last result. The negative correlation between GDP and COSTS would suggest that the service costs of ICT are negatively correlated with the purchasing power of the populations. This result is consistent with that of other analyses involving the purchasing power of the populations of the countries under study and the costs structure of the telecommunication service and confirms most of the findings in this study.

I will now discuss the regression analysis. The MARS computational model was used for the regression analysis. I ran two different models of regression that will be discussed here. The first model is the Ordinary Least Square (OLS) and the second is the Splines regression. Readers will find the full description of the MARS models in chapter 4 but I will quickly remind here that the OLS regression assumes a linear relation between the predictors and the target variable whereas the Splines regression analyses how different ranges of the predictor variables impact the target variable. Therefore, running an OLS alone in the case of complex relationships between the predictor variables and the target variable may not be sufficient since it might not capture all the regions of impact of the predictor variables; further, it would certainly not give any indication of interactions between the predictors. The results of the OLS model are displayed in Table 5-4 below. The results of the Splines regression are discussed in section 5.3.1.

Dependent Variable: TE CRS		R-squared		0.43227
		Adjusted R-squared		0.40116
		Uncensored observations		78
		Right censored observations		0
		Total observations		78
VARIABLES	ESTIMATE	Std. Error	T-RATIO	P-VALUE
CONSTANT	80.94813	4.198132	19.28108	0.0000
COSTS	-0.42488	0.08130	-5.22615	0.0000
GDP	0.03254	0.00819	3.97285	0.0016
LITERACY	0.08037	0.10337	0.77749	0.0000
AIRPORTS	-0.68212	0.11390	-5.98854	0.0000
Regression Validation Statistics				
S.E. of regression	9.27969	F-statistics		13.89536
Residual Sum of Squares	6286.21933	P-value		0.00000
Regression Sum of squares	4786.26129	[MDF, NDF]		[4, 73]

Table 5-4: Summary of the Ordinary Regression Statistics.

The R^2 of the OLS analysis = 0.43227. This would suggest that 43% of the variance of TE_{CRS} is explained by the statistically significant independent variables. This result is satisfactory because I am well aware that in setting up this model, I have omitted many of the possible predictors of technical efficiency as stated earlier. Other variables such as number of technical schools, electricity,

enrollment in school, and many others – had they been available to me - would have helped build a stronger model. Nevertheless, in spite of the relatively small number of variables and observations (78), the p-values of the validation statistics are acceptable within the context of specified level of significance (e.g. 5%); (see Table 5-4), thus allowing scientific discussion of the findings.

Given the results of my regression analysis, I can state with a 95% level of confidence that economic factors (as measured by GDPPP) positively impact the technical efficiency of ICT expansion. As GDP per capita for these countries increases, the technical efficiency of ICT expansion will increase. I can also state with 95% confidence that ICT usage fees and tariffs (as measured by business and residential connection charges) negatively impact TE_{CRS} ; as these charges increase, TE_{CRS} will decrease. ICT services in developing countries are more price sensitive than in developed countries because low levels of income; and small increases in the price of services can push individuals out of the market and inhibit access for newcomers. This is not surprising as the GDP per capita in these countries is relatively low (compared to more developed countries like Canada, US, etc.), therefore ICT usage fees and tariffs can be a burden to large segments of the populations of developing countries.

Education level as measured by the variable LITERACY is another predictor of technical efficiency in this model. Further the model suggests that this variable has an impact on TE_{CRS} . This result is consistent with that of many researchers on the topic of ICT and development in developing countries who usually point to the lack of literacy as a major obstacle to the expansion and use of ICT. The current result also suggests that the higher the level of literacy in the country; the more likely they are to use ICT therefore improving the efficiency of its expansion. Finally, contrary to the belief that civil infrastructure would help in ICT infrastructure expansion, as hypothesized by several researchers (Rauch, 1995; Munnell, 1992) and the popular wisdom that ICT infrastructure will follow highways, road and railway construction, the results of my analysis suggest that AIRPORTS (number of airports) negatively impact technical efficiency of ICT infrastructure expansion. In the case of developing countries the theoretical arguments (Rauch, 1995; Munnell, 1992) which hold that civil infrastructure would have a positive impact on efficiency of ICT expansion are not verified. The

theoretical arguments of Rauch (1995) and Munnell (1992) are understandable, as the expansion of ICT infrastructure depends on existing roads for moving heavy equipment for the construction of microwave towers, and telephone lines are usually strung along existing roads and highways. But given that other civil infrastructure and ICT infrastructure are competing for the same investment resources, investments in one sector impacts investments in another. Further, developing countries have more challenging geographical and infrastructure issues to contend with as they are at an earlier stage of development. As a matter of fact, for most of these countries, building an infrastructure could be the only investment planned for an annual budget. I will now discuss the regions and levels of impact of the different variables from the MARS analysis of the factors affecting technical efficiency.

5.3.1 Splines Analysis of Factors affecting Technical Efficiency

The results of the OLS regression were able to show the general direction of the slopes but did not inform properly about the relationships between the variables. The results displayed in Table 5-4 assume a linear relationship between the predictors and the dependent variable. Given that I am studying different countries with different levels of investment and usage, it was necessary to investigate the relationship between the variables. Since simple regression could not allow me to determine the quantity of any particular variable needed to produce a particular effect, MARS Splines regression, with its ability to expose non-linear relationships and allow an analysis of each BF separately, is a suitable computational method to help in this situation. For this Spline analysis, I set the maximum number of basis functions (BFs) to 180 and the degrees-of-freedom charge per knots to 10 fold cross-validation and allowed for interaction between the variables. I did not want to over-fit the model but to have reasonable parameter settings for the inquiry. The results from the model produced the following combination:

$$TE_{CRS} = 81.3323 - 0.069485 * \max(0, 470 - GPPPP) - 0.73101 * \max(0, AIRPORTS - 20) - 0.261596 * \max(0, COSTS - 2.64185) + 0.816124 * \max(0, LITERACY - 26.60) + 1.72496 * \max(0, 26.60 - LITERACY) + 0.975658 * \max(0, LITERACY - 46.40);$$

The basis functions are summarized in the following table. For ease of discussion, each variable and its impact formulae and the impact zone will be presented in a separate table.

N: 78.00		R-SQUARED: 0.58610		
MEAN DEP VAR: 73.66769		ADJ R-SQUARED: 0.55112		
		UNCENTERED R-SQUARED = R-O SQUARED: 0.98945		
PARAMETER	ESTIMATE	S.E.	T-RATIO	P-VALUE
Constant	81.33227	2.83292	28.70967	0.00000
Basis Function 2	-0.06948	0.01444	-4.81283	0.00001
Basis Function 3	-0.73101	0.12538	-5.83022	0.00000
Basis Function 5	-0.26160	0.05716	-4.57692	0.00002
Basis Function 7	0.81612	0.19305	4.22747	0.00007
Basis Function 8	1.72496	0.48503	3.55642	0.00067
Basis Function 9	0.97566	0.28740	-3.39472	0.00113
F-STATISTIC = 16.75631		S.E. OF REGRESSION = 8.03420		
P-VALUE = 0.00000		RESIDUAL SUM OF SQUARES = 4582.93080		

Table 5-5: Summary of the Spline Regression Statistics.

The R^2 for the Splines analysis model is equal to 0.58; which is much higher than the R^2 of the OLS model which was equal to 0.43227. This model can then explain 58.6% of the variation of the target variable. It is therefore a much stronger model than the OLS and yields more precise information about the technical efficiency than the OLS model discussed earlier. All the p-values of the basis functions are in an acceptable range; therefore allowing interesting scientific discussion. Following the summary statistics presented in Table 5-5, the details about the different ranges of the impact are displayed in Table 5-6 below.

Basis Function	Coefficient	Variable	Expression	Knot
0	81.33228			
2	-0.06949	GDPPP	$\max(0, 470 - \text{GDPPP})$	470.0000
3	-0.73101	AIRPORTS	$\max(0, \text{AIRPORTS} - 20)$	20.00000
5	-0.26160	COSTS	$\max(0, \text{COSTS} - 2.64185)$	2.64185
7	0.81612	LITERACY	$\max(0, \text{LITERACY} - 26.60)$	26.60000
8	1.72496	LITERACY	$\max(0, 26.60 - \text{LITERACY})$	26.60000
9	0.97566	LITERACY	$\max(0, \text{LITERACY} - 46.40)$	46.40000

Table 5-6 Description of the Basis Functions of the MARS model

First of all, the reader will notice that the variable LITERACY impacts TE_{CRS} in three different regions. And from Table 5-6 above, COSTS and GDPPP also impact TE_{CRS} . The nature and direction of the impact are discussed a little later in this chapter.

Variable	Importance
AIRPORTS	100.00000
GDPPP	78.55995
COSTS	73.40623
LITERACY	35.05190

Table 5-7 Importance of the variables of the MARS analysis

For the model in Table 5-6, Table 5-7 above provides a ranking of the variables by order of importance in the model; variables with no importance are not shown because they were not retained in the final model. The reader will notice in Table 5-7 that AIRPORTS is the most important predictor and GDPPP is the second most important predictor; the importance column tells us that GDPPP is important at 78.5% relative to AIRPORTS, followed by COSTS, important at 73.4% and finally LITERACY with is important at 35% important relative to AIRPORTS. I will discuss the impact of each of the variables on TE_{CRS} and the complementarities between the variables next.

Rate of Impact of LITERACY				
Interval	Relevant BFs	Contribution	Slope	Impact
(0.00, 26.60)	$BF8 = \max(0, 26 - LITERACY)$	$(-1 * 1.72496)$	-1.72496	Negative
(26.60, +46.40)	$BF7 = \max(0, LITERACY - 26.60)$	$(1 * 0.81612)$	0.81612	Positive
(46.40, +∞)	$BF9 = \max(0, LITERACY - 46.4) + BF7$	$(1 * 0.81612) + (1 * 0.97566)$	1.79178	Positive
Rate of Impact of GPDPP				
Interval	Relevant BFs	Contribution	Slope	Impact
(470.0, +∞)	$BF2 = \max(0, 470 - GPDPP)$	$(-1 * -0.06949)$	0.06949	Positive
Rate of Impact of COSTS				
Interval	Relevant BFs	Contribution	Slope	Impact
(2.641, +∞)	$BF5 = \max(0, COSTS - 2.641)$	$(1 * -0.26160)$	-0.26160	Negative
Rate of Impact of AIRPORTS				
Interval	Relevant BFs	Contribution	Slope	Impact
(20.0, +∞)	$BF3 = \max(0, AIRPORTS - 20)$	$(1 * -0.73101)$	-0.73101	Negative

Table 5-8 Rate of Impact of Predictor Variables

5.3.2 Discussion of the Findings of the MARS Splines model

The result in the present MARS model is a confirmation of what had already been found in the DEA analysis of this study. As we have seen from the regression analysis, AIRPORTS have no impact on TE_{CRS} if $AIRPORTS \leq 20$. But it has a statistically significant negative impact if $AIRPORTS > 20$. Similarly, COSTS have a statistically significant negative impact on TE_{CRS} when $COSTS > 2.641$. Below that mark, the impact of COSTS has no impact. LITERACY has a statistically significant positive impact on TE_{CRS} in its higher interval. The MARS model here gives us more details about the regions where these impacts occur which will be discussed later. The impact of GPDPP is negative until it reaches the 470.00 mark; then there is no significant impact. The negative impact of COSTS suggests that technical efficiency may be cost sensitive in developing countries. The aspect of cost sensitivity has not been investigated in the current research but the results seem to suggest that cost could be one of the determinants of technical efficiency because as COSTS increase beyond 2.641, technical efficiency is negatively affected. The impact slope has a V shape for LITERACY. When LITERACY is in its lower interval, (e.g. $LITERACY \in 0.00 - 26$) there is a negative impact on technical efficiency. But when LITERACY is in the interval (20-46), its impact on TE_{CRS} becomes positive. When LITERACY is in its higher interval (e.g. $LITERACY \in 46.40, +\infty$), that variable has much steeper positive impact on technical efficiency. This result is consistent with most research in this area that points to literacy as one of the major determinants of the expansion of ICT.

5.4 DEA Empirical Observations on Scale Efficiency of ICT Expansion

The results from the CRS, VRS and NIRS analyses are summarized in Table 5-8-1 and 5-8-2. The objective of this analysis is to determine if there are potential alternative development policy options that could move the inefficient countries closer to the efficient production frontier. However, I start my discussion by examining the VRS results for those countries that ranked very high (at or around 100%) on the CRS analysis. The complete results of the scale efficiency are displayed in Appendix A. I have extracted a few rows of the appendix (Table 5-8-1) for ease of the discussion.

DMU	CRS Score	VRS Score	NIRS Score	SE
Benin 1993	59.14%	100.00%	160407.82%	DRS
Senegal 1993	66.08%	100.00%	242288.51%	DRS
Cameroon 1993	68.98%	93003.54%	93832.29%	DRS
Cote d'Ivoire 1993	62.04%	179793.14%	190301.02%	DRS
Burkina Faso 1993	57.73%	100.00%	485731.39%	DRS
Mali 1993	62.88%	66978.75%	113874.96%	DRS
Benin 1994	63.83%	100.00%	34025.69%	DRS
Senegal 1994	73.98%	100.00%	95061.32%	DRS
Cameroon 1994	65.83%	8541.47%	8541.47%	DRS
Cote d'Ivoire 1994	68.53%	9917.06%	10680.42%	DRS
Burkina Faso 1994	64.21%	100.00%	173019.24%	DRS
Mali 1994	100.00%	100.00%	100.00%	MPSS

Senegal 2001	100.00%	100.00%	100.00%	MPSS
Cameroon 2001	73.55%	150.16%	150.16%	DRS
Cote d'Ivoire 2001	84.56%	113.14%	113.14%	DRS
Burkina Faso 2001	71.64%	175.23%	218.56%	DRS
Mali 2001	69.87%	283.42%	309.55%	DRS
Benin 2002	72.93%	104.05%	140.13%	DRS
Senegal 2002	92.68%	106.23%	117.55%	DRS
Cameroon 2002	71.33%	191.93%	191.93%	DRS
Cote d'Ivoire 2002	88.18%	100.00%	100.00%	IRS

Table 5-8-1 Extract of appendix of scale efficiency

As stated earlier, scale efficiency (SE) is determined by the comparison of the CRS, VRS and NIRS. The scale efficiency can be Increasing Returns to Scale (IRS), Decreasing Returns to Scale (DRS) or Most Productive Scale Size (MPSS), which can be seen as the allocative efficiency. (Ref. scale efficiency section in Chapter 4 for more details about scale efficiency). For doing this, results from these 3 analyses are put side by side (see extract Table 5-8-1) above. The summary of the scale efficiency results is provided in full in Table 5-8-2.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Senegal	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	MPSS	DRS	DRS	MPSS	MPSS
Côte d'Ivoire	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	IRS	DRS	MPSS	IRS
Mali	DRS	MPSS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	MPSS
Cameroon	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS
Benin	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	MPSS
Burkina Faso	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS

Table 5-8-2: Summary of ICT Sector Scale Efficiency with regard to ICT Expansion (See Appendix A)

The variable return to scale analysis assesses technical efficiency devoid of scale effects. It provides information on over investment (or under performance) and the increase/decrease input factors necessary to attain 100% TE_{VRS} given prevailing conditions. A TE_{VRS} score of 100 means that for the given inputs that ICT sector could not have achieved any higher level of outputs. However, TE_{VRS} scores greater than 100 tells us two things: (1) the decision making unit is underperforming; and (2) the potential efficiency improvements that could accrue from alternative production plans (in the current case, alternative strategies for utilizing the ICT investments). Another important component of the analysis concerns determining: (1) if any of the ICT sectors operated at an optimal scale; and (2) for scale inefficient ones, the nature of the inefficiency. This information is important for making future ICT investment decisions. As stated earlier, scale efficiency (SE) is the ratio of TE_{CRS} to TE_{VRS} . A SE score greater than or less than 1 tells us that the economic unit is inefficient.

A close examination of the results from the VRS model shows that the countries in the study become more efficient in the model from the year 2000 onward. This is a good trend because it indicates that the countries, after some mistakes in the allocation of their resources in the early days of ICT-I, are applying better allocation mechanisms. As a matter of fact, in the years 1993 to 1999, few countries were efficient in the VRS model (Table 5-8-1); Burkina Faso and Benin are the two countries with the largest number of VRS efficiency in the early years. At this point I need to explain the good performance of these two countries. In fact, Benin and Burkina Faso's investments in ICT-I were too low compared to its counterparts in the early years especially the number of staff in the ICT sector. From this observation, it cannot be concluded that Benin and Burkina Faso were good examples to

follow for the other countries because they are performing poorly in the CRS and NIRS models in these same years.

As an example of the not so good performance of the two countries in that period, Burkina Faso for instance operated at decreasing returns to scale (DRS) during all the years of the period. For the period before 2000, only Mali operated once at most productive scale size (MPSS) in 1994 (Table 5-8-2). Unfortunately, this trend is not sustained: in the following years, Mali falls back into DRS and comes back to MPSS again only in 2005. Of all countries Senegal has the best sustained progression in the present scale efficiency model. As a matter of fact, Senegal has good performances both in CRS and VRS models from 2000 onwards. It finally attains MPSS in 2001, 2003 and 2005.

Côte d'Ivoire also has similar progress as Senegal but operates at MPSS in 2003 and 2004. Its scores in the three models from 2000 onwards are excellent allowing it to operate at IRS in 2002 and 2005. Of the three big investors, Cameroon is the country with the worst relative efficiency scores in this model. The reason is that this country operated at MPSS only in 2005 and has been operating at DRS most of the time in spite of the very high level of its investments in the ICT-I sector. It would appear that Cameroon never found the right mechanism to allocate its resources in this area. At a lesser level, Benin follows the same trend as Cameroon in this model. It operated at DRS all the time with bad scores in VRS. Burkina Faso and Mali showed some improvements: for example, Mali operated at MPSS in 1994 and 2005, and even though Burkina Faso did not attain MPSS, its CRS and VRS scores improved over time. For each country that did not achieve efficiency in the CRS model, the system suggests alternative investment possibilities that would bring the country to the efficiency frontier. The full result of this slacks and factors analysis is displayed in Appendix B. I have extracted some rows from that table in Table 5-9-1 for ease of this discussion.

Years	Countries	Score	Factor Invest	Factor Staff	Slacks Cellular	Slacks Landlines
1993	Benin	59.14%	30.68%	10.89%	32219.66	4948.17
	Senegal	66.08%	28.12%	27.15%	100463.03	15134.83
	Cameroon	68.98%	83.26%	18.77%	72632.28	0
	Cote d'Ivoire	62.04%	26.98%	15.66%	114624.43	0
	Mali	62.88%	66.29%	6.47%	17547.22	0
2004	Benin	80.00%	100.00%	47.65%	0	1320.7
	Senegal	100.00%	100.00%	100.00%	0	0
	Cameroon	82.34%	100.00%	54.11%	0	17341.1
	Cote d'Ivoire	100.00%	100.00%	100.00%	0	0
	Burkina	63.86%	23.17%	38.17%	0	0
	Mali	76.28%	100.00%	34.97%	0	0
2005	Benin	100.00%	100.00%	100.00%	0	0
	Senegal	100.00%	100.00%	100.00%	0	0
	Cameroon	100.00%	100.00%	100.00%	0	0
	Cote d'Ivoire	90.58%	85.82%	83.55%	0	103537.25

Table 5-9-1 Extract of Appendix B

The slacks in the output variables display the potential improvements in the output variables (number of mobile phones, number of landlines). Whereas the factors of the input variables e.g. investments in ICT and ICT staff show the proportion of that variable that was used in the production of the output. This observation informs the decision maker that there are investment policy alternatives that could lead to higher levels of efficiency. As a general observation, almost all the countries in the model did not perform well enough in the early year of this study hence exhibiting too much slack. But towards the end of the period there is better efficiency and zero slacks (Table 5-9-1). To go through each year for each country would be tedious and repetitive. So I will use one example to illustrate how the findings can be interpreted. Let us now examine the year 1993 for Benin. The reader will notice that with only 59.14% relative efficiency score, there are alternative options that could yield significant improvements. In fact the results suggest that, the level of investment in ICT-I this year for that country could have produced 32219.66 more mobile phones and 4948.17 more landlines. Now, seen from the output perspective, the model suggests that 30.68% of the investments and only 10.89% of the staff were enough to achieve the level output produced in the year 1993 for Benin. Whichever way the decision maker wants to analyze it, the model suggests the possible improvement of the output or the necessary reduction of the input variables a decision making unit needs in order to become efficient at the prevalent level of technology.

I will now briefly discuss two countries that did perform well in the year 2004 (see lower section of Table 5-9-1). First Senegal; Senegal achieved 100% relative efficiency. The result suggests that this country used 100% of its investments in ICT-I and 100% of the staff to achieve the current level of output which is the best possible given the level of technology of all countries in the sample. Another example is Cote d'Ivoire; this country only achieves 90.58% efficiency score in 2005. This result suggests that the country could have achieved 100% efficiency if it had reduced its staff by about 15% (factor of 85.82% of use of ICT investment) and concurrently reduced its number of ICT staff by about 17%. The proportion of this variable that was necessary to achieve the current level of efficiency is only 83.55%. The alternative the result suggests is from the output oriented perspective. It says that if the input were kept at their current level, Cote d'Ivoire could still attain 100% efficiency if it had produced 103537.17 more landlines (Table 5-9-1). The present analysis is limited to only a few but significant variables; I have shown elsewhere in this study, complementary investments in health and education, other civil infrastructure and a shift in GDP per capita could lead to higher levels of ICT infrastructure expansion for the same ICT investments (Ngwenyama and Morawczynski, 2009). The constraints on expansion are structural. I will return to this issue in the concluding discussion. Let us now examine the nature of the ICT infrastructure expansion on the countries.

5.5 Empirical Observations on Productivity of ICT Expansion

The present section presents the total factor productivity of the ICT sector. Some researchers claim that ICT's effect on development could be dependent on the time lag. (Oulton, 2004; Limam & Miller, 2004). They claim that the investments realized one year might not have immediate incidence that same year but start having an impact some years later. Studying the rate of growth of the ICT sector over the years assures that learning, improvement of management methods and overall progress is being made in the sector. Proponents of the time lag dimension invite researchers to give some time for the technology to mature or for its effects to show. Figure 5-4 and 5-5 summarize the productivity ratios of the six West African countries investigated in this study. This productivity ratio is the measure of self sustainability and vitality of the ICT sector over time. The variables used to compute the ratio are listed in Table 5-9-2 below. The goal of this inquiry is to calculate the rate of

improvement of the output of the ICT sector relative to the input over the years. In order to investigate the self-sustainability of the sector, Revenue of the ICT sector, number of Internet Users and Traffic (outgoing telephone minutes) were added to the output variables that were used to assess Technical Efficiency (TE) of expansion studied in the previous section. All variables are assigned equal weight of one.

Input	Output
Investments in Telecomm ICT	Revenue ICT
Staff ICT in Telecomm	Internet
	Landlines
	Cellular Phones
	Traffic

Table 5-9-2 Variables used in Productivity Ratio

The following table (Table 5-10) summarizes the productivity ratios. The complete table which puts side by side productivity ratio and technological change for comparison is provided in Appendix C.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	AVG
Benin	0.1	1.78	1.58	3.12	1.71	1.23	1.59	1.91	1.63	1.4	0.66	2.63	1.24	1.71
Senegal	0.1	1.11	1.5	4.38	1.87	1.58	1.86	1.71	1.7	1.07	1.34	1.73	1.18	1.75
Cameroon	0.1	3.28	1.28	4.37	1.03	1.24	1.44	0.99	2.22	1.14	1.2	1.23	1.34	1.73
Cote d'Ivoire	0.1	2.38	1.21	3.49	1.82	1.68	1.32	2.06	1.18	1.21	1.39	1.21	0.89	1.65
Burkina Faso	0.1	1.68	1.21	1.41	2.65	2.54	1.22	1.07	1.41	0.85	0.62	1.01	1.2	1.41
Mali	0.1	2.79	0.34	2.38	1.22	1.87	1.67	1.23	1.19	1.15	1.37	2.25	0.99	1.54

Table 5-10: Productivity Ratios over the Period 1993 to 2005

As a general definition, the productivity ratio is the ratio of outputs over inputs. In the present section, in order to account for the time lag as mentioned earlier, I use the Malmquist function of DEA to compute the ratio. As a reminder, the equation for this ratio is defined as follows: (output of period $t+1$ – output of period t) over (input of the period $t+1$ – input of period t). A ratio > 1 would suggest that the proportion of increase of the output is bigger than the proportion by which the input has been increased for that period of time. Conversely, if the ratio is < 1 , this means that there have been more

investments in the input that resulted in lesser output comparatively for the period of time in question.

5.5.1 Discussion of the Evolution of Productivity over Time

In order to facilitate the discussion of the productivity of the ICT sector of the countries under study, Table 5-10 above summarizes the ratio. Further, Figures 5-4 and 5-5 display the slopes of the evolution of the productivity. For ease of reading the countries are grouped into two groups as identified earlier - Group 1 composed of Cameroon, Cote d'Ivoire and Senegal, and group 2 composed of Benin, Burkina Faso and Mali.

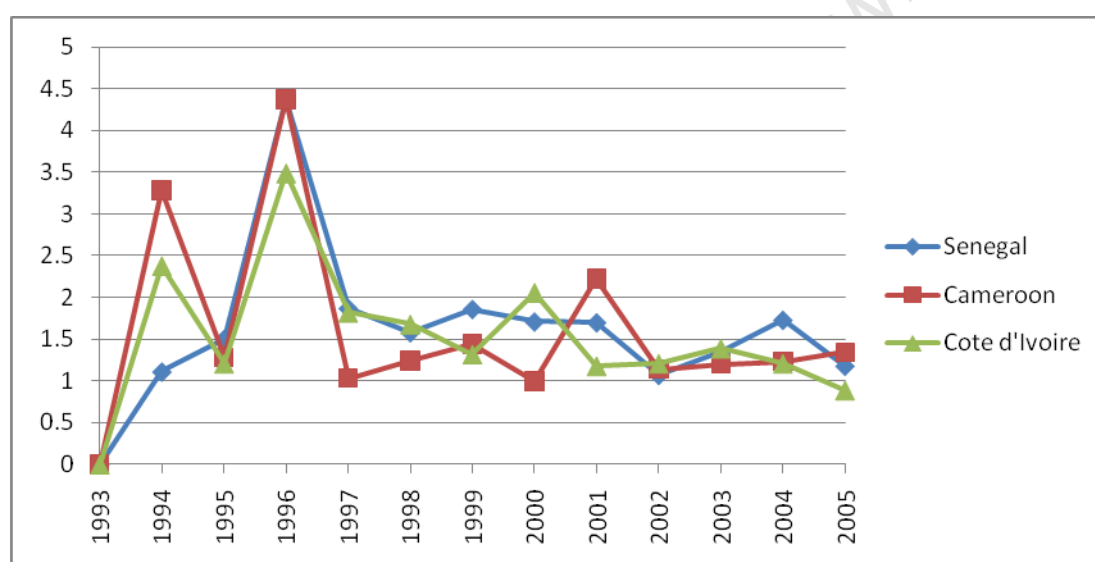


Figure 5-4 Evolution of the Productivity Ratio over Time (Group 1)

The average productivity ratio for all countries is situated around 1.63% over the period of the study. Across all countries, the ratios vary from 0.62% to 4.38%. From Figure 5-4 we can see that Senegal, Cameroon and Côte d'Ivoire have similar evolutions: these three countries start with a good ratio in 1996 at 4.38% for Senegal, 4.37 for Cameroon and 3.49 for Côte d'Ivoire. The following year the ratio drops dramatically to reach 1.87%, 1.03% and 1.83% in 1997 respectively and continues its decline to pass below the 1% critical bar to 0.99% in 2000 for Cameroon and 0.87% in 2005 for Côte d'Ivoire. Senegal is the only country that remains productive throughout the entire period of the study. It can be concluded that in spite of pretty high productivity ratios in the early years, the three countries in

Group 1 experience a drop of their productivity ratio over time. This ratio becomes even negative for Cote d'Ivoire in the latter years. The ratios for countries in Group 2 are illustrated in Figure 5-5.

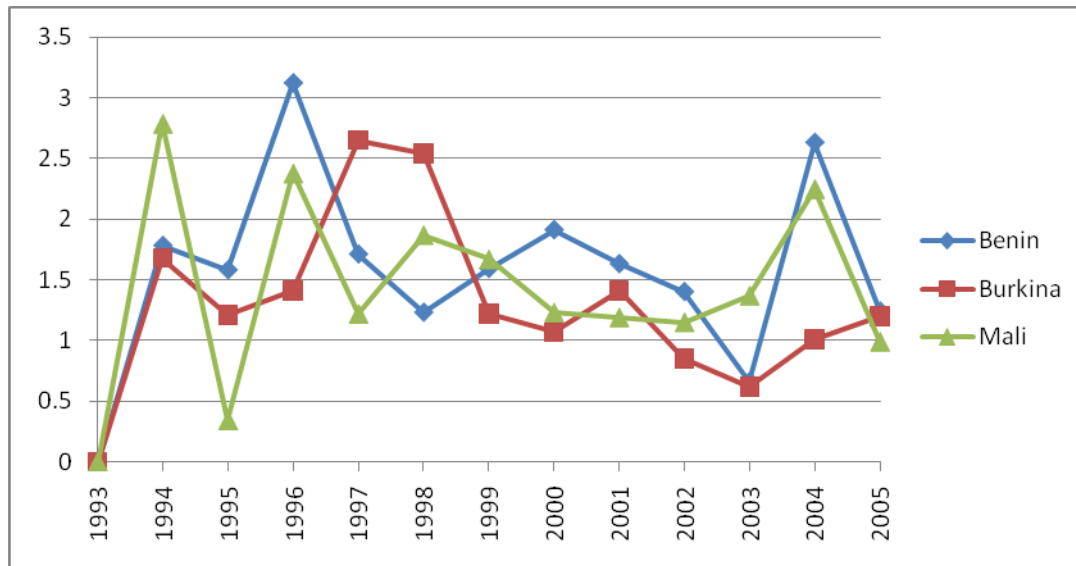


Figure 5-5 Evolution of the Productivity Ratio over Time (Group 2)

The average productivity ratio ranges from 1.41% for Burkina Faso to 1.71% for Benin. Mali has an average ratio of 1.54%. For these three countries, the slopes have many ups and downs unlike those of Group 1. An illustrative example is Mali; which starts with a very high productivity ratio in 1994 at 2.79% then drops the following year below 1% at 0.34%. The ratio rises again in 1996 to 2.23% before another drop at 1.22% the following year. This movement continues throughout the years until a final drop in 2005 where productivity remains below 1% at 0.99%. Burkina Faso and Benin have their own up and down patterns.

Two points are important to note when one closely analyses these findings: (1) the productivity ratio is equal to the Technological Change (TC) index in all cases; (2) the slowing down of productivity ratio over time for most countries. With regard to the first point, the current model shows that there is continued technological progress over the period of the study but this TC index has the same pattern as the productivity ratio and the rates are the same in all cases. This result indicates that the productivity growth observed is entirely due to the technological change or shift in the frontier

technology. This situation suggests that the countries are not benefiting from scale economies and that the ICT sector is not producing any residual growth in the output which is not a direct consequence of the input. Evidence for this is that any variation in the input variables is reflected in the variation of the productivity ratio almost in the same proportion. For example, the other variables not considered, in 1996, Senegal increased its investments in ICT 60% from USD 33,977,764 in 1995 to USD 54,657,412 (Appendix D); this augmentation was reflected by an important increase in the productivity ratio from 1.5% in 1995 to 4.38% in 1996. The following year the reduction of the investments by 33% was equally reflected in almost the similar drop of the Productivity ratio. This means that a diminution of the capital investments, for example, will result immediately in a drop in the productivity ratio and technological change at the same time. This raises the issue of maturity and development threshold of the sector. Based on the result of this analysis, I can conjecture that the ICT sector of these countries has not yet attained the level from which it can start producing residual growth and benefiting from economies of scale. Further studies are necessary to investigate the directions of the investments and help to establish such thresholds.

The second remark is the most interesting part of the result in this study. Although all of the countries are making a sustained effort in their investments in ICT at an average rate of 20% over the years, the increase of the productivity ratio is slowing. For instance, the productivity ratio drops below 1% in years 2002 and 2003 for Burkina Faso; in year 2003 the productivity ratio drops to 0.66% for Benin. In 2005, Cote d'Ivoire and Mali experience a drop of their productivity ratios to 0.89 and 0.99 respectively (Figures 5-4 and 5-5). To further illustrate these contrasting trends between the investments in ICT and productivity; let us look at the example of Senegal. I am well aware that some lags effects (discussed in Chapter one) could have some impact here. Anyways, in 2002, Senegal for instance has increased its investments by 63%, the staff in ICT has also increased by 1.9%, and there are more internet connections, more telephone minutes generated by the use of the landlines and more cellular phones by about 10% increase for that year - only the number of land lines decreases slightly by 1%. Still Senegal has no productivity growth for 2002; to the contrary,

there is a 0.7% decrease in productivity with the ratio at 1.07% compared to the year before where the ratio was 1.7%. The same pattern is seen for Mali, Cameroon and Burkina Faso which increase their investments respectively by 25% and 15%, have about 5% increase in the other variables, but experience a decrease of productivity of 0.2% and 0.13% respectively. As a general observation, the slowing down of the productivity ratio concerns all countries. This situation might shed light on the investment patterns and call for a closer observation of the investments. If the investments are not leading to productivity growth, there is a need for deeper investigation of the investment patterns and to consider other investment possibilities such as education. The model used in this analysis does not give us all the answers we need to understand the trend and the formation of this ratio. In Chapter 8 there is a discussion of the regression analysis which sheds more light on the investigation. With this method, I attempt an explanation of the elements that are impacting Total Factor Productivity.

5.6 Benchmarking the Efficiency of ICT Expansion

One of the goals of this research is to be able to identify countries that can be used as benchmarks for the less efficient ones in order to help the latter shape their ICT investment policies by following the investment patterns of those countries that performed better than them. In the present benchmarking with regards to technical efficiency, I use the DEA Constant Returns to Scale model to determine the rank of the countries from best practice to worst practice with regard to the efficient utilization of the ICT sector inputs to produce the outputs. Table 5-11 below displays the TE_{CRS} scores.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	AVG
Senegal	66	73.9	76.8	76	87	83.9	85.6	94.3	100	92.6	91.8	100	100	86.7
Côte d'Ivoire	62	68.5	71.4	71.2	73.8	75.8	72.7	83.7	84.5	88.1	100	100	91.4	80.2
Cameroon	68.9	65.8	65.1	65.6	66.7	73.4	72.6	62.7	73.5	71.3	75.0	82.1	100	72.5
Mali	62.8	100	56.7	56.1	55.7	59	64	65.9	69.8	70.6	76.3	86.7	100	71.06
Benin	59.1	63.8	64.1	71.2	67.4	64.1	63.2	66.1	70.6	72.9	61.5	79.7	100	69.5
Burkina Faso	57.7	64.2	66	62.3	61.6	68.2	70.4	69.7	71.6	70.9	63.3	63.8	69.3	66.0

Table 5-11: DEA CRS Technical Efficiency Scores (copy of table 5-2)

The Technical Efficiency Constant Returns to Scale (TE_{CRS}) scores for Senegal show that this country is by far the best performing country in the group with 86.7% overall average efficiency score. It is important to note that Senegal has ranked first 10 of the 13 years of our study. It attained a TE_{CRS} of 100% 3 times in the years 2001 and 2004 and 2005 and has been referred to as 'good example' in converting its investments into optimal output 78 times in the model. The example of this country can be followed by the rest of the countries in this study all the years except in only three years: 1993 where Mali was the most efficient, 1994 where Cameroon ranked first and 2003 where Cote d'Ivoire performed better than Senegal. Cote d'Ivoire ranks second with an average TE_{CRS} score of 80.2%. Cote d'Ivoire operated at 100% TE_{CRS} in 2003 and 2004 but has second highest score behind Senegal most of the years. Cote d'Ivoire has been benchmarked in the year 2003 only. Mali ranks fourth with an overall efficiency score of 71.06% behind Cameroon. Mali attained 100% efficiency in 1994 and 2005. Mali has been designated good example for the other countries 7 times in the model in year 1994 and 16 times in year 2004. In its performance, Mali gives a good example of how the optimum utilization of minimal available infrastructure can be beneficial to a country.

Cameroon was never cited as benchmark even once in this study. Ranking third with an overall efficiency score of 72.5%, Cameroon displays one of the worse performances of all countries in this study relative to the importance of its investments in ICT. This performance can be considered poor because Cameroon is the most developed of all countries. Cameroon's counter-performance calls for a deeper investigation in the causes of such a poor performance for this country which has the highest GDP of all countries, and the highest urban population. In addition to Benin and Burkina that rank respectively fifth and last in this analysis, Cameroon's ICT-I investment pattern is an example that should not be followed except for the year 2005.

In summary, Senegal is the benchmark country in the present study with regard to the technical efficiency. In fact, Senegal's investment pattern in ICT-I has yielded the best results compared to the others in the sample so far.

5.7 Conclusion

This chapter analyzed the technical efficiency of ICT infrastructure expansion in the countries under investigation. The empirical observations from my analysis provide perspective on the Claim 1 of the ICT4D hypothesis that ICT infrastructure expansion will have a direct contribution to TFP growth in the less developed countries (cf. Table 3.3). The results of the above analysis of over thirteen years of expenditure on ICT infrastructure expansion provide the following empirical observations about: (a) the truth and (b) legitimacy of Claim 1 of the ICT4D hypothesis.

- a) Truth of the claim: The empirical evidence does not provide support for the claim that ICT-I expansion will make a direct contribution to productivity growth in the society. In fact, the results of the productivity analysis suggest that there is no learning accumulation because the Productivity ratio is strictly equal to Technological Change in all cases (see Appendix C); in addition to this, productivity ratio is slowing over time and, as a consequence, productivity is not sustained. At this rate, it would not be wise to claim that the expansion of ICT infrastructure alone will bring about TFP growth and growth of the economy in general. The second claim stating that ICT infrastructure expansion will give rise to broad utilization of the ICT infrastructure in the society is not verified. In fact, the slowing of the productivity ratio is not an indicator of growing utilization of the ICT infrastructure but this aspect will be further investigated in chapter 6.
- b) Legitimacy of the claims: It would be appropriate to say that Claim 1 of the ICT4D hypothesis is rather incomplete. Based on the findings of my empirical observations (Tables 5-8 and 5-10, Figures 5-4 and 5-5) it is not correct to claim that heavy investments in ICT infrastructure will bring about growth in the economy and will give rise to massive utilization in the case of these African countries. The results of my analyses suggest that complementary sectors are required before the ICT sector becomes fully productive in the countries under investigation. Table 5-10 displays a very weak and non-sustained productivity in spite of the heavy investments conveyed in the ICT sectors over the years. These complementarities are fully investigated in

chapter 7 and the alternative solutions are offered and at length discussed in Chapter 8.

University of Cape Town

Chapter 6: ICT Sector Revenue Performance Analysis

6.0 Introduction

In this chapter I set out to interrogate two important issues: (1) How well are the ICT sectors of the countries under investigation converting investments in ICT infrastructure and ICT staff into revenue? (2) Is there complementarity of investments (ICT staff and ICT capital), and further, what is the nature of the interaction between these two variables? The analysis of question 1 was broken down into three components: (a) an analysis of ICT infrastructure utilization; (b) an analysis of factors influencing utilization; and (c) analysis of revenue performance. Question 2 is then analyzed subsequently as a fourth component: (d) an analysis of complementarities between ICT staff and ICT capital in revenue performance. This analysis is conducted using multiple data analytic methods. In Section 6.1 I use DEA models to analyze the relative efficiency of utilization of the ICT infrastructure (component a). In Section 6.2 I conduct a regression analysis using MARS to understand the relationships among a set of factors, GDPPPP, Literacy and Cost that influence ICT utilization (component b). In Section 6.3 I use DEA models to analyze the relative efficiency of revenue performance (component c). Then in Section 6.4 I present the analysis of the second question (component d). Here I use a *translog production function* and MARS to examine the interactions between investments in ICT and investments in ICT staff. The reader will recall that each of the methods used in the analysis that follows were described in Chapter 4.

6.1 Analysis of ICT Infrastructure Utilization

In Chapter 5, my main interest was in determining how efficient the investments in the ICT sectors were in terms of transforming the investments into infrastructure building. In the present chapter I intend to investigate the intensity of utilization of the infrastructure. Utilization is a key factor in the growth and sustainability of the ICT sector. Since the main focus has to be utilization of the infrastructure that is built, the analysis is limited to the elements that are directly concerned with ICT

infrastructure. Therefore in the present model, the ICT infrastructure variables are used as input and the utilization (internet users and telephone minutes generated) are used as output variables. Public payphones is one of the means by which telephone calls are made therefore it is considered part of the infrastructure. Variables that are just figurative and do not serve in the calculation of the efficiency score are classified as non-discretionary. These variables are listed in Table 6.1 below.

Input Variables (ICT Infrastructure capacity)	Output Variables (ICT infrastructure use)
Landlines	Traffic : overall telephone minutes (generated in the country landlines + cell phones)
Cellular phones	Number of Internet users
Public payphones	
Non-discretionary variables	
Households with a telephone	

Table 6-1: List of Variables used in DEA of Utilization Intensity

The first model of the present analysis aims to determine the relative efficiency of the utilization of the infrastructure relative to the capacity that was built; in other words, in this model, I am investigating what proportion of the infrastructure is being used by the populations of each country in the study. I use the DEA Efficiency Measurement System (EMS) Constant returns to scale input oriented (DEA_CRS_MAX_IN) model to compute the relative efficiency score. The results of the analysis summarized in Table 6.2 below clearly show that the infrastructure that is built in the countries under study is in some cases not optimally used. For ease of discussion and comparison Table 6-2 reports simultaneously the efficiency score of the infrastructure expansion (from chapter 5) along with the scores of the efficiency of the present utilization model. In this table, there are two rows for each country for each year. The first row named (*name of the country* Infra. Score) displays the score obtained for the ICT infrastructure building analysis performed in chapter 5 and summarized in Table 5-5. The second row named (*name of the country* Util. Score) displays the score of ICT infrastructure utilization analysis run in the present section. The two scores were put side by side for ease of discussion and comparison.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	AVG
Cameroon Infra. Score	68.9	65.8	65.1	65.6	66.7	73.4	72.6	62.7	73.5	71.3	75	82.1	100	72.5
Cameroon Util. score	100	80.2	76.7	85.4	81.8	81.6	100	76.5	57.8	65.5	83	100	100	83.8
Mali Infra. Score	62.8	100	56.7	56.1	55.7	59	64	65.9	69.8	70.6	76.3	86.7	100	71.06
Mali Util. Score	81.2	100	72	69.5	100	87.5	84	100	75.8	82.6	67	64.7	100	83.5
Cote d'Ivoire Infra. Score	62	68.5	71.4	71.2	73.8	75.8	72.7	83.7	84.5	88.1	100	100	91.4	80.2
Côte d'Ivoire Util. Score	80	100	100	83.7	86.2	76.3	78.7	66.1	56.9	56.7	62.2	58.2	58	74.1
Burkina Infra. Score	57.7	64.2	66	62.3	61.6	68.2	70.4	69.7	71.6	70.9	63.3	63.8	69.3	66
Burkina Util. Score	100	64.6	59.3	53.5	77.1	88.8	84.6	63.2	63.8	67.6	75.3	69.2	72.9	72.3
Senegal Infra. Score	66	73.9	76.8	76	87	83.9	85.6	94.3	100	92.6	91.8	100	100	86.7
Senegal Util. Score	75.9	63.6	63.5	54.4	51.9	52.8	60.4	52.9	66.5	80.2	80.7	100	100	69.5
Benin Infra. Score	59.1	63.8	64.1	71.2	67.4	64.1	63.2	66.1	70.6	72.9	61.5	79.7	100	69.5
Benin Util. Score	58	52.4	47.6	49.5	63	73.8	100	69.7	64.8	64.1	77	100	75.6	68.9

Table 6.2: ICT Infrastructure Expansion and Utilization Scores (DEA CRS_Max_IN)

It appears in this study that countries that scored high in the ICT infrastructure expansion analysis (Chapter 5) are not scoring as high as might be expected in the present ICT infrastructure utilization model. These are very interesting findings of this investigation that will certainly help interested researchers investigate the thresholds or levels of technology that are required before countries can begin to benefit from their ICT investments. It will also raise awareness for policy makers and help them understand their ICT investment patterns and the gap between their ICT infrastructure building and the utilization of that infrastructure. Such awareness will therefore guide them in their future investments decision making process. The underutilization of the infrastructure as it is observed for most countries here can also result from various causes: lack of proper measurement or evaluation mechanisms; lack of public interest in ICT; or lack of incentives in these countries with regard to their ICT sector. This section begins a discussion of the empirical observations by looking at the ranking, scores and average scores of the ICT utilization model. At the end of this chapter, focus will be placed on the best practice country of the model to further understand the dynamics that play out in this sector.

I will start the discussion by closely examining two countries with opposite performances in the two models, namely Côte d'Ivoire and Senegal. The two countries performed exceptionally well in the infrastructure building analysis model (see result in the infrastructure building row in Table 6-2).

As the results in these rows suggest, it appears clearly that Côte d'Ivoire had an excellent ICT infrastructure expansion over the period of the study. For example, Côte d'Ivoire's scores in the early years were not that good but over time, the country began to score higher and higher with scores between 90 and 100%. The country finally had over 90% relative efficiency scores towards the end of the period of the study: 2003 to 2005 in that model. Conversely, Côte d'Ivoire's scores show a completely different tendency in the ICT infrastructure utilization model. (Infrastructure utilization scores row in Table 6-2). As a matter of fact, Côte d'Ivoire's score is relatively good in the early years, 1994 and 1995. Remember that these two years were when Côte d'Ivoire performed the worse in the infrastructure building model. This performance begins to drop consistently over the following years. The country achieves a score of only 83% in 1996 and the drop continues all the way down to 58% in 2005, with the lowest score in 2001 at 56.9%. The lesson that can be drawn from Côte d'Ivoire's situation can be summarized as follows: as the country strives to build good ICT infrastructure over the years, obtaining good scores in that exercise, the intensity of use is not matching the effort, hence the relatively poor scores in the utilization model. In other words, building more and more infrastructure alone does not automatically engender the corresponding stimulus of utilization of the infrastructure being build unless the time lag before the result shows is too long and is not reflected in the present study. This situation, if not reversed, can ultimately result in a waste of resources.

Another example for this is Senegal. The same observation about Cote d'Ivoire's performance applies to Senegal as well with little differences. In fact Senegal also performed relatively well in the infrastructure building ranking first in the overall score average; but in the utilization model Senegal performs relatively poorly. With an average score of 69.5% in the utilization model, Senegal is far from its 86.7% average score of the infrastructure building model (Table 6-2). The performances of Cote d'Ivoire and Senegal in general call for deeper investigation and quick corrective actions for

Cote d'Ivoire. In the case of Senegal, it seems as if the corrective actions are progressively taking place because the results of the utilization model show some improvements that are worth noting. In fact, Senegal scores 100% in 2004 and 2005 in the utilization model matching the scores of the infrastructure development model which is the ideal situation. If no corrective actions are taken like it seems to be in the case of Senegal, the continuous waste of resources can lead to a complete drop of productivity of the ICT sector of Cote d'Ivoire.

As pointed out in chapter five, Senegal is the biggest investor relative to its GDP. Côte d'Ivoire and Cameroon can also be considered big investors in real terms; therefore the revenue performance of these three countries can be determinant considering the weight of their investments. The performance of the first two countries in the infrastructure building model shows that the sustained investments made by these two countries are yielding excellent outcome in term of the expansion of their ICT infrastructure. To the contrary, the performances of these two countries in the utilization model are rather low relative to the importance of their investments in the ICT sector in the early years, but improve for Senegal towards the end of the period of the study whereas Cote d'Ivoire's performance in the utilization model remains low throughout the period of study. In other words, the result from this first comparison is telling us that the increasing investment in ICT infrastructure does not necessarily respond to a need in utilization from the population. An investigation of this phenomenon could lead to the discovery of patterns and help to establish the relationships between investments in ICT infrastructure development and use of that infrastructure. This investigation is beyond the scope of this research.

To further confirm the observation of the opposite trends between infrastructure building and ICT infrastructure utilization in the countries of interest, Cameroon and Mali rank respectively first and second in the ICT infrastructure utilization model. The reader will recall that these two countries ranked respectively 3rd and 4th of the infrastructure building model. For example, Cameroon, with only 72.5% average score in the infrastructure building model appeared to be a country that was not correctly transforming its investments in ICT into proper ICT infrastructure. In the infrastructure

utilization model, with an average score of 83.8% (Table 6-2), Cameroon is the country where the level of ICT infrastructure and the utilization of that infrastructure seems to be the best balanced of all countries in the present study. In fact Cameroon and Mali actually performed at 100% relative efficiency level 4 times out of 13 which is the overall highest of the ICT infrastructure utilization model. More surprising is the performance of Mali. In effect, a close look at Mali's performance reveals that the minimum level of infrastructure could be sufficient for the level of use at the present time for some countries. With regards to Mali, this is the country that developed the least ICT infrastructure in the infrastructure building model along with Burkina Faso and Benin. The utilization model reveals that Mali's intensity of use is relatively high compared to the level of its infrastructure development (Table 6-2). A deeper investigation of Mali's ICT sector, but also the ICT sectors of each individual country, would help to unravel the complex relationship between ICT infrastructure and the utilization of ICT, and further help us to understand the dynamics between ICT infrastructure building and the utilization of that infrastructure.

Benin remains constant in both models at about 69% level of average efficiency. Burkina Faso improves from 66% of its average score of the infrastructure building model to 72.3% in the utilization model. These scores are not high enough for the infrastructure building and the utilization compared to the other countries. In fact, Benin has the lowest score in the utilization model. This situation calls for a deeper investigation of the factors affecting ICT infrastructure utilization in Benin and other countries. One area to investigate in order to find out why utilization is low is the cost of ICT. An analysis of the effect of the price element is discussed in section 6.2 below.

In summary, the empirical observations of the analysis in the present section suggest three observations.

- 1) ICT use intensification: Given the relatively low rate of the ICT infrastructure utilization in the countries under investigation, the following suggestions could be made: Since price is usually one of the factors affecting utilization in countries with low revenues as mentioned in several studies,

the intensification of use could be achieved by incentives such as reduction in hook-up price or monthly charges. Another initiative to foster ICT utilization in these countries is government involvement in creating a secure and more favorable legal ICT environment that will attract more businesses to offer more digital services. And finally local content injection; for example knowing that English or French literacy is low in these countries, the use of local language could broaden the potential number of users; also the possibility to purchase local products or get domestic service via this medium would probably attract more users. For example, local search engines recently developed in Cameroon (kerawa.com and Kwalai.com) have attracted an increasing number of users over the past two years.

- 2) ICT investments pattern change: given that the countries have invested increasing shares of their national budget in ICT infrastructure development, this observation suggests that the countries change their ICT investment patterns; this means that the systematic increase of the annual ICT budget over the years as we observe in the data of this study is no longer a guarantee of positive outcomes and intensification of use of the infrastructure; for that reason this observation suggests alternative investment patterns such as investing more in education or in other basic infrastructure which in turn could lead to an increase of the ICT infrastructure utilization due to higher literacy and more enabling factors for the use of the technology. Considering the relatively poor efficiency scores of the ICT utilization compared to the ICT infrastructure expansion of the countries in the present study, it would be wise to inform countries that have already built good ICT infrastructure that they should begin using it to full capacity before continuing building more infrastructure according to demand.
- 3) Another hypothesis that could explain the low level of utilization in these countries is the Threshold of ICT infrastructure: In fact compared to developed countries, it is clear that the ICT infrastructure built in developing countries is way too small. This could suggest that there is a minimum level that the ICT infrastructure should attain before it attracts enough utilization. Below that level, all investments may seem to be wasted due to the lack of sufficient capacity, content

and users capable of making the investment worthwhile and self-sustainable. For example, it would be unwise for a business to put their business online if it takes several minutes to download a page due to slow connection and narrow bandwidth. Therefore expanding the capacity to a level that is acceptable is the only way to resolve this problem.

6.2 Factors Influencing ICT Utilization

In order to analyze the factors influencing ICT utilization, I use MARS as the computational method. The model aims to bring forth the relationships between the predictor variables, namely LITERACY, COSTS and GDPPP, and the dependent variable, UTILIZATION. In this analysis, I am interested in finding out the impact of the variables LITERACY, COSTS and GDPPP on the target variable UTILIZATION. These three variables were chosen as predictors because they were available to me at the time of the analysis and it had been conjectured earlier that these variables could help to explicate the relative inefficiency of the utilization of the ICT infrastructure. It is evident that there are many other factors that could potentially impact ICT utilization such as the availability of basic infrastructure, the population's information seeking behaviour, the country's political orientation and laws. I will start by presenting the summary of the Spline statistics in the table below. Given that the values of the variables used in the present analysis are widely spread, I decided to use the logs of the variables.

N: 78.00		R-SQUARED: 0.23024		
MEAN DEP VAR: 0.08267		ADJ R-SQUARED: 0.19903		
		UNCENTERED R-SQUARED = R-D SQUARED: 0.26903		
Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	0.65784	0.13893	4.73503	0.00001
Basis Function 1	-0.21128	0.06562	-3.21949	0.00191
Basis Function 3	1.89318	0.46748	4.04973	0.00013
Basis Function 4	0.80145	0.27240	2.94217	0.00435
F-STATISTIC = 7.37792		S.E. OF REGRESSION = 0.32328		
P-VALUE = 0.00022		RESIDUAL SUM OF SQUARES = 7.73386		
[MDF,NDF] = [3, 74]		REGRESSION SUM OF SQUARES = 2.31323		

Table 6-3: Summary of the Spline Regression statistics

The P-values and basis functions coefficient from this table are used in the MARS model discussed next.

For this MARS model, the maximum number of BFs was set to 180 and the degrees-of-freedom charge per knots to 10 fold cross-validation. The description of the basis functions retained in the final model is presented in Table 6-4.

BFs	Coefficient	Variable	Expression	Knot (log)	Knot (Actual)
1	-0.2112	COSTS	$\max(0, \text{COSTS} - 0.525)$	0.525	3.35
3	-1.89318	LITERACY	$\max(0, 1.568 - \text{LITERACY})$	1.568	37
4	-0.80145	GDP PPP	$\max(0, \text{GDP PPP} - 2.342)$	2.342	220

Table 6.4: Description of the Basis Functions of the MARS model

All three variables are very important in the determination of the final model. As shown in Table 6.5 below, LITERACY is 100% important, COST and GDP PPP are 61% and 45% important respectively. This means that LITERACY is the most important and COSTS and GDP PPP weigh respectively is 61% and 45% of the importance of LITERACY in the model. It also confirms that these three variables are of great importance in the variation of the dependant variable among other things.

Variable	Importance
LITERACY	100.00 %
COSTS	61.60 %
GDP PPP	45.15 %

Table 6.5 Importance of the variables of the MARS analysis

For ease of discussion of the impact of the predictor variables of utilization, I have summarized the impact formulae of each variable in Table 6-6 below. In that same table, the overall slope and direction of the impact for each relevant BF is determined.

Rate of Impact of Literacy				
Interval	Relevant BFs	Contribution	Slope	Impact Direction
$(-\infty, +1.5682)$	$\text{BF3} = \max(0, 1.5682 - \text{LITERACY})$	$(1 * -1.89318)$	1.89318	Positive
Rate of Impact of GDP PPP				
Interval	Relevant BFs	Contribution	Slope	Impact Direction
$(2.34242, +\infty)$	$\text{BF4} = \max(0, \text{GDP PPP} - 2.34242)$	$(1 * -0.80145)$	-0.80145	Negative
Rate of Impact of COSTS				
Interval	Relevant BFs	Contribution	Slope	Impact Direction
$(0.525966, +\infty)$	$\text{BF1} = \max(0, \text{COSTS} - 0.525966)$	$(1 * -0.211276)$	-0.211276	Negative

Table 6.6: Rate of Impact of Predictor Variables

6.2.1 Discussion of the MARS model

The impact formula for the ICT infrastructure utilization as defined by the current MARS model is as follows:

$$\text{Utilization} = 0.657843 - 0.211276 * \max(0, \text{COSTS} - 0.525966) - 1.89318 * \max(0, 1.5682 - \text{LITERACY}) - 0.801445 * \max(0, \text{GDPPP} - 2.34242)$$

With an R^2 of 0.23, the present model can explain as much as 23% of the variation of utilization of ICT infrastructure. I am well aware that other variables can help in the explanation of the variation of the utilization of the ICT infrastructure, but those variables are not available to me at this time. Nonetheless, the p-values of the BFs of the model are in acceptable ranges allowing a scientific discussion of the results. With regard to the variable LITERACY, the impact formula is determined by Basis Function 3 as follows: $\text{BF3} = \max(0, 1.5682 - \text{LITERACY})$. Hence, the model suggests that when LITERACY is in its lower interval (i.e. $\text{LITERACY} < 37\%$), this variable has a negative impact with a positive slope on ICT infrastructure utilization. This suggests that low literacy rate does not foster the utilization of the ICT infrastructure. This is understandable given the very high literacy rates (over 90%) in the western countries where ICT infrastructure utilization is much higher. This finding is consistent with that of other research where the low literacy rate was designated as the main obstacle to the ICT utilization in developing countries especially Sub-Saharan Africa.

The GDPPP has a Negative impact on the utilization when it is in its higher interval. For example, the model suggests in Basis Function 4 (Table 6-6) that the impact formulae for GDPPP is $\text{BF4} = \max(0, \text{GDPPP} - 2.34242)$. This means that when GDPPP is > 220 , it has a no significant negative impact on utilization; below that, GDPPP has not impact. Likewise, COSTS has a negative impact on utilization when it is in its higher interval (i.e. $\text{COSTS} > 3.35$). In summary, it can be concluded that literacy and GDPPP are too low to have a significant impact on utilization. With regards to COSTS, the model suggests that the higher the costs, the less the utilization of the ICT infrastructure. This remark is consistent with other economic analyses where the cost of acquisition or use of the technology and the material impedes its utilization.

With the results of the current analysis, it can even be conjectured that access and utilization of the new technology is price sensitive in the developing countries. For example, study by Balamoune-Lutz has shown that income influence ICT utilization (Balamoune-Lutz, 2003). Therefore, given the low level of revenue in the countries under study, an important factor that might have an influence on ICT utilization could be the service-cost structure. All the countries in the study are economically challenged; their GDP per capita during the period of the study did not rise above USD 1000 (see Table I). Consequently, any change in the service-cost structure is likely to cause dramatic shifts in consumer response. For example, with regards to landlines, in Côte d'Ivoire the cost of acquiring a business or residential telephone line dropped from USD 150 in 1995 to less than USD 50 in 2002 and remained in that neighborhood until the year 2005 (Figure 6-6). This may explain why the demand of landlines rose in that country. In the other countries the hook-up price did not drop at that rate; rather it remained the same or kept rising during the period of our study in some cases leading to less demand of landlines. For example, in the case of Cameroon the costs remained unchanged for the period 1994 to 2002; then they rose slightly towards the end of the period of the study (2003 – 2005). For Senegal both residential and business hook-up charges went up by 50% between 1995 and 1999 then dropped by about 60% in 1999 and rose again to just below the 1995 levels. In Benin and Burkina Faso these charges dropped by about 20% from 1995 to 2002, and for Mali they went up 20% over that same period. This decline in telephone cost in hook-up cost in Côte d'Ivoire has undoubtedly led to increasing demand for telephone landline service as stated earlier whereas the demand for landlines remained relatively low in the other countries. A second aspect of the service-cost structure that has had a dramatic effect in ICT in Côte d'Ivoire is the cost of initiating cellular telephone service. From 1998 to 1999 the cost of initiating cellular telephone service dropped by 24% then again by another 31% between 1999 and 2000. Following the reductions in 1998, cellular telephones in Côte d'Ivoire increased from 91,000 subscribers to 257,000 subscribers in 1999. Then in conjunction with the drop in cost from 1999 to 2000 cellular telephones increased again to reach 472,952 units. They then continued to increase, reaching 1 million in 2002.

From the observation of the data at hand, it can be conjectured that the rapid drop of all telephony costs by over 50 percent in average (Figures 6-1 and 6-2) between 1993 and 2002, resulted in a rapid increase of the use of the telephone service in general and contributed particularly to the rapid expansion of the ICT infrastructure in Côte d'Ivoire as we saw earlier. On the other hand, Cameroon which has the second highest growth in cellular telephone service and also the highest per capita GDP for the entire period of the study; during 1998 and 2001 Cameroon reduced its cellular service connection price by 90%. During that same period it realized an increase in cellular telephone subscribers from 5,000 to 417,295. Benin, however, had the opposite experience; from 2002 to 2004 its cellular service connection charges increased by 200% and its monthly service charges also increased by 100% but it still managed to achieve expansion in the number of cellular telephone subscribers from 7,269 to 218,770 in the same period. In Burkina Faso cellular telephone connection charges gradually declined by 33% from 1998 to 1999, then by a further 23% in 2000, and 50% in 2002. Along with these price changes the number of cellular telephone subscribers in Burkina Faso rose from 2,730 in 1998 to 5,036 in 1999, and to 25,245, 76,000 and 113,000 in 2000, 2001 and 2002 respectively. In 1995 Senegal had a total of 122 cellular telephone subscribers; a 30% reduction in the connection cost resulted in an increase to 1,412 telephone subscribers in 1996. In 1997 there was a further 50% reduction followed by a rapid increase of cellular telephone subscribers, to 6,942 in 1997, then 27,487 in 1998 then a steep rise to 301,000 by 2002.

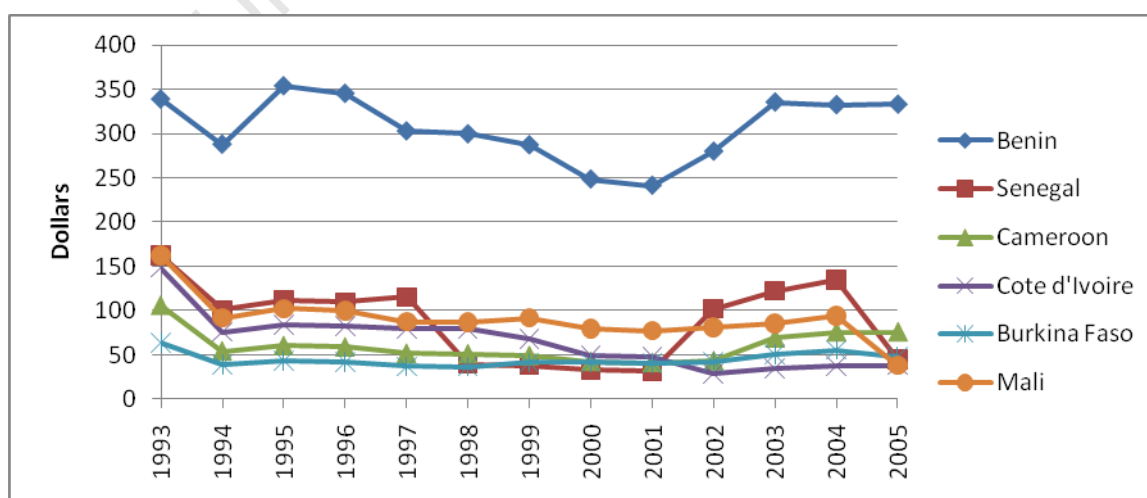


Figure 6-1: Hook-up Cost for Business Telephone Lines

6.2.2 Residential versus Business Telephone Costs

In developed countries, residential and business telephone costs are defined on different scales. Residential telephone charges are usually less than those for business. In the African countries studied in the present research, with the exception of Benin, residential and business hook-up costs are almost the same. Figure 6-1 above and 6-2 present these two aspects of the cost structure.

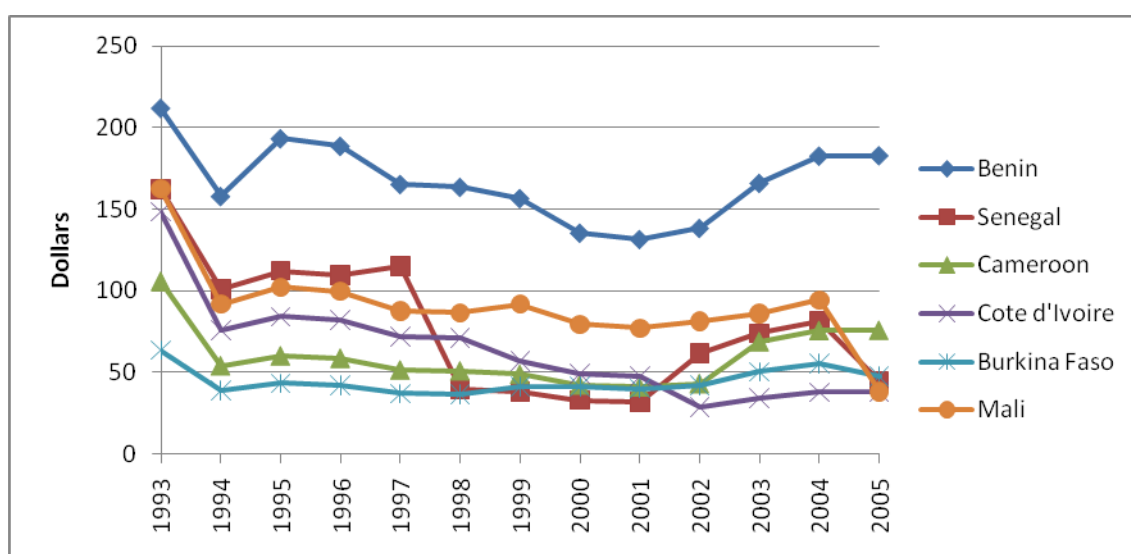


Figure 6-2: Hook-up Costs for Residential Telephone Lines

As stated before, the cost structure may have played an important role in the expansion of the ICT infrastructure and the intensity of use because of the price sensitivity mentioned earlier. As can be seen in the two figures above, the residential and business cost structures strictly followed the same evolution trend, and in most cases on the same scale. The general trend that all countries followed in this regard is the steep drop from 1993 to 1994, then a progressive reduction of the costs, from year 1994 to 2001, then a slight readjustment of the costs upwards from 2003. Two countries merit special attention given their slopes and the consequences on the use of the infrastructure. Côte d'Ivoire's vigorous action towards price reduction in the early years certainly triggered its fast growing infrastructure due to increased demand. In fact, in 1993, the residential hook-up cost was USD 150. This price was reduced by 50% in 1994; and further reduced continually over the years to sit at less than USD 50 from 2002 onwards. The monthly payment followed roughly the same trend. It was

reduced by 50% in 1994, dropping from above USD 12 to just USD 6. The reduction continued steadily over the years until 2001. It rose again rapidly to just below USD 12 in 2005. It is worth noting that Côte d'Ivoire entered a troubled period of civil war in 2002. From that year onwards, all prices tend to rise in that troubled country.

Benin, the second country of interest, has a different approach to the cost structure. As a matter of fact, as displayed on the above diagram, Benin stands out by the exceptional high price of its business telephone hook-up price compared to the rest of the countries in the study. Benin kept its residential and business telephone hook-up costs very high. Starting at over USD 211 in 1993 for the residential telephone hookup price, the cost drops slightly following the general movement in 1994 to USD 157 in Benin. The following year, the price goes up again to around USD 200. But it drops again and stays at around USD 150 a little before 1999, and then it passes just under the USD 150 bar in year 2000. Hook-up cost rises again to about its original value in 2005. Concerning the residential use cost, in spite of its high prices compared to the other countries, Benin is more reasonable and follows the cost reduction movement the other countries have been applying.

After staying relatively high from 1993 to 1997, Senegal finally dropped its hook-up cost, by over 50%, in 1998. This reduction is the most important in the model. In that country, the residential hook-up cost went from USD 115 to USD 38 in 1998. The price remained steady over three years but started fluctuating up and down from 2002 to 2005. For Burkina Faso and Mali, there was no significant structural change in the telephone costs.

6.3 ICT Revenue Performance Analysis

This section discusses the revenue performance of the investments in ICT for the countries under investigation. Two aspects will be considered in this inquiry: (a) How much of their national income (as measured by GDP) is affected to the investments in ICT? and (b) what is the share of the national revenue that comes from the ICT sector? Figure 6-3 shows the trend of the evolution of the investments. Further, Figure 6-4 shows the revenue of the ICT sector as a percentage of GDP.

6.3.1 Importance of the Investments in ICT Infrastructure relative to GDP

For ease of presentation of data and comparison, I have divided the countries into the same two groups as I did in the previous chapter; as a reminder, group 1 is composed of Cameroon, Côte d'Ivoire and Senegal, and group 2 is composed of Burkina Faso, Benin and Mali. Another reason for the grouping is that members of group 1 have much higher GDPs than those of group 2. As an example, Cameroon, the country with the highest GDP per capita, had USD 932.2 GDP per capita in 2005 whereas Burkina Faso had a per capita GDP of only USD 389.4 that same year.

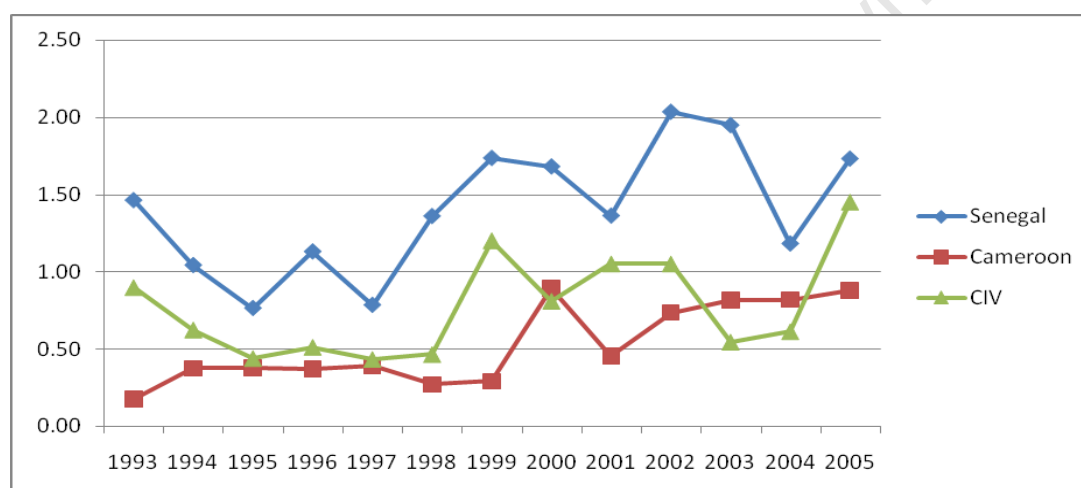


Figure 6-3: Investments in ICT as a Percentage of GDP, Group 1

In the six African countries in the present study, the beginning of intensification of investments in ICT started in 1993 and these investments attained their highest levels in 1999 and 2002. (Appendix E). By one measure of analysis, the ratio of investment to income, produced as a percentage of GDP, these investments seem to have been successful. In Figure 6-5 further down, the reader will notice that for each of the countries the revenue from ICT as a % of GDP has increased over time. It is also noticeable that as a % of GDP Senegal invested consistently the highest each year and got the highest income from its ICT infrastructure than all the other countries. In addition to that, one will note that the other two countries in group 1 have their investment in ICT on average between 0.5% and 1% of their GDP after 1999 onward (Figure 6-3). That rate goes as high as over 2% for Senegal in 2003. The other 2 countries of the group try to catch up, raising their investment rates up to 1.5% for Côte

d'Ivoire and around 1% of the GDP for Cameroon in the latter years. Concerning the countries in group 2, their investment patterns remained pretty much the same between 0.5% and 1.5% until some changes started happening after the year 2002 (Figure 6-4). In 2003, Burkina made a big jump in its investment in the ICT sector, spending successively 1.8% then 2% of its GDP in the ICT sector in 2004. In 2005 year, the investments drop back to 1.8% of the GDP which is still high in this group. Benin is the other country that introduced some changes in its investments patterns. In effect, during the year 1999, Benin spent up to 1.4% of its GDP in ICT. That rate decreased gradually the following years to close to 0.5% in 2005. Mali also, after some initial heavy investments up to 1.6% in 1997, kept reducing its investments rate constantly after 1999 to settle below 0.5% from 2000 onward.

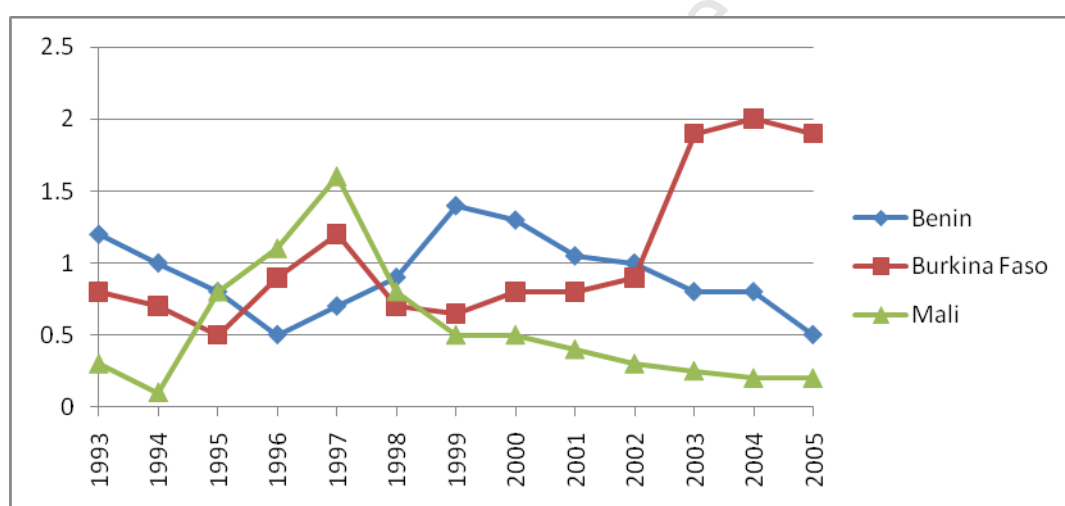


Figure 6.4 Investments in ICT as a Percentage of GDP, Group 2

6.3.2 Importance of ICT Revenue Relative to GDP

The second observation that stands out from this analysis is that the general trend of the revenue slopes is rising for all countries. They rise constantly from 1996, until 1999 when they slow down slightly in 2000 and 2001, and then accelerate with some ups and downs for the rest of the period of study. In terms of ICT revenue performance, Senegal has the highest rate of revenue relative to GDP (Figure 6-5). In 1995 Senegal's rate of revenue (as a percentage of GDP) was 2.4 %. It rose consistently each year to attain 8% in 2005. The second high performance country in terms of

revenue is Côte d'Ivoire. Côte d'Ivoire has a relatively modest rate at the start, with a rate of revenue at 2% in 1993; this rate drops in 1995 and 1996 to less than 1.5% but rises again and sustains its growth constantly to reach 5% in 2005. Cameroon, the third country in the model, follows pretty much the same trend. But Cameroon's rate of revenue remains low; below 1% until the year 1999. The increase begins for Cameroon in year 2000 and continues to rise to attain 3% of its GDP from the ICT sector in 2005 (Figures 6-7 and 6-8).

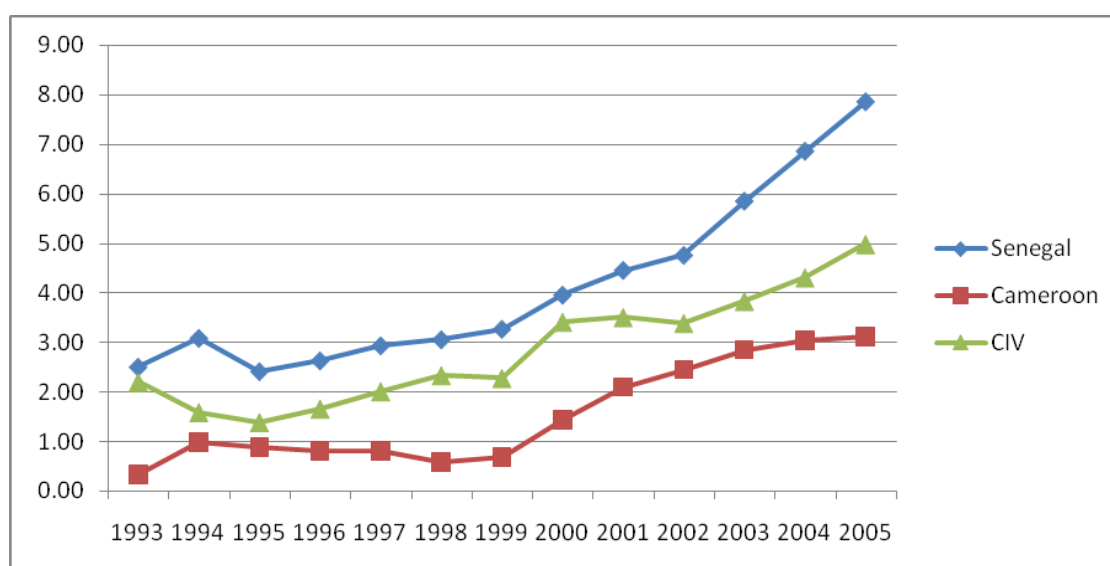


Figure 6-5: Revenue from ICT as a Percentage of GDP, Group I

The country with the lowest revenue as a percentage of GDP is Benin. Although Benin has a relatively weak investment in ICT, the revenue from ICT rose consistently between 1996 and 2001 (Figure 6-6). Benin's ICT investments range from 0.8% of the GDP in 1996 to 1.1% in 2002. Likewise Benin's ICT revenue rose from 1.6% to 2.8% over the same period, and then crashed to 1% in 2005. Remember that Benin kept its costs of telephone very high during the entire period of the study with minor reductions. The high cost of telephone service of Benin must have played a role in the crash of the revenue for this country. This situation created an obstacle to the use of the telephone services in Benin. As a consequence, while all the other countries have above 3% of revenue rate, Benin dwells at 1% in 2005. Cameroon, the second largest investor in ICT after Côte d'Ivoire in terms of capital (constant dollars) and ICT staff earned surprisingly low revenue from its ICT investments compared to the others. In fact Cameroon has the lowest rate of ICT revenue as a percentage of GDP (below 1%

for the period 1993 to 1999 (Figure 6-5). Cameroon's revenue starts rising rapidly from then to attain 3% in 2005. Côte d'Ivoire has a fairly good ratio of returns on ICT investments compared to its investments; however, one could have expected better returns given the importance of the investments in the ICT sector in this country.

Senegal made the highest ICT investment as a percentage of GDP and obtained the highest income return (as a percentage of GDP) from its ICT investments for almost the entire period of 1993-2005. Therefore a decision to reduce inputs might not be palatable to the decision makers. Furthermore the objective is to improve social development, not maintain it at the current low levels as measured by the HDI. So an important question is: are there alternative courses of action that could help Senegal improve development as measured by HDI? For an answer one should look to the VRS analysis. Remember that the output oriented VRS model looks for alternate possibilities that could move productive efficiency closer to the efficiency frontier (Chapter 5).

To clearly understanding the present analysis, it is important to recall some of the demographic information of the countries presented in Table 4.1. It is important to note that of all the countries in the present study Cameroon has the highest urban population and the highest GDP per capita (USD 932.2). The GDP for Senegal is just USD 739.8. Burkina Faso has the lowest GDP per capita (USD 389.4) and the third highest population behind Côte d'Ivoire and Cameroon. Concerning Mali, it has the fourth highest population at 12.7 million with only 31% of urban population, the second lowest literacy rate (46%), the second lowest GDP per capita (USD 472.5) but the largest land mass. In this configuration, the penetration of mobile phones is not expected to be too high.

It is important to note here that Mali stands out with its exceptional increase of revenue from ICT (Figure 6-6). Mali almost doubled its revenue from USD 214,365,216 in 2004 to USD 405,711,808 in 2005 (Appendix E). This increase represents over 7.5% of its GDP. It is the second biggest increase in ICT revenue after that of Senegal in the same year.

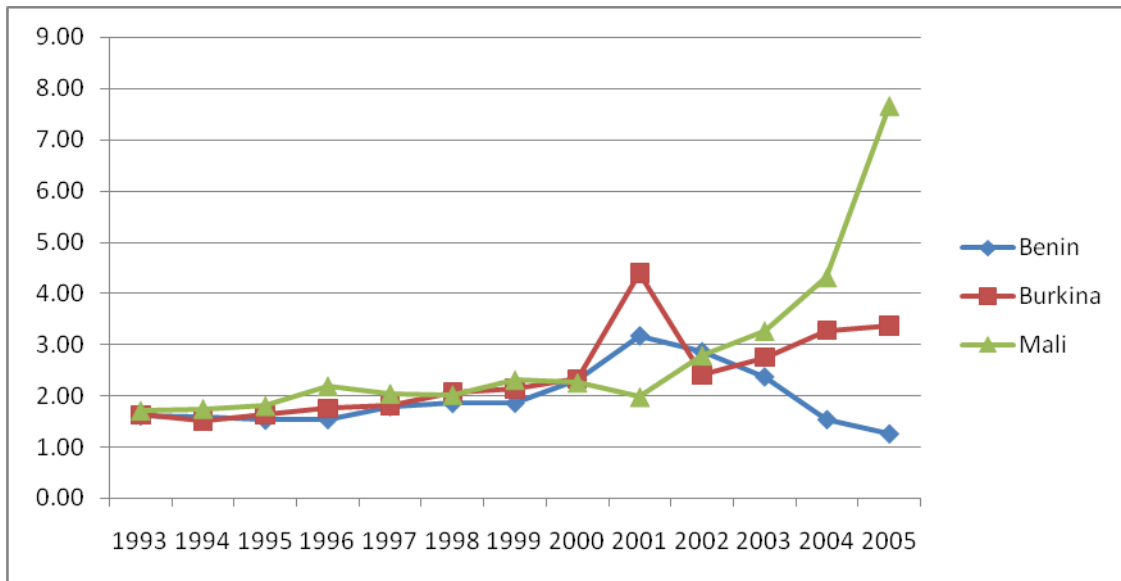


Figure 6.6: ICT Revenue as a Percentage of GDP, Group 2

Côte d'Ivoire has been continually investing in ICT at a sustained rate of about 1% of its GDP annually, which in dollars is a significant sum of capital investment; as this country has the third highest GDP per capita (behind Cameroon and Senegal) of the countries in the present study. Cameroon and the three countries of group 2 have been investing proportionally smaller amounts of their GDP in ICT. Over the period of study only Senegal, has been investing more than Côte d'Ivoire relative to their respective GDPs. For the period of the study Côte d'Ivoire had the second highest ICT revenue per dollar of investment behind Senegal. Benin has the least return of all countries in the study. To summarize, based on the results observed from the DEA-CRS analysis it can be concluded that none of the countries has negative returns on investments. Apart from Benin which is crashing in 2005, all the other countries have excellent returns above 3% in 2005.

6.3.3 Efficiency of ICT Revenue Generation

When compared to other countries, a country might happen to be inefficient in its revenue generation in the ICT sector compared to the others. But that is relative efficiency because the country's performance is being assessed relative to the other countries in the sample. But how each country transforms its ICT capital into revenue can also be analyzed individually in order to show how the

country at its own level learns from its investment patterns and adjusts over time. This question is investigated in the present section. Table 6-7 below summarizes the variables used in this computation.

Input Variables	Output Variables
Investment ICT in Telecomm	Revenue from ICT
Number of ICT Staff in Telecomm	

Table 6-7: List of variables used in DEA analysis

The goal of this analysis is to understand how each country has combined its ICT investments and staff over the thirteen years of our inquiry to generate revenue and determine in which year they made the best combinations possible in their input variables to generate the best possible revenue. For this reason, the variables in Table 6-7 above were chosen. This analysis will help us understand the investment patterns of each country and how the country adjusts in its ICT investments over the years. Time lag is likely to influence the results but since I am looking for patterns, the observation of the trend over the years will be valuable. DEA model was used for the computation. The DEA method used is the constant returns to scales, maximum average distance from the efficiency frontier input orientation (CRS_MAX_IN). This method begins by determining the efficiency frontier given the level of technology of all decision making units (DMUs) for example all the years in the present analysis. Next, it determines how efficiently the inputs were combined to achieve the output. The result gives the distance of each year's performance from the efficiency frontier and proposes alternative combinations that could lead to more efficiency.

The 100% efficiency score will be granted to DMUs - in this case the years in which the country made the best combination of inputs and realized the output on the efficiency frontier level. For the DMUs that did not attain 100% efficiency, the method offers an analysis of the factors that led to the inefficiency. These factors and slacks will be discussed later. Figure 6.7 below shows the percentage efficiencies of the trend of the countries in group I.

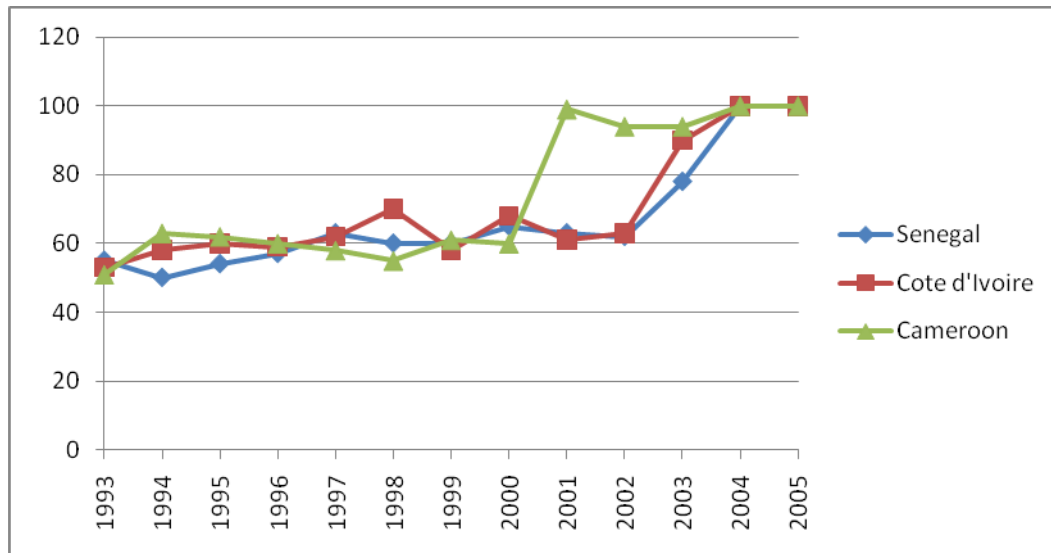


Figure 6.7: Revenue generation efficiency by country (Group 1)

Taken individually, all the countries perform relatively at the same scale in their revenue generation. The countries in group 1, (Figure 6-7 above) show a more linear progression in their revenue generation. The three countries begin at 50% efficiency score in 1993 and progress steadily throughout the years to reach 100% efficiency towards the end of the period of study. This trend differs from the one observed by the countries in group 2; Figure 6-8. For these countries, the progression movement is not uniform. Compared to the slopes of the trend of the countries of group 1, the slopes of the trend of the countries in group 2 (Figure 6-8) follow different patterns in this analysis.

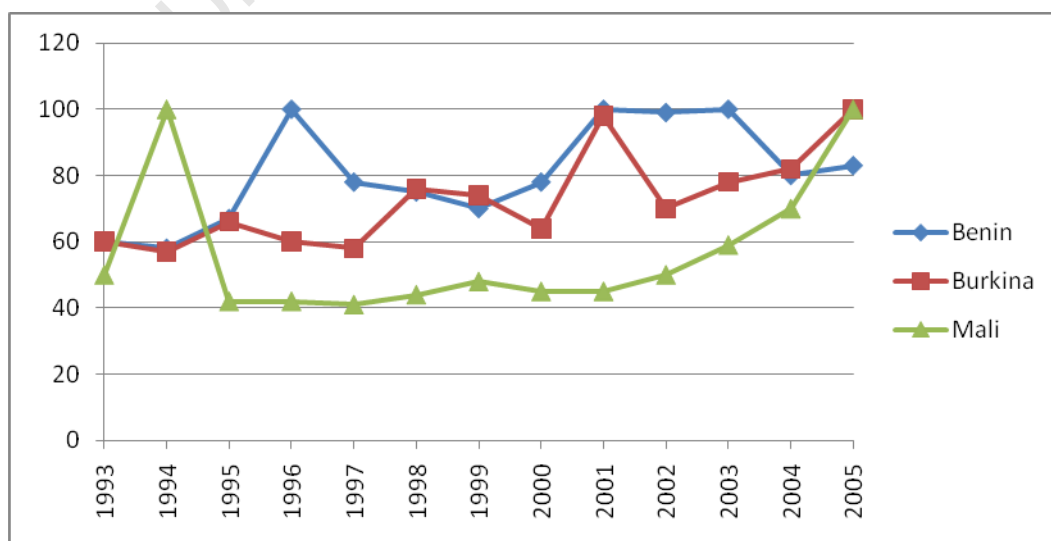


Figure 6.8 Revenue generation Efficiency by countries (Group 2)

6.3.4 Discussion of the findings

First of all, the slopes in Figures 6.7 and 6.8 indicate that there is an upwards tendency in the efficiency scores for all countries. The efficiency level was smaller - about 50% in average in 1993 - but grew constantly to reach 100% or thereabout for many countries in 2005. I would like to analyze two countries with similar revenue generation paths. In fact, Côte d'Ivoire and Senegal seem to have a more linear progression over the years than the rest of the countries. The two countries start with close to 50% efficiency in 1993. They maintain a steady progression throughout the years to reach 100% efficiency in the latter years (2004, 2005). Given this progression, it can be said that these two countries had some kind of follow up policy of their investments over the years. As a matter of fact, the countries kept reducing their investments and staff in telecommunication over the years. For example, Côte d'Ivoire reduced its staff by 1.5% each year to go from 3,779 staff in 1993 to 2,950 in 2005. Concerning the investments, there were some ups and downs, but the general movement was a reduction of 20% on average. Senegal followed the same movement, reducing the number of staff from 1,910 in 1993 to 1,815 in 2005. Its investment was also cut down regularly by 15% on average. At the same time, the revenue from telecoms for these two countries has been increasing regularly leading to the 100% efficiency of the latter years. This can also be considered good performance given the fact that there was no ICT policy handbook available to the decision makers at the time these countries started their investments in the early 1990s. In fact, in the beginning period of this analysis, the inputs showed some large slacks; for example, according to the results in the model, Côte d'Ivoire could have realized the same performance in 1993 with only 26% of the investments and 16% of the staff of the telecoms (see Appendix F). Côte d'Ivoire did not immediately remedy this situation for a long time until its performance dropped further in 1999 with the political crisis in the country. The country then changed its investment strategy by reducing the investments and also adjusting the number of staff in the telecoms sector in 2003 which resulted in the improvement of its efficiency score to 89% and 100% in the following two years. The right balance between the investments and staffing for the level of revenue the ICT sector produces were found in the latter years.

Senegal is in exactly the same situation as Côte d'Ivoire. It started with a very high level of investments and staffing in telecoms - about 60% more than necessary in the early years. This trend is corrected gradually in early 2000. The country finally reaches the right balance in its input in 2004 and 2005. Cameroon did not follow exactly the same investment trend as Côte d'Ivoire and Senegal. Throughout the period of investigation, Cameroon increased its investments in ICT constantly by 0.5% each year and also increased the number of staff by about the same rate. Nonetheless, Cameroon managed to realize in average a much higher efficiency score than any other country in the present model. Cameroon starts with a low efficiency score at 53% in 1993, keeps this range of score until 1999, then it picks up in 2000, gets to the efficiency frontier and stays at efficiency level or very close for the rest of the time. Concerning the countries in group 2, Burkina Faso and Benin have wavy slopes. Like everyone else they start on the low end - around 50% efficiency - which means that less than 50% of the input was necessary to produce the output. Somehow the countries manage to improve this situation but they fall in inefficiency and move back and forth. This result corresponds strictly to the up and down movements in their investments and staff over the years. This behavior gives the impression that the two countries did not have an investment plan. Mali is the only country with an unusual slope. This country had a very good performance in the early years, but quickly fell in inefficiency and stayed there throughout the entire period of the study. Some improvement started showing only in the last year. Considering these results, it can also be conjectured that the country shows some difficulties in implementing a coherent strategy for its ICT infrastructure expansion.

In conclusion, it can be said that most of the countries under investigation have roughly much of the same trend in their investments and staffing in the ICT sector. Their revenue also increased over time and there is an overall better ratio of revenue to ICT investment and staff in ICT towards the end of the period of investigation in spite of some uncertainty in the early years. From the general trend of the slopes, it is perceptible that all countries came to understand the dynamics of the new technology very late in their implementation process. This caused them to spend too much in the beginning with very little return. This situation is being corrected as time goes on. The time lag effect may have also played a role in these results as well.

6.4 Complementarities between ICT investments and ICT staff

The primary goal of the present analysis is to investigate the relationship between the revenue generated in the ICT sector and the two inputs that generated it, namely Investments and Staff. For this study I use the Translog production function because I am also interested in the interactions between the input variables. The variables used for this analysis are: *Investments in ICT (T)*, and *ICT Staff (S)*, and the output variable, *Revenue of the ICT (REV)*. The relevant Translog function that applies has the following form:

$$\log_e \text{REV} = \beta_0 + \beta_S \log_e S + \beta_T \log_e T + 1/2 \beta_{SS} (\log_e S)^2 + 1/2 \beta_{TT} (\log_e T)^2 + \beta_{TS} (\log_e T)(\log_e S) + \varepsilon$$

Using this function, I am interested in finding out the impact of the variables *ICT Staff* and *Investments in ICT* individually, and the impact of the combination of these two predictor variables on the target variable *Revenue*. I use the Multiplicative model because it has some advantages that suit the present analysis. First of all I use the logs of the variable hence the ranges of the variables are greatly reduced and the Multiplicative model gives the variables more equal weight. It also calibrates nonlinearities and accommodates percentage adjustments.

6.4.1 Data analysis and findings

My focus in this analysis is on two general questions: (1) Are investments in ICT impacting Revenue? And (2) are there interactions between Investments in ICT and staff in ICT that impact revenue? In the present section the findings from MARS analysis are discussed. I treat the variables, *Investments in ICT*, and the *ICT Staff* as independent variables, and *Revenue* of the ICT sector as a dependent variable (Table 6-8 presents sample statistics). For the MARS analysis I set the upper bound on allowable basis functions to 180, a number which ensures a good deal of flexibility in fitting the regression spline model. I use 10-fold cross validation for determining the degrees-of-freedom charged per knot. I also allow two-way interactions among the variables.

Variables	Min	Q25	Q50	Q75	Max
LOGITRE	7.374	7.731	7.963	8.336	8.911
Ordinal Predictor Variables: 2					
LOGICTIN	6.144	7.295	7.531	7.905	8.447
LOGICTST	3.077	3.122	3.184	3.345	3.591

Table 6.8 descriptive statistics of the Impact of investments on Revenue

The translog regressions splines model for predicting revenue of ICT (REV) generated from the MARS analysis has 6 basis functions (see Table 6-9), and R-squared value of 0.832, indicating that the two independent variables can explain as much as 83.2% of the variance in ICT revenue. Thus there are some other variables that explain 16.8% of the variance in ICT revenue that I cannot account for in the present model. The corresponding log linear regression equation for the regression spline model is:

$$\text{Log_REVENUE} = 7.629 + 0.721 * \max(0, \text{Log_ICTIN} - 7.211) + 23.765 * \max(0, \text{Log_ICTST} - 3.281) - 30.300 * \max(0, \text{Log_ICTST} - 3.246) - 5.602 * \max(0, \text{Log_ICTST} - 3.470) - 1.101 * \max(0, \text{Log_ICTIN} - 8.089) + 9.707 * \max(0, \text{Log_ICTST} - 3.176);$$

This can be summarized in Table 6.9 below.

Basis Function	Coefficient	Variable	Expression	P-value	Knot
0	7.629				
1	0.721	Log ICTIN	$\max(0, \text{Log_ICTIN} - 7.211)$	0.0000	7.211
5	23.765	Log ICTST	$\max(0, \text{Log_ICTST} - 3.281)$	0.0000	3.281
7	-30.300	Log ICTST	$\max(0, \text{Log_ICTST} - 3.246)$	0.0000	3.246
9	-5.602	Log ICTST	$\max(0, \text{Log_ICTST} - 3.470)$	0.0000	3.470
11	-1.101	Log ICTIN	$\max(0, \text{Log_ICTIN} - 8.089)$	0.0000	8.089
13	9.707	Log ICTST	$\max(0, \text{Log_ICTST} - 3.176)$	0.0000	3.176

Table 6.9: Description of Basis Functions – impact of revenue

After the forward and backward movements, the MARS model retained 6 basis functions that are meaningful to the inquiry. There are several impact intervals as shown by the different knots and direction of the impact indicated by the best coefficient of each variable in Table 6-9. A deeper discussion of the impact intervals and directions is provided later for each variable.

Impact of Investments in ICT				
Interval	Relevant BFs	Contribution	Slope	Direction
(0.00 – 7.211)	BF I	(1*0.721)	0.721	Positive
(7.211 – 8.089)	BF I , BF II	(1*0.721) + (1*-1.101)	-380	Negative
(8.089 + ∞)	BF II	(1*-1.101)	-1.101	Negative
Impact of ICT Staff				
Interval	Relevant BFs	Contribution	Slope	Direction
(0.00 – 3.176)	BF I3	(1* 9.707)	9.707	Positive
(3.176 – 3.246)	BF I3, BF 7	(1*9.707) + (1*-30.300)	-20.593	Negative
(3.246 – 3.281)	BF 7, BF 5	(1*-30.300 + (1* 23.765)	-6.535	Negative
(3.281 – 3.470)	BF 5, BF 9	(1* 23.765 + (1*-5.602)	18.163	Positive
(3.470 + ∞)	BF 9	(1*-5.602)	-5.602	Negative

Table 6-10: Impact of Investment in ICT, Staff on Revenue of ICT.

6.4.2 Discussion of the MARS Results

Given that my interest is in understanding the relationships between *Investments in ICT*, *ICT Staff* and *Revenue*, I now focus on those basis functions in the regression equation that include these three variables. Table 6-10 displays the log values of investment in ICT ($\log_ICTIN$) and staff ICT ($\log_ICTST$), and in the "Impact Formulae" columns (contribution) and the overall slope of the impact. The relevant basis functions and corresponding coefficient for regions of the regression spines model are laid out in the 'Interval' column. Table 6-10 is composed of two parts for clarity: the upper part titled 'Impact of Investments in ICT' present the two relevant BFs and the relevant regions of impacts of the investments. And the bottom part titled 'Impact of ICT Staff' presents the relevant regions of impact for the ICT staff variable.

6.4.3 Impacts and Complementarities

The results from the analysis show that when the log of *investments* in ICT is in the interval (7.211 – 8.089), it has a negative impact on Revenue with an increasing slope. But when log of *investment* in ICT is in its upper interval e.g. > 8.089, the rate of its impact on *revenue* is negative with a decreasing slope. For this variable, there is no statistical impact below 7.211. The impact of *staff* has 5 intervals. Below 3.176, there is a positive impact. When the log of *staff* is in the next two intervals (3.176 –

3.246) and (3.246 - 3.281), it has a negative impact; then the impact becomes positive in the interval (3.281 - 3.470). Finally, in its upper interval, when it is > 3.470 there is a negative impact.

In the following section, I will analyze the behavior of the two predictor variables in combination and comment on the interactions. As displayed in Table 6-8, there are no significant interactions between the two predictor variables. I will briefly comment on the different possible combinations. In fact, there is 15 different combinations since there are 3 intervals for the *Investment* variable and 5 intervals for the *Staff variable*. But I will be commenting on a few that represent the general trends.

a) Investment ICT in the lower interval:

When log of *investment* in ICT is in the lower interval, there is no impact. But when it moves to the middle interval, (e.g. 7.211 - 8.089), the rate of its impact on *Revenue* is negative. Further, if log of *staff* is in the lower interval at the same time, the overall impact of the combination of the two variables is Positive; the rate of impact of this combination, e.g. $((1 * 0.721) + (1 * 9707)) > 0$. The rate of the impact of the combination of these two variables becomes negative once *staff* moves to the middle interval. Since the rate of log of *staff* in the middle interval is higher than that of investment in the lower interval, $((1 * 0.721) + (1 * -30.300)) < 0$, the overall slope of the combination of the two variables has a positive impact on *revenue*. But if log of *investment* is in the lower interval and log of *staff* moves to the upper interval, the rate of impact of the combination on *revenue* is negative, e.g. $((1 * 0.721) + (1 * -5.602)) < 0$.

b) Investment in the middle interval

When *investment* is in the middle interval, its impact formulae $= (1 * 0.721) + (1 * -1.101) < 0$; therefore the impact is negative. When at the same time *staff* is in its lower interval, the new formula becomes $(1 * 0.721) + (1 * -1.101) + (1 * 9707)$ which is > 0 . The impact of the combination is now positive. When *staff* moves to its middle interval, the impact becomes negative with the following contribution formula. $(1 * 0.721) + (1 * -1.101) + (1 * -30.300)$. Even when *staff* is its upper interval, the impact of the combination is still negative. Only when *staff* is in the interval (3.281 - 3.470), is the impact positive with the following contribution formula:

$$(1*0.721) + (1*-1.101) + (1* 23.765 + (1*-5.602) > 0.$$

c) Investment in the upper interval:

When log of *investment* in ICT is in its upper interval, e.g. log of Investments > 8.089, the rate of its impact on *revenue* is negative given the values of this variable computed in Table 6-9; but put in combination with log of *staff*, the rate of the impact depends now on the interval of the variable *staff*. If *staff* is in the lower interval when *investment* is in the upper interval, the impact formula becomes $(1*8.089) + (1*-30.300) < 0$. The impact becomes negative. When *staff* moves in its middle interval, the new formula becomes $(1*8.089) + (1* 23.765) > 0$. Therefore the impact becomes positive. The latest possible combination is *investment* in the upper interval and *staff* in the upper interval at the same time; with the following impact formula: $(1*-1.101) + (1*-5.602) < 0$, *investment* and *staff* in their upper interval at the same time yield a negative impact on revenue.

Summary of the complementarities

The present model did not detect any significant interactions between the variables Investments in ICT and Staff ICT. Nevertheless, the simulation about their possible combinations shows that the decision maker should be aware of some complementarities between these two variables that can change the direction of the impact. Determining the right amount of capital investment in the ICT sector and the appropriate level of staff in that same sector is not self-evident. The underutilization of the ICT infrastructure observed in the preceding section could also be a consequence of the bad combination of these two factors among others. Two comments can be made after observation of the empirical observations: a) although the model has not detected any significant combinations between the two predictor variables, it could be recommended that a good combination of the two variables could lead to better revenue generation in the ICT sector. It can be conjectured that more studies could help unravel the complex relationship between the two variables that could help policy making decisions. Moreover, a complementary study at the level of each country would yield more precise information.

6.5 Conclusion

This chapter analyzed the revenue performance of the ICT sector of the countries under investigation. In the light of the empirical observations analyzed in the present chapter, I can attempt an answer to the questions relative to the ICT4D claim outlined in step two of my interrogation strategy (cf Table 3.3). Responses to the questions of: (a) truth; and (b) legitimacy of the claims pertaining to the utilization of ICT infrastructure are provided below:

- a) Truth of the claim: The empirical observations in this study did not provide enough evidence to support the claim that 'ICT Utilization will lead to more efficient resource allocation in the society that will increase TFP growth' or to others such as 'ICT infrastructure utilization will lead to learning accumulation and spillover in the society that will increase TFP growth'. According to the findings of my empirical observations of the countries studied, there is no evidence that learning accumulation has occurred in the countries under investigation. Hence, TFP is slowing over time and, as a consequence, productivity is not sustained. At this rate, it would not be wise to claim that the expansion of ICT infrastructure alone will bring about TFP growth and growth of the economy in general. The second claim stating that ICT infrastructure expansion will give rise to broad utilization in the society is not verified either. In fact, utilization is very low relative to the rate of expansion, as shown by the findings of the empirical observations.
- b) Legitimacy of the claims: The utilization of ICT infrastructure is not increasing fast enough to induce growth in the ICT sector which is the precondition for all the other claims to hold. Heavy investments in infrastructure building seem not to help much in the utilization according to the empirical observations. Therefore, it is not accurate to claim that utilization of the infrastructure will be the expected outcome of heavy investments. There are complementary actions to be taken in order to boost ICT utilization in developing countries. These alternative actions are discussed in Chapter 8.

Chapter 7: Social and Economic Impact of Investments in ICT

7.0 Introduction

In the present chapter, I discuss the second and last stage of the inquiry. After analyzing the efficiency of the investments in the ICT sector and subsequently studying the sector performance, the next step is to interrogate if there is any social or economic impact of the investments in ICT in the countries under study (cf. ITU framework, Figure I-1). It can be imagined that the ICT infrastructure development may have other effects not captured in this study and that there are also potential network externalities that cannot be measured in the present study; therefore I will particularly focus my discussion on two aspects that are of utmost importance in the empirical investigation of the present thesis, namely the economic and the social development aspects. Referring to the working definition of development provided in chapter one, the notion of HDI was retained as the indices through which development would be evaluated. In addition to analyzing the impact of the investments in ICT on HDI as the main targeted variable, the impact on three components of HDI (income, education and health) taken individually will be analyzed as well for a deeper and more complete investigation. This chapter is divided into five sections: The first section is a report on the challenges in putting together a meaningful data set for the present analysis. The second section investigates and discusses the impact of ICT investments on HDI. The last three sections discuss respectively the impact of ICT investments on income, education and health.

7.1 Challenges and Data Collection

Although this is an important aspect of the inquiry, several challenges constrained me to limit the scope of the analysis of the impact. In fact, studying the impact required additional social and economic variables particularly data concerning governments' expenditure in education and health. This data was not available for the entire period of the study for all the countries of interest. However, even though the data was difficult to collect and does not cover the whole period of the study, it was sufficient for statistical analysis. Therefore, I made the decision to study this aspect with

a reduced sample. For the sake of completeness of this thesis, it is better to analyze a reduced set of data rather than delaying this very important aspect of the investigation. Consequently, relative to the rest of the analyses conducted in this research, the data for the present analysis spans from 1993 to 2003 inclusive.

Most of the data for this study was collected from the habitual major sources I have been using since the beginning. These are: the ITU, the WDI of the World Bank, and the United Nations' specialized databases (UNDP). Since collecting the data for this chapter was particularly challenging, I consulted some additional sources such as the African Telecommunications Union (ATU), national statistical institutes of the different countries, CIA Factbook, and the Toronto Public Library archives. It should be noted that the 10-year period considered in the present analysis was one of the periods when the investments in ICT on the African continent has been very important; also the results that were produced from this analysis are statistically valid and confirm most of the observations discussed in earlier chapters.

7.2 Impact of the Investments in ICT on HDI

The reader will recall that the primary goal of this study is to find out if investments in ICT have some impact on the social and economic development of the countries selected. The present section reports and discusses the empirical observations of the analysis of the impacts. The HDI, as defined in chapter one is the index that measures economic and social development through the combination of three dimensions namely income, education and health. In the present MARS model, the HDI called LOGHDI is the target variable and the investments in ICT (INV_ICT), Education (INV_EDU) and health (INV_HLT) are the independent variables. All variables are logged. For this investigation, I use Translog production function because I want to determine the importance of the three independent variables in predicting HDI and the relationship that exists among the three predictors. In the equation of the Translog function used, INV_ICT is represented by the letter C, INV_EDU by D and INV_HLT by the letter H. The function has the following form:

$$\log_e \text{HDI} = \beta_0 + \beta_c \log_e C + \beta_d \log_e D + \beta_h \log_e H + 1/3 \beta_{cc} (\log_e C)^2 + 1/3 \beta_{dd} (\log_e D)^2 + 1/3 \beta_{hh} (\log_e H)^2 + \beta_{cd} (\log_e C)(\log_e D) + \beta_{ch} (\log_e C)(\log_e H) + \beta_{dh} (\log_e D)(\log_e H) + \varepsilon$$

For this analysis, the parameters of the model were set as follows: the upper bound on allowable Basis Functions was set to 30; this value ensures a good deal of flexibility in fitting the regression spline model. I use 10-fold cross validation for determining the degrees-of-freedom charged per knot. I also allow two-way interactions among the variables. Table 7-1 below summarizes the results from the regression.

N: 55			R-SQUARED: 0.74445	
MEAN DEP VAR: -0.36608			ADJ R-SQUARED: 0.71251	
			UNCENTERED R-SQUARED = R-0 SQUARED: 0.99197	
PARAMETER	ESTIMATE	SE	T-Ratio	P-Value
Constant	-0.36763	0.00978	-37.59684	0.00000
Basis Function 1	0.86407	0.22945	3.76589	0.00045
Basis Function 4	-0.78112	0.13517	-5.77859	0.00000
Basis Function 5	-0.23225	0.03970	-5.84999	0.00000
Basis Function 6	-0.26280	0.04797	-5.47797	0.00000
Basis Function 9	0.52999	0.07840	6.75998	0.00000
Basis Function 15	-1.54367	0.53785	-2.87006	0.00069
F-STATISTIC = 23.30550			S.E. OF REGRESSION = 0.03568	
P-VALUE = 0.00000			RESIDUAL SUM OF SQUARES = 0.06110	
[MDF,NDF] = [6, 48]			REGRESSION SUM OF SQUARES = 0.17799	

Table 7-1: Results of the Spline regression for LOGHDI

The P-value of this model = 0.00, thus allowing interesting scientific discussion of the results. Further, with an adjusted R-Squared of 0.71251, this model has a very high predictive power. The variables in the model can explain as much as 71% of the variation of HDI. Plus, all variables are very important in the model retained. The P-values of all variables are in acceptable ranges; which means that all the variables have some impact and are worth commenting on. None of them could be dropped. Investment in ICT is the most important with 100% importance, followed immediately by the product of the investments in ICT and investments in education with 85% importance. Investments in health and the investments in education weight respectively 71.76% and 41.44% (Table 7-2).

Variables	Importance	GVC
INV ICT	100.000	0.00389
EDUxICT *	85.72115	0.00336
INV HLT	71.76163	0.00292
INV EDU	41.44598	0.00223
INV_EDU2*	25.60716	0.00202

Table 7-2 Importance of the variables impacting LogHDI

*EDUxICT = product of Investments in Education and ICT, *INV_EDU2 = Investment Education squared

As stated earlier, according to the P-values of the basis functions, all the variables in the model have some impact on HDI. It is evident that since this model can explain 71% of the variance of HDI, there are other variables that explain the remaining 29% that are missing in the present analysis. The following section will discuss the MARS analysis and the impact of the variables. A brief summary of the basis functions that were retained in the MARS regression is listed in Table 7-3 below.

BFs	Expression	Knot	BF Coefficient
1	$\max(0, \text{INV_EDU} - 0.146128);$	0.146128	0.86407
4	$\max(0, 0.478566 - \text{INV_HLT});$	0.478566	-0.78112
5	$\max(0, \text{INV_ICT} - 0.568636);$	0.568636	-0.23225
6	$\max(0, 0.568636 - \text{INV_ICT});$	0.568636	-0.26280
9	$\max(0, \text{EDUxICT} - 0.120396);$	0.120396	0.52999
15	$\max(0, \text{INV_EDU2} - 6.08974);$	6.08974	-1.54367

Table 7-3 Basis functions of the impact on HDI

Given the combinations of the Basis functions in the table above, The MARS model for predicting HDI (LOGHDI) can be summarized by the following equation:

$$Y = -0.367626 + 0.864061 * \max(0, \text{INV_EDU} - 0.146128) - 0.781115 * \max(0, 0.478566 - \text{INV_HLT}) - 0.232249 * \max(0, \text{INV_ICT} - 0.568636) - 0.2628 * \max(0, 0.568636 - \text{INV_ICT}) + 0.529985 * \max(0, \text{EDUxICT} - 0.120396) - 1.54364 * \max(0, \text{INV_EDU2} - 6.08974);$$

As displayed in the above equation, six Basis functions (BF1, BF4, BF5, BF6, BF9 and BF15) were retained in the final model. For the sake of clarity of the discussion, the BFs and the expression of their impact formulae are displayed in Table 7-4 below. Their impact is discussed thereafter.

Rate of Impact of INV_EDU				
Interval	Relevant BFs	Contribution (rate)	Slope	Impact Direction
(0, 0.120396)	BF 9	(1* 0.52999)	0.52999	Positive
(0.120396, 0.146128)	BF9, BF1	0.52999 - (1*0.86405)	-0.33406	Negative
(0.146128, 6.08974)	BF9, BF1, BF 15	0.52999- 0.86405 - (1*-1.54367)	1.20961	Positive
Rate of Impact of INV_ICT				
Interval	Relevant BFs	Contribution (rate)	Slope	Impact Direction
(0, 0.568636)	BF 6	(-1*-0.26280)	-0.26280	Positive
(0.568636, + α)	BF 5	(-1*-0.23225)	0.23225	Positive
Rate of Impact of INV_HLT				
Interval	Relevant BFs	Contribution (rate)	Slope	Impact Direction
(0, 0.478566)	BF 4	(-1*-0.78112)	0.78112	Negative

Table 7-4 Contributions of each variable

7.2.1 Discussion of the Contribution of the Variables

In the present section, I analyze and discuss the contribution of each predictor variable to the target variable HDI. The contribution of each variable is discussed separately first and the interactions and complementarities are analyzed afterwards.

7.2.2 Contribution of Investments in Education

The investment in education represented by the variable (INV_EDU) is a very strong predictor of HDI in the current model. There are three intervals in which the contribution of the investments in education can be commented on relative to the empirical observation reported in Table 7-4 above:

Case 1/: When investment in education is in its lower interval i.e. $\log_e \text{INV_EDU} \in (0, 0.120396)$, it has a positive impact on HDI. This confirms the observation made in an earlier chapter that proposes that investments in education and investments in ICT should be made simultaneously in order to spur development.

Case 2/: When the investment in education moves to its middle interval $\log_e \text{INV_EDU} \in (0.120396, 0.146128)$ and the investment in ICT remains in its lower interval, there is a slight decrease of 0.33 in the impact's overall slope. The direction of the contribution then becomes negative.

Case 3/: Finally when the investment in education is in its higher interval, it has a bigger positive impact on HDI with a much steeper overall contribution slope up to 1.260.

7.2.3 Contribution of Investments in ICT

The contribution of investments in ICT alone is negative in its lower interval i.e. $\log_e \text{INV_ICT} \in (0, 0.568)$; but the impact becomes positive above that value. From the observation above, this contribution will be positive if the investments in ICT are made in combination with investments in education as observed earlier. Further, the negative impact of the investments in ICT in its lower interval means essentially that there is a threshold below which the investments in ICT have no impact on HDI. In other words, there is a minimal level of investments in ICT that must be reached before it can have some impact on HDI in the countries under investigation if the countries were to invest in ICT alone.

7.2.4 Contribution of Investments in Health

The present MARS model suggests that if the investment level is in its lower interval i.e. $\log_e \text{INV_HLT} < 0.478$, it has a negative impact. Above that mark, it has no impact on HDI. Interactions between investments in health with the other two sectors have not been noticed.

To summarize, it can be said that the empirical observations of the analysis of the impact of investments in ICT, Education and Health have very little impact on HDI in the countries studied here. Given the slopes of the contributions, it can be conjectured that the investments are too small to determine the variations of HDI. The evidence for this is that the combination of the investment in education and ICT has a relatively significant impact when those are in their higher intervals.

7.3 Impact of Investments in ICT on GDP PPP, Literacy and Life Expectancy

In this section, I systematically analyze the impact of the investments in ICT, Health and Education on three of the proxies of HDI namely GDP PPP, Literacy and Life Expectancy. Although the three variables are not the only components used in the calculation of HDI, they constitute a large part of it. The

present analysis helps me examine the claims of the ICT4D hypothesis encouraging investments in ICT for their impact on economic (GDP) and social (Health and Education) factors. Three different analyses are performed in the present investigation. For all three, the independent variables are investments in health, investments in education, and investments in ICT. The target variable for the first analysis is GDP to investigate the impact on income. The second analysis sets Life Expectancy as target variable to explain some social impact. Finally, the dependent variable in the third analysis is Literacy rate in order to explain another social aspect of the impact. My specific focus in this analysis is on two general questions: (1) Are investments in ICT impacting the three variables? And (2) Are there interactions among Investments in ICT, Health and Education?

7.3.1 Impact of Investments in ICT on GDP

The present analysis is designed to investigate the impact of the investments in ICT on economic development. For the present study, the index chosen for assessing economic development is GDP. Therefore GDP was defined as the target variable, investments in ICT (INV ICT), investments in education (INV EDU) and investments in health (INV HLT) were set as predictors. For the model, I set the upper bound on allowable Basis Functions to 30, in order to ensure a good deal of flexibility in fitting the regression spline model. I use 10-fold cross validation for determining the degrees-of-freedom charged per knot. I also allow two-way interactions among the variables. Table 7-5 summarizes the results from the regression.

N: 55			R-SQUARED: 0.66556	
MEAN DEP VAR: 2.63812			ADJ R-SQUARED: 0.64589	
			UNCENTERED R-SQUARED = R-SQUARED: 0.99854	
PARAMETER	ESTIMATE	SE	T-Ratio	P-Value
Constant	2.41163	0.03189	75.63501	0.00000
Basis Function 1	0.95272	0.11661	8.17010	0.00000
Basis Function 3	-1.94737	0.37100	-5.24903	0.00000
Basis Function 4	-1.20624	0.51385	-2.34748	0.02282
F-STATISTIC = 33.83096			S.E. OF REGRESSION = 0.10499	
P-VALUE = 0.00000			RESIDUAL SUM OF SQUARES = 0.56219	
[MDF,NDF] = [3, 51]			REGRESSION SUM OF SQUARES = 1.11880	

Table 7-5 Regression of the Impact on GDP

The regression results (Table 7-5) above give good statistical values (P -value = 0.0000). This model can explain as much as 64% of the variation of GDPPP with an adjusted R -squared at 0.64589. Only three variables were used in this analysis; therefore, it is obvious that there are missing variables that explain the remaining 34% of the variation. All variables in the present model are significant given the values of the P -values; further all statistical values are within acceptable ranges. The final model retained three Basis functions reported in Table 7-6 below.

BF#	Expression	Knot	BF Coefficient
1	$\max(0, \text{INV_EDU} - 0.25527)$	0.25527	.0952719
3	$\max(0, 0.478566 - \text{INV_HLT})$	0.478566	-1.94737
4	$\max(0, \text{INV_EDU} - 1.70672)$	1.70672	1.20624

Table 7-6 Basis Functions of impact on GDPPP

Of the three predictor variables, only two have an impact on GDPPP namely INV_EDU (investments in education) and INV_HLT (investments in health). INV_EDU appears in two Basis functions and INV_HLT appears in one basis function. Investment in ICT (INV_ICT) which is the third variable does not appear in any basis function. Therefore, in the present model, this variable has no impact on GDPPP and will not be considered in the calculation of the impact (Table 7-7) below.

Rate of Impact of INV_EDU				
Interval	Relevant BFs	Contribution (rate)	Overall slope	Impact Direction
$(1.70672 + \infty)$	BF 4	$(1 * 1.20624)$	1.20624	Positive
$(0.25527 - 1.70672)$	BF 4 – BF 1	$-1.20624 - (1 * 0.0952719)$	-1.109681	Negative
Rate of Impact of INV_HLT				
Interval	Relevant BFs	Contribution (rate)	Overall slope	Impact Direction
$(0.478566 + \infty)$	BF 3	$(-1 * -1.94737)$	1.94737	Positive

Table 7-7 Contributions of each variable

7.3.2 Discussion of the empirical observation

The Translog regression splines model for predicting GDPPP generated from the MARS analysis has an R-squared value of 0.645, indicating that it has fairly high predictive power. The corresponding log linear regression equation for the regression spline model is:

MODEL GDPPP = (BF1, BF3, BF4); hence the equation:

$$Y = 2.41163 + 0.952719 * \max(0, \ln_{\text{EDU}} - 0.25527) - 1.94737 * \max(0, 0.478566 - \ln_{\text{HLT}}) - 1.20624 * \max(0, \ln_{\text{EDU}} - 1.70672);$$

One of the most important remarks for this analysis is that the investment in ICT does not have any impact on GDPPP. The second observation is that there were no significant interactions among independent variables so it will not be discussed in this section. The variation of GDPPP is explained mainly by the two predictor variables $\ln_{\text{EDU}}$ and $\ln_{\text{HLT}}$. There are two impact regions for $\ln_{\text{EDU}}$. In the first interval e.g. $(0.25527, 1.70672)$, investments in education have a negative impact on GDPPP. In fact the impact is negative until $\ln_{\text{EDU}}$ reaches the bar of 1.0. From that point onwards the impact becomes positive. In its upper interval, when $\log_e \ln_{\text{EDU}} \in (1.70672, +\infty)$ there is a positive impact on GDPPP. In that case, the overall slope of the impact is about 1.206 steep.

In other words, the investments in education have a positive impact on GDPPP as they increase. The empirical observations suggest that the more investments in education, the better the impact on the economic factor (GDPPP). With regards to the investments in health, when it is in its higher interval (i.e. $\log_e \ln_{\text{HLT}} < 0.478566$), the contribution of the investments in health is positive. In other word, the investments in health have a positive impact on HDI above this threshold otherwise there is negative impact. The investments in ICT can have a positive impact on GDPPP as suggested by the empirical observations of the countries in the present analysis only in its upper interval. Based on this observation, it can be conjectured that contrary to the ICT4D hypothesis, not all investments in ICT are delivering positive economic benefits. This result suggests that there must be a threshold that some developing countries have not yet crossed. Since some studies have already shown that there

are economic benefits of ICT implementation in developed countries, questions about the implementation strategy can be posed. These interrogations will be discussed in chapter eight.

7.4 Impact of Investments in ICT on Life Expectancy

In this section, I investigate the second aspect of my inquiry which is the impact of investments in ICT on economic and social development. The first analysis investigated the economic impact by targeting GDPPPP. The present analysis tackles one of the social aspects of the impact. Life expectancy represents the quality of life aspect of the HDI. It is believed that if people are in good health and in good general living conditions, their life expectancy is higher. Discovering if investments in ICT can have an impact on this is important for the hypothesis. First of all, I would like to comment on the results of the regression reported in Table 7-8 below before discussing the MARS results.

N: 55			R-SQUARED: 0.76457	
MEAN DEP VAR: 1.70227			ADJ R-SQUARED: 0.72362	
			UNCENTERED R-SQUARED = R-D SQUARED: 0.99993	
PARAMETER	ESTIMATE	SE	T-Ratio	P-Value
Constant	1.67113	0.00780	214.38248	0.00000
Basis Function 1	0.08848	0.02299	3.84914	0.00036
Basis Function 2	1.37182	0.33036	4.15245	0.00014
Basis Function 4	-0.91413	0.19148	-4.77402	0.00002
Basis Function 7	-0.04411	0.01255	-3.51546	0.00000
Basis Function 8	-0.09610	0.02873	-3.34459	0.00165
Basis Function 10	-0.99961	0.26349	-3.79380	0.00043
Basis Function 12	0.53066	0.13329	3.98132	0.00024
Basis Function 14	0.06267	0.01387	4.51910	0.00004
F-STATISTIC = 18.67298			S.E. OF REGRESSION = 0.01605	
P-VALUE = 0.00000			RESIDUAL SUM OF SQUARES = 0.01184	
[MDF,NDF] = [8, 48]			REGRESSION SUM OF SQUARES = 0.03846	

Table 7-8 Regression for the impact on Life Expectancy

This is the third model of the investigation of the impact. In this model, the target variable is Life Expectancy which represents one of the social development aspects as defined in HDI. Though it is obvious that there are many possible factors affecting life expectancy that are not included in this analysis, it is interesting to see that the variables used in the present model can explain as much as 72% of the variation of life expectancy and all of them have some impact on Life expectancy which

allows a scientific discussion of the results. As the final result of the computation displays, eight basis functions were retained in the final model (Table 7-9).

BFs	Expression	Knot	BF Coefficient
1	$\max(0, \text{EDUxICT} - 0.177161);$	0.177161	+0.0884839
2	$\max(0, \text{LINV_HLT} - 1.3962);$	1.3962	+ 1.37181
4	$\max(0, \text{LINV_EDU} - 0.528735);$	0.528735	- 0.914128
7	$\max(0, 0.243364 - \text{LINV_ICT});$	0.243364	- 0.0441095
8	$\max(0, \text{LINV_EDU} - 1.59218);$	1.59218	- 0.0960963
10	$\max(0, \text{LINV_HLT} - 1.34951);$	1.34951	- 0.999599
12	$\max(0, \text{LINV_EDU} - 0.447158);$	0.447158	+ 0.53066
14	$\max(0, \text{LINV_HLT} - 0.576272);$	0.576272	+0.0626653

Table 7-9 Basis functions of the impact on life expectancy

The model for the impact of investments in ICT on life expectancy retained eight basis functions as stated earlier. All three predictor variables have some impact on the variation of life expectancy. The impact equation is outlined as follows:

$$Y = 1.67113 + 0.0884839 * \text{BF1} + 1.37181 * \text{BF2} - 0.914128 * \text{BF4} - 0.0441095 * \text{BF7} - 0.0960963 * \text{BF8} - 0.999599 * \text{BF10} + 0.53066 * \text{BF12} + 0.0626653 * \text{BF14};$$

For ease of reading and facilitation of the discussion of the impact, Table 7-10 summarizes the combinations of the basis functions, the intervals of impact, the impact formulae and contribution.

Rate of Impact of INV_EDU				
Interval	Relevant BFs	Contribution (rate)	Overall slope	Impact Direction
(0.177161, 0.447158)	BF 1	(1* 0.0884839)	0.0884839	Positive
(0.447158, 0.528735)	BF1, BF12	0.0884839 + (1*0.53066)	0.6191439	Positive
(0.528735, 1.59218)	BF1, BF12, BF 4	0.6191439 + (1*-0.914128)	-0.2949841	Negative
(1.59218, + α)	BF1, BF12, BF4, BF8	-0.2949841 + (1* - 0.0960963)	-0.3910804	Negative
Rate of Impact of INV_ICT				
Interval	Relevant BFs	Contribution (rate)	Overall slope	Impact Direction
(0, 0.243364)	BF 7	(-1* - 0.0441095)	0.0441095	Positive
(0.243364, 0.177161)	BF 7, BF1	0.0441095 + (1*0.0884839)	0.1325934	Positive
Rate of Impact of INV_HLT				
Interval	Relevant BFs	Contribution (rate)	Overall slope	Impact Direction
(0.576272, 1.34951)	BF 14	(1* 0.0626653)	0.0626653	Positive
(1.34951, 1.3962)	BF 14, BF 10	0.0626653 + (1*- 0.999599)	-0.9369337	Negative
(1.3962, + α)	BF 14, BF 10, BF2	-0.999599 + (1* 1.37181)	0.4348763	Positive

Table 7-10 Contribution of each variable to Life expectancy

7.4.1 Impact of Investments in Education on Life Expectancy

The results of this analysis confirm the findings in the first analysis that suggested complementarities between investments in education and investments in ICT. In fact in the present model again, combinations of the two variables have an impact on the target variable. For example, when the investment in education is in its lower interval it has a positive impact on life expectancy if the investment in ICT is also in its lower interval at the same time. But if investment in education is in its higher interval (i.e. $\log_e \text{INV_EDU} > 0.159218$) and the investments in ICT remains in its lower interval, the impact becomes negative. Based on this empirical observation, it can be conjectured that these two variables are complementary in their impact on economic and social development.

7.4.2 Impact of Investment in ICT on Life Expectancy

As displayed in the contribution table above, the investment in ICT has a positive impact on Life expectancy no matter how small or big. But when the investment in ICT is in its lower interval, there is a smaller impact. This impact becomes more important as the investments in ICT move to its higher interval and at the same time investment in education also move to its higher interval. These complementarities have already been discussed and will be discussed further in chapter eight.

7.4.3 Impact of investments in Health on Life Expectancy

There are three intervals in which the contribution of the investment in health can be commented on relative to its impact on life expectancy. Below 0.576272, there is a zero impact; but when investment in health is in its lower interval (i.e. $\log_e \text{INV_HLT}$ is in the interval (0.576272, 1.34951) the impact is positive. But when investment in health is in the middle interval the impact becomes negative. There is again a positive impact when investment in health is in its higher interval (i.e. $\log_e \text{INV_HLT} > 1.3962$). It can be concluded at this stage that the higher the investments in health, the better its contribution to life expectancy.

7.5 Impact of Investments in ICT on Education

The third dimension of HDI investigated in this research is education which is the other social aspect. Literacy rate is used to represent the level of education of the countries under study. The goal of the present analysis is to uncover the determinants of variations of education. Since the model retained here can only explain 12% of the variation of Literacy, it is obvious that there are other variables missing in this study that explain the remaining 88% of the variation. The results of the regression are reported in Table 7-II below.

N: 55			R-SQUARED: 0.14503	
MEAN DEP VAR.: 1.55020			ADJ R-SQUARED: 0.12889	
			UNCENTERED R-SQUARED = R-SQUARED: 0.99018	
PARAMETER	ESTIMATE	SE	T-Ratio	P-Value
Constant	1.62929	0.03385	48.12597	0.00000
Basis Function 3	-0.15491	0.05167	-2.99836	0.00413
F-STATISTIC = 8.99016			S.E. OF REGRESSION = 0.15737	
P-VALUE = 0.00413			RESIDUAL SUM OF SQUARES = 0.31251	
[MDF,NDF] = [1, 53]			REGRESSION SUM OF SQUARES = 0.22264	

Table 7-II Regression for the impact on Literacy

The MARS regression gives a less important R-squared than the ordinary least square regression. The MARS model for Literacy exhibits no scientifically exploitable results. With an adjusted R-squared of

0.12, the model's predictive power of Literacy is relatively weak. Two remarks can be made from this observation. Either the variables used in the present analysis are not suited enough for predicting Literacy or the variables that have not been taken into account in this study have a very high predictive power on literacy. These observations are counterintuitive because one would expect investments in education to be a good enough predictor of literacy. More discussion about these findings will be provided in chapter eight.

7.6 Conclusions

In this chapter I use a Translog production function in a MARS analysis to explore the impact of investment in ICT-I on economic and social development in the countries under investigation. My interest in this investigation is to attempt an answer to the interrogation questions relative to the ICT4D claim outlined in step three of my interrogation strategy (cf. Table 3.3). Responses to the questions of: (a) Truth and (b) Legitimacy of the claims pertaining to the investments in ICT infrastructure expansion are provided below:

- (a) The claim states that "Heavy investments in ICT infrastructure expansion will lead to rapid social and economic development". According to the empirical observations of the countries studied, it is not accurate to state that investments in ICT will improve economic or social development; and there are many reasons for this claim: First, the analysis concerning the impact of investments in ICT-I on HDI clearly demonstrates that investment in ICT alone does not have any positive impact on the variation of HDI. Positive impact occurred only when there was equally investment in education in the same interval. Next, the specific investigation of the impact of investments in ICT-I on GDDPP did not verify the ICT4D hypothesis. As a matter of fact, based on the empirical observations from the second analysis, investments in ICT-I does not have any significant impact on GDDPP. Furthermore, investment in ICT does not have any impact on literacy rate. The positive impact of the investment in ICT-I on life expectancy is also bound to the investments in education as mentioned earlier. Therefore, based on the empirical observations of the countries in the present study,

there is ample evidence that heavy investments in ICT alone will not bring about social and economic development.

- (b) As evidenced by the empirical observations from the MARS analysis, there exist competing explanations of the development dynamics not represented in the ICT4D hypothesis. These are of two orders. Firstly, the ICT4D hypothesis does not state any prerequisites before the successful implementation of ICT. Recent research by Samoilenko and Ngwenyama (2008) has demonstrated the importance of complementarities between investments in ICT and ICT staff. Others such as Bollou (2006), Ngwenyama and Morawczynski, (2009) have also demonstrated that civil infrastructure, for example: numbers of schools, number of roads and railways are prerequisites for successful ICT implementation and use. Furthermore, the ICT4D hypothesis does not suggest that complementarities of investments in other sectors are necessary for a positive impact on social and economic development. The abundant evidence provided in this research underline the importance of complementarities. Therefore, the ICT4D claim on social or economic development is not legitimate. It could be argued that this claim is incomplete because it has been amply demonstrated through the present study and others that in order to have some positive social or economic impact, the investment in ICT must be synchronized with the investments realized at the same time in education and health. Further discussion on the impact and the complementarities will be done in chapter 8.

Chapter 8: Findings from Analysis of the ICT4D Hypothesis

8.0 Introduction

I will now discuss the empirical findings concerning the validity of the underlying claims of the ICT4D hypothesis. This discussion is based on the integration of empirical findings outlined in Chapters 5, 6 and 7. The reader will recall that the central focus of the empirical analysis was the critical interrogation of the core argument of the ICT4D Hypothesis. The argument structure was laid out in Chapter 3, but I will summarize it here for the convenience of the reader (cf. Figure 8.1): ICT infrastructure expansion directly contributes to ICT utilization which in turn leads to: (1) technology change (learning accumulation and spillovers) in the society; (2) improvements in the allocation of scarce resources (the technical efficiency); (3) new business formation (the network externalities argument); and (4) influences the expansion of democratic freedoms (the network externalities argument); (5) finally, 2, 3, and 4 lead to improvements in economic and social development (as measured by components of HDI). The focus here is an analytical discussion of the *truth* and *legitimacy*¹⁶ of each of the claims (and their sub claims) in light of the empirical observations. I will present a general summary of the empirical findings and outline more generally my theoretical conclusions about the ICT4D argument derived from the empirical analyses reported in Chapters 5, 6, and 7. In the discussion, each of the basic claims of the ICT4D hypothesis is interrogated from a critical theory perspective. This analysis focuses on answering the following general question concerning the *truth* of the ICT4D claims: (a) Does the empirical evidence support the claim? And the general question about the *legitimacy* of the ICT4D claims: (b) Is the reasoning provided in the ICT4D hypothesis sufficient to support the claim? The key focus of the *legitimacy* test is to determine if there are relevant arguments (or factors) that are overlooked or ignored by the proponents of the claim (Cukier et al, 2009). The discussion of the empirical analyses relevant to the *truth* and *legitimacy* claims is organized around three foci, ICT Infrastructure Expansion, ICT Infrastructure Utilization, and ICT Sector Performance and Complementarities.

¹⁶ The *sincerity* test is beyond the scope of this thesis, and the *comprehensibility* is taken at face value.

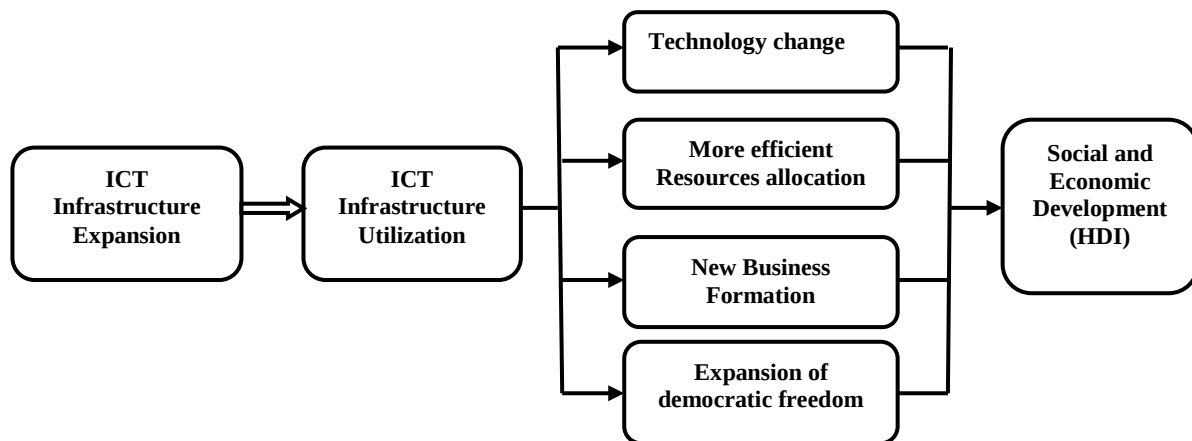


Figure 8.1 Conceptual Structure of the ICT4D Core Argument

8.1 Empirical Findings on ICT Infrastructure Expansion

Efficient ICT infrastructure expansion is foundational to the ICT4D hypothesis. Rapid and efficient expansion of ICT infrastructure is necessary for deploying ICT services for the utilization for members of the society. Further, a central claim of the ICT4D hypothesis is that ICT infrastructure expansion will directly contribute to *TFP* growth in the wider economy. For this claim to be supported there must be: (a) efficient management of the ICT infrastructure expansion; (b) learning accumulation sufficient to ensure TFP and technology change. The recent boom of mobile telephony in African countries has led many researchers to claim that ICT sectors of African countries are efficient (Scott, Batchelor, Ridley & Jorgensen, 2009). Further, the ITU has ranked Africa as the fastest growing ICT market that promises developmental outcomes (ITU, 2004). But the empirical analysis of the ICT sectors of the countries in this study presents a different picture. The results of my analysis suggest that it would be more accurate to say that ICT sectors of these six West African countries remain relatively inefficient after thirteen years of heavy investment. The summary of the DEA empirical findings in Figure 8.2 shows that the ICT sectors operated below their maximum technical efficiency. The reader will observe that the efficiency frontier is attained only 4 times during

the 13 years of this study. The average efficiency score for these six countries is around 70%. The findings from the analysis lead to three critical empirical observations:

- (1) The ICT sectors are underperforming in terms of ICT expansion; most of them failed to reach their maximum potential for expanding the infrastructure. As a general observation, the ICT sectors of these six countries are inefficient 90% of the time in ICT infrastructure expansion.
- (2) The percentage of utilization of the inputs (investments in ICT and ICT Staff) for the production of outputs (ICT infrastructure) is below 100% in most cases (cf. Table 8.1).
- (3) For most of the 13 years, the ICT sectors of these six countries are operating at decreasing returns to scale.

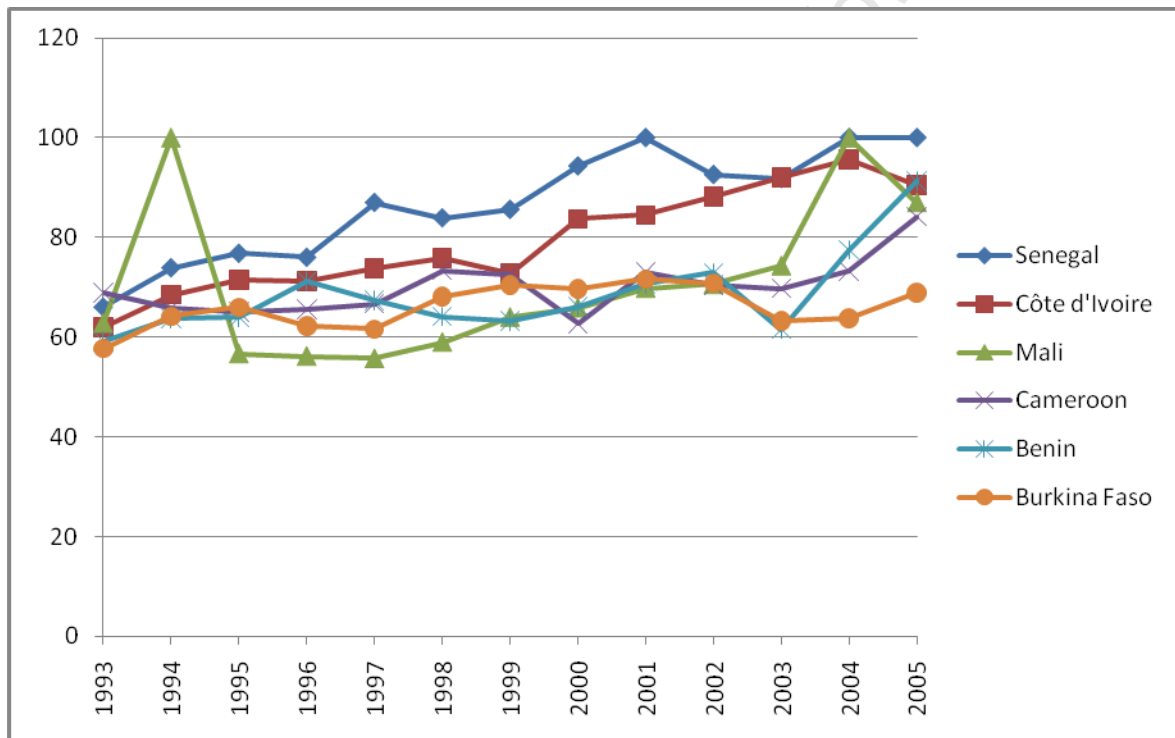


Figure 8.2: Efficiency score of ICT infrastructure development

These empirical observations suggest that these six countries could have rolled out much more ICT infrastructure and more effectively utilized their resources with better management (I will return to this issue in section 8.3). I will now illustrate these findings with two examples, Senegal, the best performing country and Burkina Faso, the least performing with regard to ICT infrastructure

expansion. I will look at two aspects, technical efficiency and the utilization of resources. In 1993, Senegal operated around 69% technical efficiency but slowly improved, finally reaching 100% efficiency in year 2001; and fluctuated in the 90-100% efficiency range from 2002 to 2005 (cf. Figure 8.2). In terms of utilization of resources (ICT investments and ICT Staff) the reader will note that while Senegal was the most efficient of the six countries in ICT infrastructure expansion it was significantly underutilizing its ICT investments and staff (cf. Table 8.1); it could have achieved the same level of outputs with a significant reduction of resources (I will return to this issue when discussing learning accumulation).

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Benin	ICT Invest	30.6	55.1	53.0	91.4	67.3	46.9	38.3	49	68.8	79.3	9.57	76.9	100
	ICT Staff	10.8	13.2	15.5	18.2	19.9	20.6	23.1	27.6	32.4	34.7	36.5	50.7	76.9
Senegal	ICT Invest	28.1	69.5	79.1	55.5	98.7	61.8	54.7	75.2	100	65.8	59.7	100	100
	ICT Staff	27.1	30.1	34.2	48.2	63	73.2	81.8	98.8	100	96.2	96.8	100	100
Cameroon	ICT Invest	83.2	63.7	55.5	56.0	59	99.0	91	31.9	67.6	51.7	29.7	28.5	50.9
	ICT Staff	18.7	19.5	22.2	23.7	27.1	24.6	28.1	28.1	41.8	44.0	45.8	52.9	75.1
Cote d'Ivoire	ICT Invest	26.9	60.2	73.3	65.1	78	79.5	40.7	90.9	82.9	90.0	100	100	58.9
	ICT Staff	15.6	18.1	21.1	25.0	26.2	30.6	38.7	45.0	52	60.7	63.1	81.9	84.5
Burkina Faso	ICT Invest	26.9	62.3	70.7	45.1	39.9	75.2	84.5	76.1	83.8	72.0	29.7	23.1	47.0
	ICT Staff	12.0	14.2	16.1	18.2	19.1	21.6	24.7	27.4	29.7	34.1	32.5	38.1	40.4
Mali	ICT Invest	66.2	100	26.7	20.2	15.8	32.9	58.2	65.5	80.6	84.5	86.3	100	96.0
	ICT Staff	6.4	100	8.4	10.3	11.7	13.4	16.4	18.9	24.6	24.2	33.8	100	63.8

Table 8.1 Percentage Utilisation of ICT Investments and ICT Staff

The second case, Burkina Faso, is the least performer for ICT infrastructure expansion. The ICT sector of Burkina Faso never reached the efficiency frontier. Its average performance remains around 65%. Further, the trajectory for Burkina shows little improvement throughout the period of the study. In 1993 Burkina's technical efficiency of ICT infrastructure expansion was just below 60%, increasing

only slightly over the following years to just above 60%; but remaining flat around 65% for the period of the study. The interested reader will also see that Burkina's percentage of utilization of investment does not pass 50% overall, similarly, the percentage of usage of the staff is also very small; it barely reaches the 30% mark relative to the production of its ICT sector over the years (cf. Table 8.1). A 50% percentage of utilization of the investment in ICT means that half of the investment did not realize any output. That portion of the investment could have been allocated to some other activities.

8.1.1 Empirical Observations on Inefficiencies of ICT Infrastructure Expansion

I would now like to examine the nature of the inefficiencies in the ICT sectors of these six countries. According to the neoclassical growth accounting theory, upon which the ICT4D hypothesis is based, to achieve optimum total factor productivity (TFP) a social system must operate at or very close to most productive scale size (MPSS). However, when new technology is implemented into a system (i.e. the ICT sectors) productivity is expected to drop until enough learning accumulation has occurred and the ICT sectors move up the progress curve. In ideal circumstances the ICT Infrastructure expansion dynamics should follow a progress curve (cf. Figure 8.3) of the following four phases (Rosenberg, 1972; Geroski, 2000; Stoneman, 2001):

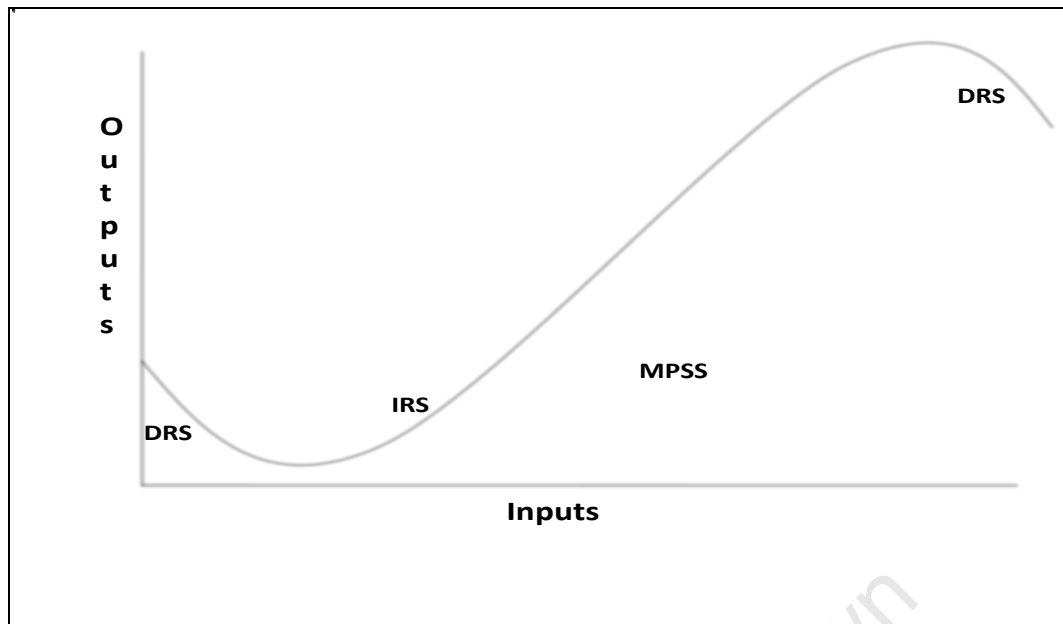


Figure 8.3 Example of Progress Curve Illustrating the Dynamics of Learning and Productivity

1. At the start of the infrastructure expansion process there is a short period of DRS during which the ICT sector is developing capacity and learning.
2. After learning has accumulated, and capability for the infrastructure expansion is enough, the sector moves up the progress curve operating at IRS. (In the case where the sector has not yet reached the productivity frontier but new investments are resulting in increasing outputs).
3. When sufficient capability has accumulated, the sector is mature and productive and is expected to operate at MPSS: (This is the ideal situation in which the sector is producing the maximum output possible and at the same time it is also using the best possible combination of its inputs).
4. At some point in time, new technology comes along that eclipses the capacity of older technology. The sector can switch to new technology and start a new progress curve (as in 1 above) or stay with the old technology beyond its useful life which results in DRS. (In this situation, the sector will produce below the expected output or below productivity frontier but given the level of technology, any additional input will pull the firm or sector farther from the productivity frontier).

The scale efficiency observations from the empirical analysis in Chapter 6, will further illustrate where each of the six ICT sectors are on the progress curve. Table 8.3 below provides a summary of the scale efficiency performance of each of the thirteen years of the empirical analysis. The reader

will observe from Table 8.3 that three of the ICT sectors operated at most productive scale size (MPSS) for four years of the 13 years studied. These are: Mali in 1994, 2004 and 2005; Senegal in 2001, and Cote d'Ivoire in 2005. It is also important to note that Cote d'Ivoire and Burkina also operated at Increasing Returns to Scale in 2001, 2002 and 2004, 2005 respectively. Apart from these exceptional years, the six ICT sectors operated at decreasing return to scale (DRS). These empirical observations confirm the other empirical observations on inefficiency of infrastructure expansion and the underutilization of resources (inputs) discussed above. With the few cited exceptions, the infrastructure outputs are increasing at a much slower rate than the increase of inputs over this 13 year period. A conclusion can be drawn that over the 13 years of this study the ICT sectors of these countries have been over-investing relative to their capabilities to manage and execute the ICT expansion. Another conclusion that can be drawn from this analysis is that these sectors almost never accumulate enough learning (or develop enough technical and managerial capability) to move up the progress curve. This is a challenging issue for the ICT4D hypothesis, for according to the neo-classical growth accounting theory, learning and knowledge accumulation is essential for the realization of TFP growth (and contribution to the wider economy). But as we can see from the empirical observations in Table 8.2, with regard to ICT expansion the six ICT sectors are not moving up the progress curve. They are stagnant at the beginning. This situation gives rise to at least two important questions: (1) Are there other factors influencing the efficient expansion of ICT infrastructure that have not been considered in the ICT4D hypothesis? (2) Are there alternative investment plans that could improve the ICT expansion performance of these sectors?

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Senegal	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	MPSS	DRS	DRS	MPSS	MPSS
Côte d'Ivoire	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	IRS	DRS	MPSS	IRS
Mali	DRS	MPSS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	MPSS
Cameroon	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS
Benin	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	MPSS
Burkina Faso	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS	DRS

Table 8.2 Scale Efficiency Performance of the Six ICT sectors

8.1.2 Factors Affecting ICT Infrastructure Expansion Performance

I will now address the question: Are there other factors influencing the efficient expansion of ICT infrastructure that have not been considered in the ICT4D hypothesis? Here I will give a summary discussion, the detail findings on this question can be found in Chapter 5. Proponents of the ICT4D hypothesis have largely ignored the question of the importance of prevailing conditions, or the absorptive capacity (readiness) of the least developed countries for implementation of new technologies. In the empirical analysis in Chapter 5, Section 5.5, I investigate the impact of human capital, other civil infrastructure and per capita GDP on ICT expansion performance. The results of the MARS analysis show that these factors can explain up to 43% of the variance in ICT infrastructure expansion efficiency. Therefore, a logical conclusion is that the ICT4D program needs to consider existing conditions of the least developed countries if it is to be effective. The current ICT4D hypothesis does not take into account that development depends on many factors in many economic sectors at the same time in which prevailing conditions enable or constrain achievement of future development goals. One area important to efficient ICT expansion that has been overlooked is the technical expertise needed to deploy and maintain the ICT infrastructure.

Some descriptive statistics from this study can help illustrate the importance of these factors on ICT infrastructure expansion. The countries in our sample with better civil infrastructure, per capita GDP and capacity for training technical specialists have done relatively better at ICT expansion performance. For example, Cote d'Ivoire's ICT expansion performance may be partly related to its capacity to educate annually some 30,000 ICT engineers and technicians at its ten tertiary institutions for technological education¹⁷. This capacity to produce a large number of high trained ICT professionals is unparalleled in the other five countries. On the contrary, Cameroon and Senegal each has only one polytechnic institution with limited capacity for training ICT engineers and technicians, and the others have none. Essentially, most of the aspiring ICT engineers and technicians from the

¹⁷ For example: Ecole Nationale Supérieure d'Ingénieurs, Ecole de Technologie Tertiaire, Ecole Nationale des Techniciens Supérieurs, the Centre de Formation Continue, Ecole Supérieure Interafricaine de l'Électricité, Institut National Polytechnique Houphouët-Boigny, Ecole National Supérieure des Travaux Publics and Ecole Militaire Préparatoire Technique.

region seek training in Cote d'Ivoire, and most of them remain there to work after completing their studies. Perhaps this is why its ICT sector has ten times the number of ICT staff employed in Benin, twice that of Cameroon and three times that of Senegal. The ability of Cote d'Ivoire to train its own staff gives it an advantage over the other five countries. It is no surprise that Cote d'Ivoire leads these countries in the reliability of its telephone circuits, as seen by the low level of failures per 100 telephone circuits.

8.1.3 Summary of Findings on Efficient ICT Infrastructure Expansion

Fundamental to the ICT4D hypothesis is the efficient expansion and maintenance of ICT infrastructure. The empirical evidence of my analysis does not support the attainment of efficient ICT infrastructure expansion. Secondly, the legitimacy of the efficient ICT expansion claim of the ICT4D hypothesis is not supportable by the evidence. Proponents of the ICT4D hypothesis fail to explicate the importance of prevailing conditions, when it is logical to assume that these would affect the efficient expansion and maintenance of the ICT infrastructure. Further as it has been reported elsewhere, complementary investments in education, healthcare and other civil infrastructure lead to higher impact of ICT on human development (Ngwenyama et. al. 2006). Some earlier critiques of the ICT4D hypothesis have also argued that ICT expansion is dependent or complementary to other civil infrastructure, such as roads, railways, airports, electricity and so on (Rauch, 1995; Munnell, 1992, Roller & Waverman, 2001). Other researchers, Gholami et al. (2004) and Ngwenyama and Morawczynski (2009) found that human capital, as well as the overall wealth of the country, impacts ICT infrastructure expansion efficiency. In summary, a foundational component of the ICT4D program, efficient ICT infrastructure expansion and maintenance is difficult to attain for these six West African countries. More attention needs to be focused on addressing the factors (such as human capital) that influence efficient deployment and management of the ICT infrastructure. If the ICT4D program is to be successful the issue of efficient and effective management of the infrastructure will need to be directly addressed.

8.2 Empirical Observations on ICT Infrastructure Utilization

Another key dependency of the ICT4D hypothesis is the utilization of ICT infrastructure by people and businesses of the society. The key claims of the ICT4D hypothesis that ICT utilization will lead to: (a) learning accumulation and spillovers (technology change) in the society; (b) to more efficient allocation of resources in the society; (c) new business startups, innovation and new economic sectors; and (d) expansion in democratic freedoms¹⁸; all depend on effective utilization of and innovation upon the ICT infrastructure. Three issues of ICT utilization are central to my analysis: (1) The level of utilization of the ICT infrastructure. (2) The nature of the ICT utilization. (3) Factors affecting utilization of ICT infrastructure. I will now discuss the empirical findings relevant to these three issues.

8.2.1 The Level of ICT Utilization

The level of utilization of ICT infrastructure is one measure of how well the society is progressing according to the ICT4D hypothesis. However, it is also a measure of the effectiveness of investments in ICT in the country and its ability to leverage the infrastructure for development. Table 8.4 provides a summary of the relative efficiencies of ICT infrastructure utilization of the six sectors. However, the reader is cautioned when interpreting these statistics. First it is important to note that these are relative efficiencies as opposed to absolute efficiencies. These figures tell us how these countries are doing relative to each other (I will discuss the implications of this later). Second, it must be remembered that some of the six countries have deployed more ICT infrastructure than others. This ICT infrastructure capacity also affects the relative efficiencies of utilization. An examination of the empirical observations about ICT infrastructure utilization shows that the top performers are Cameroon in first place with an average of 83.9% and Mali in second place averaging 83.5%. It is also important to note that Cameroon and Mali ranked at the bottom of the ranking in the infrastructure expansion. So their high performance on ICT utilization is not a surprise; both Cameroon and Mali are

¹⁸ The claim of expansion of democracy is beyond the scope of this research; it deserves the focus of another PhD thesis.

expanding ICT services on lower ICT infrastructure capacity than Cote d'Ivoire and Senegal which were the most aggressive in expanding their ICT infrastructures. In terms of ICT infrastructure utilization, Cote d'Ivoire ranks third with an average of 74.1% and Senegal ranks fifth with an average of 69.5%. Table 8.3 shows that utilization barely reaches the 100% score in many of the countries under investigation, with an average below 70% utilization efficiency. Senegal remains mostly inefficient until the last two years where it finally reaches 100% efficiency. Benin, Burkina and Cote d'Ivoire were relatively efficient in the first years but remain mainly inefficient for 11 years out of 13. While these utilization measures are useful for comparing these six countries as a group, they provide little insight about how efficient these six ICT sectors are relative to countries ranked higher in development (HDI) such as South Africa. Since the purpose of this ICT infrastructure and utilization is to achieve a higher level of development, it is important to try to understand the importance of utilization to development.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	AVG
Cameroon	100	80.2	76.7	85.4	81.8	81.6	100	76.5	57.8	65.5	83	100	100	83.8
Mali	81.2	100	72.0	69.5	100	87.5	84.0	100	75.8	82.6	67.0	64.7	100	83.5
Cote d'Ivoire	80.0	100	100	83.7	86.2	76.3	78.7	66.1	56.9	56.7	62.2	58.2	58.0	74.1
Burkina	100	64.6	59.3	53.5	77.1	88.8	84.6	63.2	63.8	67.6	75.3	69.2	72.9	72.3
Senegal	75.9	63.6	63.5	54.4	51.9	52.8	60.4	52.9	66.5	80.2	80.7	100	100	69.5
Benin	58.0	52.4	47.6	49.5	63.0	73.8	100	69.7	64.8	64.1	77.0	100	75.6	68.9

Table 8.3 Relative Efficiencies of ICT Infrastructure Utilization

8.2.2 What is the Nature of the ICT Utilization?

A second issue important to the realization of the ICT4D goals is the nature of utilization. Various institutions and some researchers have applauded the rapid rise in mobile telephony in Sub-Saharan Africa and have argued that this utilization of ICT will have a significant impact on development (Fleming, 2002; ITU 2004 and 2007; Mbarika & Mbarika, 2006; Djiofack-Zebaze & Keck, 2009). For example, Mbarika & Mbarika (2006) point out that farmers in remote areas are now able to

communicate with buyers in city markets. Fleming (2002) suggests that mobile phones can result in the development of new businesses. However, research has shown that the use of mobile phones is not always a major determinant of economic or social development (Alzoumana, 2005; Polikanov & Abramova, 2003). Another measure of ICT infrastructure utilisation is Internet usage. Recently the ITU reported that internet penetration in Africa is barely 5.6%, whereas for the rest of the world it is 26.6% (ITU, 2004). The Internet is the core technology of e-business, and a penetration rate 5 times lower in Africa than the rest of the world does not bode well for e-business formation. Another key argument of the ICT4D hypothesis is that ICT utilization will lead to technology change (learning accumulation and spillovers). So if the ICT utilization in Africa is dominated by mobile phone calls, from where will the technology change that is needed for TFP growth come? Technology change comes from knowledge accumulation from the sophisticated application and innovation on technology to solve problems, and from business and process innovations that lead to more efficient resource allocation (Parente and Prescott, 1994). This is not occurring in these six West African countries.

8.2.3 Factors affecting the Utilization of ICT

Finally, the question: Is the reasoning provided in the ICT4D hypothesis sufficient to support the claim concerning ICT infrastructure utilization? Several researchers point out there is a knowledge gap impeding people and small and medium businesses in developing countries from exploiting ICT (Schech, 2002; Wong, 2002:). Lack of access, illiteracy, lack of network security, lack of business incentives, etc, all these reasons are regularly brought forth to explain the reasons Africa is virtually kept out of the digital world. In Chapter 6, I empirically investigated the impact of some factors affecting ICT infrastructure utilization for which data existed. Findings from the MARS analysis point to literacy rate as the most important variable influencing ICT utilization, and cost of services as the second most important variable. However, as can be seen in Chapter 6, the relationships are nonlinear. It is also important to note that the three variables, Literacy rate, Costs and GDPPP only explain 23% of the variance in ICT utilization. The findings however, confirm other empirical findings from the DEA analysis that the best performer on ICT utilization is Cameroon, which has the highest literacy rate of the group. It must be noted that literacy is a proxy for level of technology competence

which is difficult to measure as there is limited reporting on the number of ICT specialists in these countries. It was impossible to obtain figures on the number of graduates each year from the tertiary technical institutions in these countries. But recent statistics from the UNESCO's UIS fact sheet (2009) clearly show that an increasing number of sub-Saharan African countries' youth is seeking enrollment in tertiary education institutions abroad. The report says that as many as 218,000 students from sub-Saharan countries were enrolled outside their countries in 2007. This represents 5.8% of the number of those students enrolled in their home country. The same report states that tertiary education enrolment increases at the rate of 3.1% each year in the sub-Saharan countries. These data are important not only for this research, but for future planning of ICT4D initiatives in these countries. Many researchers have pointed out that innovation, technology change and productivity improvements depend on a highly skilled workforce (Machin & Van Reenen, 2007; Samoilenko & Osei-Bryson, 2008). The second factor impacting ICT utilization is cost of services. The cost of telephone and internet services as a percentage of GDP PPP in African countries is still very expensive relative to developed countries. A third factor impeding e-business development is institutional. In spite of all the talk about ICT as an engine of development, in Africa most of the continent is blacklisted for the processing of digital transactions. If you are in an African country you are more likely to be denied a purchase on amazon.com or the booking of an airline ticket online than if you are in a developed country, even when you have a verifiable means of electronic payment. A key outcome of the lack of technology competence is that African businesses and individuals cannot protect their internet servers from cybercriminals operating from developed countries. While a common internet fraud has come to be known as 'the Nigerian Letter', most of these do not originate from Nigeria or anywhere in Africa (Cukier, et al, 2009). If ICT4D's promise of new business development is to be successful African policy makers will need to pay close attention to human capital and institutional infrastructure.

8.2.4 Summary of Findings on Efficient and Effective Utilization of ICT

A corner stone of the ICT4D program is utilization of ICT. Utilization is expected to result in: (a) technology change in the society; (b) more efficient allocation of resources; (c) new business formation; and (d) expansions in democratic freedoms. The empirical evidence from Chapter 6 shows that the level and type of present utilization will not lead to the outcomes that are expected from ICT4D. Central to the realization of the ICT4D hypothesis is technology change and innovation upon ICT, but this is dependent on human capital. A high level of technological competence is needed to develop and implement ICT applications that improve business and government efficiencies and lead to better resource allocation in the society. Alzoumana (2005) and Polikanov and Abramova (2003) have argued that if the present state of ICT utilization remains the norm, ICT will not lift these six West African countries out of poverty. The new rush into mobile telephony will at best create consumers in African countries; and at worst bleed off resources of impoverished people which could be better invested. According to Polikanov and Abramova (2003), this push for the consumption of western technologies could be seen as new colonialism and imperialism. A few examples seem to support Polikanov's argument. For example, the young people in the cities of Douala, Abidjan or Lagos, buy the latest Nokia or i-Phone handsets at ten times the value that they can be obtained for in developed countries. Then to keep their phone numbers, they are forced to purchase recharge cards every day at the expense of the many other necessities, such as rent, tuition, and meals for their children and themselves. While the positive stories of mobile telephone banking and farm products price negotiation are broadcasted by the proponents of ICT4D, they are silent on the wider impact of mobile phone acquisition in many African countries. Further, they pay little attention to the need for the development of the human capital needed to realize the goals of ICT4D. Too little attention is given to investment in tertiary technological education which is needed for implementation, management and innovation with the ICT technology. Most of the six countries are too dependent on foreign experts to design and deploy ICT applications for business and government, while the human capital remains underdeveloped.

8.3 Empirical Observations of ICT Sector Performance

Development in any country rests on the ability of the various sectors of the country to generate residual outputs from their inputs. These residual outputs on individual sectors result from learning and accumulation in the wider social system. The consequence of such productivity is the guaranty of self-sustainability and growth of the sector and the country. Residual outputs also mean that without additional resource inputs, the sector can continue to produce more outputs due to learning, accumulation and innovation (technology change). In Chapter 5, I empirically investigated the learning and accumulation in the ICT sectors of the six countries of the study. The results of that analysis show that over the thirteen years of the study, with productivity ratios (PR) ranging from 0.85 to 4.38, the sectors in question are not productive. It is assumed that for an economic sector to grow and sustain itself, learning accumulation is necessary. The productivity analyses of the thirteen years for the countries in question show no substantial improvement over the years. Table 8.5 presents a summary of the productivity ratios. A discussion of the productivity follows next.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Benin	0.1	1.78	1.58	3.12	1.71	1.23	1.59	1.91	1.63	1.4	0.66	2.63	1.24
Senegal	0.1	1.11	1.5	4.38	1.87	1.58	1.86	1.71	1.7	1.07	1.34	1.73	1.18
Cameroon	0.1	3.28	1.28	4.37	1.03	1.24	1.44	0.99	2.22	1.14	1.2	1.23	1.34
Cote d'Ivoire	0.1	2.38	1.21	3.49	1.82	1.68	1.32	2.06	1.18	1.21	1.39	1.21	0.89
Burkina	0.1	1.68	1.21	1.41	2.65	2.54	1.22	1.07	1.41	0.85	0.62	1.01	1.2
Mali	0.1	2.79	0.34	2.38	1.22	1.87	1.67	1.23	1.19	1.15	1.37	2.25	0.99

Table 8-4 ICT Sector Productivity Ratios

An analysis of the productivity ratios suggests the following observations:

1. PR indices are constantly decreasing and close to 1.0.
2. PR = technology change indices

As a general observation, the ratio is close to 1.0. This is an indication that the ICT sectors of the countries are not performing well. This situation was expected. The reader will recall that there was technical inefficiency, but the sectors are not scale efficient. As a logical consequence the sectors

are not productive; this is a confirmation of earlier findings discussed above. Second, from the empirical observations, the reader will note that the trend is not progressive; for example, there is no upward trend for any of the countries studied here. The ratio goes up and down and up again back and forth without a logical trend that can help predict the direction. This is the confirmation of the lack of mastery of their investment plans on the part of the decision makers. They are investing as they feel or are pressured. Let us take for example the ICT sector of Senegal, again the best performer in this model; it realizes the highest productivity ratio of 4.38 in 1997. But this is neither sustained nor improved. It falls back to where it has always been around 1.0 productivity ratio and remains at that level for the rest of the period (Table 8.5). The same trend is followed by the ICT sectors of Cameroon, Cote d'Ivoire and Mali with even a negative productivity ratio in year 2005. At this point, it can be concluded that if this trend continues, these sectors are not going to sustain themselves.

8.4 Empirical Observations of Complementarities to ICT4D

Finally a key issue in critically interrogating ICT4D is the legitimacy of the core argument of the ICT4D hypothesis, that ICT infrastructure expansion will be an engine of growth for developing countries. The fundamental question here is: Is it legitimate to suggest that ICT infrastructure expansion will lead to: (1) technology change (learning accumulation and spillovers) in the countries; (2) improved the allocation of scarce resources; (3) new business formation; and (4) influence the expansion of democratic freedoms. Let us remember that the focus of this thesis is on the first three claims and not the fourth. To interrogate this basic claim it is necessary to examine the complementarities to investments in ICT infrastructure expansion, utilization and Social and Economic Development (HDI). For if there are significant complementarities, then the core argument of the ICT4D hypothesis is flawed, and in need of correction.

In Chapters 5 and 6, I used the MARS method to examine complementarities relevant to the critical interrogation of the legitimacy of the ICT4D core argument. Figure 8.2 above lays out the structure of this argument. Reading from right to left social and economic development, depends on: (a) technology change, (b) more efficient resource allocation, (c) new business formation, and (d)

expansions of democratic freedoms. Now a, b, c and d are all dependent on ICT effective infrastructure utilization, and effective utilization is dependent on expansion. In Chapter 5 I investigated the complementarities to efficient ICT infrastructure expansion, and in Chapter 6 I investigated the complementarities to ICT infrastructure utilization; and complementarities to investments in ICT and their impacts on components of HDI. In earlier sections of this chapter I also showed that the empirical evidence suggests that other civil infrastructure, human capital and cost of ICT services impact ICT infrastructure expansion, and that human capital and cost of ICT services impact ICT infrastructure utilization. But what do these empirical observations have to do with the legitimacy of the ICT4D core argument? First it must be clear that to achieve the four factors (a, b, c, d) which are antecedents of social and economic development, there must be efficient expansion of ICT infrastructure; second there must be efficient and effective utilization of the ICT infrastructure. We have seen from above that both expansion and utilization are dependent on human capital (especially engineers and technicians). We have also seen that there are similar dependencies for technology change and new business formation. Now let us look more closely at new business formation. The first question that must be asked is: Is the newly deployed ICT infrastructure necessary and sufficient for significant new business formation? The answer is clearly no! I have pointed out earlier that institutional infrastructure is needed to realize the dream of e-business for these six countries and many others in Africa. Second, an often overlooked factor in the ICT4D argument about e-business development is other civil infrastructure needed to move products between sellers and buyers. Proponents of ICT4D seem to forget that unless you are selling digital products, e-business is dependent on physical supply chains and transportation systems. Further, electricity is needed to run the servers, light the offices and run other equipment in the business. It follows that other civil infrastructure, roads, ports, electricity and so on are complementary factors to ICT infrastructure.

In the past the laying of telephone cables required the building of roads and laying of electrical cables, now cellular telephony towers deployed in most of Africa are powered by a single solar panel. Consequently the rapid expansion of mobile telephone service to remote areas of the African

continent does not result in complementary infrastructure development. Populations in rural areas cannot expect to benefit from other civil infrastructure that was once complementary to telephone infrastructures. This is the very infrastructure needed for new business formation; consequently rural entrepreneurs still encounter many barriers to new business development. Often the only benefit rural populations receive from new ICT infrastructure is a better signal, they remain without electricity and roads experiencing no more progress than the ability to make calls at costs beyond their means.

8.5 Complementarities of Investments and Impacts on HDI Components

Complementarities of investments and impacts on the components of the HDI have been lengthily discussed earlier in this chapter and in chapters 6 and 7. Nonetheless I would like to give an illustration of this aspect of the argument in this section of the critical analysis chapter. As stated earlier, I have demonstrated that there is a complex relationship between three sectors of the economy namely ICT, Education and Health to give a little illustration of the complementarities. As in other research, it has equally been demonstrated that such complementarities exist between ICT and other civil infrastructures (D'emurger, 2001; Estache, Perelman, & Trujillo, 2005; Ngwenyama et al. 2009). Based on this evidence, I can easily conjecture that there are more complementarities between ICT and other sectors that are overlooked in the ICT4D argument. Since the ICT4D argument fails to clearly and expressly call for the need for these complementarities in investments, it can be concluded that this argument is not legitimate. And it is easily understandable that aspects of the national economy are interconnected. Investing in one, no matter how intensively, at the expense of others could result in counter productivity because of the lack of complementarities. The empirical observations of thirteen years of intense investments in the ICT sectors of the six countries studied in the present thesis confirm this assertion.

Referring to the theoretical framework proposed by ITU which was followed in this work, (Figure 1, in Chapter 1), the impact on HDI can be assessed after the assessment of efficiencies. It is understood that only if the investments are efficient, a positive impact on HDI can be expected. To the contrary if the new sector (ICT) is inefficient and counterproductive, its effects on the national economy can only worsen the economic situation of the developing countries further complicating their effort to climb upwards on the ladder of HDI index. As was expected from the inefficiencies noticed and the lack of productivity of the ICT sectors of the countries of interest, the investments in ICT do not have any positive impact on HDI. As a matter of fact, either the countries have remained where they were thirteen years ago in the HDI ranking with little changes in the HDI scores or most of the time they have dropped several ranks like in the case of Cote d'Ivoire. One could argue that a war broke out in this particular country in the meantime but at the same time huge amounts of investments have been conveyed in the ICT sector during that period. The only country that progressed in HDI during the period of study is Cameroon. But this progress is attributed to an increase in this country's oil production in all of the country's statistics (Katz, 2004).

8.6 Conclusion

Thirteen years of heavy and steady investments in ICT alone with substantial reduction of investments in the other sectors has not yielded much progress in terms of social or economic development. The empirical observations clearly demonstrate that complementarities are needed for sustainable development. As suggested earlier in this chapter, the dynamic of complementarities must be analyzed and understood. So every investment decision in ICT or any other sector for that matter should be fully aware of the effect on the national economy and the consequences on the other sectors as well. For example, as we have learned from empirical observations if a country X decides to make investments in the higher range in ICT, the policy maker is informed that at the same time, it is required that investments in Healthcare be in its higher range as well and above a certain threshold before the investment can have a positive impact on development. Complementarities between ICT, Education and Health are more than necessary (Ngwenyama et al. 2006). There is also some

understanding about the relationship of other civil infrastructure on the performance on ICT. For example, in her study of 24 provinces in China for the period of 1985 to 1998, D'emurger (2001) was able to demonstrate that investments in civil infrastructure (railways, highways, harbours and electrification) positively influenced GDP growth in the provinces. Estache et al. (2005), who examined productivity of developing and transition economies, were able to link infrastructure expansion with TFP growth. Likewise, Ngwenyama and Morawczynski (2009) were able to demonstrate a correlation among expansion of civil infrastructure (railways, highways, etc.), education, and GDPPP with efficient ICT infrastructure expansion in six Latin American countries. Other researchers (Machin and Van Reenen, 2007 and Samoilenko and Osei-Bryson, 2008) have demonstrated that productivity improvements do not derive from investments in ICT infrastructure, but co-depend on a highly skilled workforce. Still others (Schech, 2002; Wong, 2002) have pointed to the knowledge gap impeding people and small and medium businesses in developing countries from exploiting ICT. The core argument of the ICT4D hypothesis in its present form is untenable; it needs to be modified and complementary investments in other relevant sectors must be seen as necessary to the realization of the ICT4D goals. In a recent study, Samoilenko and Osei-Bryson (2008) demonstrated that positive effects of ICT on development could occur from complementarities between investments in ICT and ICT staff. In light of the preceding, it is widely demonstrated that the ICT4D hypothesis needs reformulation and complements because in its present form, the claim is untenable.

Chapter 9: Reflections and Contributions to Theory and Practice

9.1 Reflections on the Research Challenges

As soon as I started presenting papers on early findings of this research at conferences, I realized that there was an excitement for what I was undertaking. Many colleagues and reviewers suggested extensions to the research program to include questions related to ICT and economic freedom, and ICT and democracy. But, while these are all valid questions, worth consideration I could not consider them all. The scope of the work I had undertaken was already broad and there were no theoretical models and no existing literature in the specific area to draw upon. I made a strong effort to stick to the main goals of this PhD dissertation research project which were to empirically interrogate the core arguments of the ICT4D hypothesis using existing archival data and to develop an understanding of the dynamics of ICT infrastructure expansion and social and economic development.

The initial goal of this research was to conduct an empirical study of the impact of ICT infrastructure expansion on a significantly larger sample of West African countries. The lack of existing theoretical models upon which to base the investigation meant that a critical exploratory approach would be necessary to develop an understanding of the limitations of the ICT4D hypothesis and to propose a new theoretical approach to research in the area. Given that the central argument of the ICT4D hypothesis rests on ICT infrastructure expansion (ref. Figure 1); a basic goal was to examine the impact of ICT infrastructure expansion. Such an investigation required a longitudinal panel data set of at least ten years. However, during the process of data collection it became clear that it would be necessary to eliminate a number of countries because the relevant data were not available for the required period. Second, in order to achieve comparisons across the panel data it was necessary to ensure that countries shared enough common characteristics that would support a comparative analysis. With these considerations a pragmatic decision was made to focus the study on the six Francophone countries which satisfied all the basic criteria. This strategy permitted the conduct of meaningful comparisons because the six countries share similar political and developmental histories.

On this group of countries I planned to conduct an analysis for a thirteen year period (1993 to 2005), but the data was not always reported for some of the essential variables. Therefore, in some investigations, for instance the impact of ICT infrastructure expansion on HDI, education, healthcare and GDP, I had to shorten the period of study by 3 years. None of these decisions weakened the analysis; and the empirical investigation yielded important insights that make a contribution to theory for future empirical research as well as practical advice for policy makers and ICT4D project directors. Where the data limitations most constrained the study is with regards to relevant data about other civil infrastructure (roads, railways, ports, etc) and human capital (such as school enrollments and graduation rates at all levels). For example, there were limited data about human capital to fully explore the role it plays in social and economic development. Likewise, the lack of data about other civil infrastructure forced me to defer this aspect of the investigation for a future project. However, findings from a smaller prior empirical study I conducted (Bollou, 2006) pointed out that other civil infrastructure played an important role in the expansion of ICT infrastructure. And by extension, I argue that they play a complementary role with ICT infrastructure on social and economic development. In addition to some limitations in data the lack of theoretical models capable of interrogating and uncovering some of the limitations of the ICT4D hypothesis was also a challenge. Most of the published work in this research area is in support of the ICT4D hypothesis and the recent critiques do not include alternatives for critical quantitative empirical analyses. A bit more detail of these two challenges is important to note here.

9.1.1 Difficulties of Data Collection

The choice of empirical approach for doing this research required the collection of a substantial amount of data, both economic and ICT-related, for the countries under study for the period of time considered. Shortly after I started the investigation, I realized that there was not a readily available set of data at some organization that could be used to satisfy my needs. The ITU database was somewhat helpful, but it was limited in scope (ICT related data only) besides, it had many gaps. For example for some countries, data was only filled for 4 or 5 years out of the thirteen years covered by the investigation. This situation forced me to look for alternative sources for the data that was

missing. I then searched the United Nations database, some important data were collected from the world development index from the World Bank, the UNDP database revealed important data which helped to fill the important gaps in the data set. In order to find some crucial data that was still missing I contacted national statistics institutes of the countries concerned, and also collected data from the CIA factbooks at the Toronto Public Library. Finally some variables were computed from their components using the standard formulae published by the UNDP. For example, the HDI index is published every 4 years by the UNDP. In order to have this variable for every year, I used the formula provided by UNDP to compute it for each year. Another example, the number of households with a telephone and the percentage of expenses in ICT relative to GDP were all computed. These computational formulae can be seen in Table 4.2.

One of the major challenges of the present study is the lagged effect. I am well aware that time lag between investments and return on investment could have an effect on the results obtained given the relatively small time scale of the data set that was put together because of the difficulties outlined earlier. Nonetheless, DEA, with the possibility to look at the learning effect (essentially the lag between investment and returns); helped me to investigate 'returns to scale' to determine lags between investments and returns. Also, MARS which is sensitive to small changes in effect of independent variables on dependent variables and uses splines instead of the gross approximations of ordinary linear regressions, which offers the possibility to detect smaller effects of investments than ordinary regression methods helped to minimize lagging effects but certainly didn't suppress it all. Therefore, addressing this problem will be one of the priorities in my future research.

9.1.2 Limitations of Prior Research

In spite of the abundant literature of the past decades of research on ICT4D, it is very challenging to find relevant literature on developing countries relevant to this study, particularly on Sub-Saharan African countries. It is understandable that this is a relatively new area and that many African countries have not yet defined the institutional structures to follow for monitoring ICT expansion and reporting regularly on their experiences. Nonetheless, there is some important literature available on South Africa, China and India. Given the nature of the work I was doing, I had to be careful when using

findings from other parts of the world; or comparing across regions when trying to critique. The limited literature available on Sub-Saharan Africa is dominated by conjectures, wish lists on the potential of ICT; very few of these provide empirical evidence of the claims they make. The other problem with the literature concerning African countries is that they were too general; ignoring the fact that African countries have different characteristics requiring separate treatment. Given these circumstances the wisest course of action was to pursue an exploratory research approach (Tukey, 1977; Tukey, 1980; Chatfield, 1986).

9.2 Contributions to ICT4D Theory

Chapter 8 above details the comprehensive contributions of this thesis to understanding the limitations of the ICT4D hypothesis. However, this thesis makes additional significant contribution to future empirical studies on the impact of ICT on social and economic development. Figure 9-1 below illustrates a new theoretical model which summarizes the general empirical observations from this research. The lack of a theoretical model has been a significant gap in the IS literature that has limited the development of current theory on ICT4D in our discipline. Figure 9-1 graphically illustrates this model which comprises the primary variables (based on my findings) and their relationships to Social and Economic Development (as measured by HDI). These findings point to a set of complex, non-linear and complementary relationship among investments in ICT and investments in health, human capital and social and economic development (as measured by HDI). By extension, I hypothesize similar relationships between other civil infrastructure (roads, sewer, ports, etc) and other sectors and social and economic development (as measured by HDI). However, while the findings of this research can be modeled and analyzed in future research, they also demonstrate that the current dominant focus on investing in ICT infrastructure expansion is not adequate to the problem of social and economic development. It must be adjusted; social and economic development is not only dependent on achievements of ICT infrastructure expansion and use, but on basic achievements in other civil infrastructure, human capital and national health as well. The findings of the various empirical analyses of this thesis make it possible to propose a more comprehensive theoretical model for future investigations. The solid lines in the figure depict a set of relationships that have already

been interrogated in this study, while the dashed and dotted lines indicate relationships that were partially interrogated and dotted lines indicate relationships that are hypothesized for future studies. A short discussion to illustrate these relationships is relevant here.

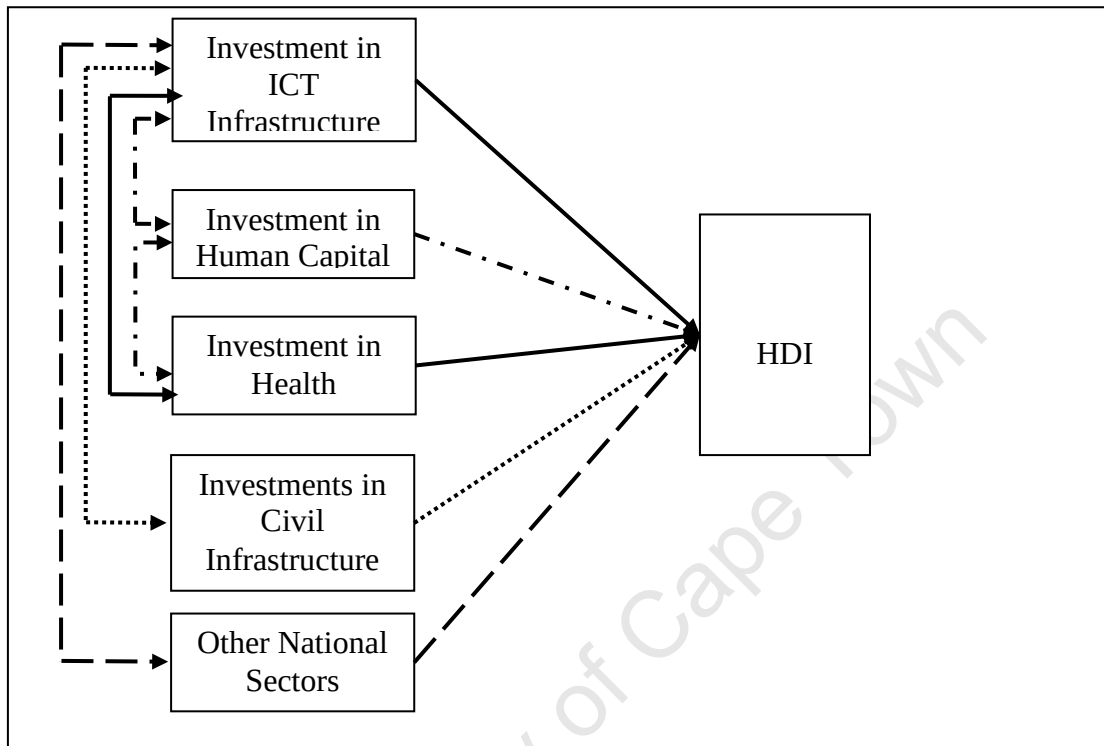


Figure 9-1 Proposed Model for Studying the Impact of ICT and other Factors on HDI

Empirical analysis (cf. Chapter, 8) points to a complex set of non-linear complementary relationships between Investment in ICT infrastructure, education and health. The lines comprising dots and dashes shown in Figure 9-1 reflect the presence of relationships even though the data on human capital were limited. The relationships among these three variables (ICT, Health and Human Capital), and HDI are non-linear and complementary. The empirical analysis of Chapter 8 illustrates this in some detail. Health outcomes are dependent on investments in education, and are complementary with investments in ICT leading to higher outcomes in HDI. Similarly, ICT outcomes are dependent on education and are complementary to outcomes in HDI. The empirical analysis also suggests that ICT expansion is path dependent; that is, ICT expansion outcomes are dependent upon a range of factors (Chapters 5 and 7). For example, a level of technological competence and civil infrastructure is

necessary for the expansion and adoption of new ICT infrastructure. The technological competence accrues from two sources, tertiary technological education and 'learning by doing' in turn which accrue from innovation and use of ICT. Another path dependent relationship concerns health, education, ICT and general productivity outcomes. Education improves health (wellbeing and mortality), and improved health outcomes contribute to improvements in education outcomes; and together they contribute to ICT sector and HDI outcomes. Finally, the dotted lines in Figure 9-1 represent hypothesized relationships based on the empirical analysis of Chapter 5. The level of civil infrastructure contributes to ICT expansion efficiency. Further, civil infrastructure is important to the adoption and use of ICT for some new business formation. A good example is e-business; while the internet is the primary vehicle for advertising and procuring sales; getting the products to the customers requires other civil infrastructure such as roads and ports. While some of these relationships have been suggested in a few studies (Bollou, 2006; Ngwenyama and Morawczynski, 2009), the empirical analysis of this research provides a strong basis for advancing ICT4D research from the new perspective offered by this model. It is clear from this thesis research that the systematic interrogation and unraveling of these relationships is required to determine the level of contribution of each factor individually and complementarily on the overall impact on HDI.

9.3 Contributions to IS Research Methods

As stated earlier one of the primary challenges I faced in starting this study was the lack of theoretical framework and models. This specialty area within the discipline of Information Systems has been limited by existing theory frameworks and research approaches that are rooted in behaviorist theory, except for the work of Pohjola (2000), Samoilenko and Ngwenyama (2008), Ngwenyama and Morawczynski (2009) and few others. The analysis of the economic and social impact of ICT cannot be accomplished by survey studies alone that gather perceptions about this phenomenon, or qualitative interviewing. Quantitative analysis is also necessary to understand the impact of ICT on the level of the sector and national economy. However, there were no models and guidelines in the field of information systems for conducting this type of research. Consequently, this study involved the conduct of exploratory research of a quantitative nature. Further, while there is

much experience in doing exploratory qualitative IS research, there is one framework (Osei-Bryson and Ngwenyama, 2010) but it focuses on survey data. However, some pioneers of exploratory quantitative research (Tukey, 1977, 1980; Chatfield, 1986) provide a set of principles which informed this critical approach. The critical quantitative analysis approach used in this study was developed as part of a larger program for the study of ICT, social and economic development covering the regions of Africa, Caribbean, Eastern Europe, Middle East and Latin America. This research project is pioneering the use of critical theory and, new and emerging computer based non-parametric analytical tools. This work is the first of its kind to interrogate ICT4D in West Africa to help build theoretical models, and to construct an approach to critical quantitative empirical analysis using multiple analytical methods to ensure cross validation of empirical observations and results. The research approach developed here; the application of multiple methods and the use of archival data, and especially the combination of the non-parametric methods, DEA and MARS is a notable contribution of this thesis to research methodology and theory building in information systems. The approach to empirical analysis used in this study also points to a fundamental limitation of the current body to theory development and testing which is dominated by linear analytic methods of structural equation modeling and ordinary linear regression. Such methods impose the condition of linearity on relationships among the variables, which in this case would have led to misspecification of the relationships and a misunderstanding of their non-linear dynamics. The combination of quantitative methods and critical theory epistemology also demonstrates an innovative approach to interrogating the claims of the ICT4D hypothesis, and offers important insights relevant to ICT4D development policy.

9.4 Contributions to ICT4D Policy Development

This research makes a contribution to both development policy makers in African countries and other developing countries. For the countries that are part of this study, this research constitutes important groundwork for policy making. The practical contributions of this research are on four levels: (1) the specific findings could inform present and future ICT4D strategies and projects; (2) an understanding of the complementary relationships of different sectors and their non-linear dynamic

impacts on HDI; (3) the empirical approach is illustrative of how policy analysts could conduct empirical analysis of their country's situation; (4) the method of analysis presented in this thesis is a solution to the challenge laid out by the ITU on the need for researchers to develop analytical methods to measure the impact of ICT on development (ITU, 2006).

While social and economic development emerges from a set of complex initiatives between the public and private spheres of an economy, the role of government policy makers is crucial in stimulating, stagnating or inhibiting development. Public policy analysts need to have a comprehensive understanding of how investments in the various sectors dynamically interact and impact social and economic development. Policy analysts need to understand how different instruments such as the national budget, policies and regulation can influence social and economic development. Figure 9-1 illustrates some of the key relationships between key variables based on findings of this PhD study. I am not making the claim that these are the complete interaction dynamics as illustrated in Figure 9-1, they are not. However, the model illustrates an understanding of some main dynamics that are relevant to policy making about ICT and economic and social development in the countries studied.

From the perspective of national planning, all sectors get a share from the national annual budget depending on development priorities. In many developing countries national budgets are diminishing as demands are increasing; thus national planners need to understand the importance of spending in health and education relative to other spending, such as ICT and other civil infrastructure. The first lesson learned by my analysis of the empirical observations of this research is that the investments as a percentage of the GDP of the countries in education, health and civil infrastructure have been stagnant or reducing at times on the one hand, and the countries have been increasing their investments in ICT Infrastructure over the years with minor variations. Given the dynamics observed in the impact formulae of my analysis, reducing investments in education and increasing investments in ICT infrastructure is not helpful, and negatively impacts HDI. This trend needs to be adjusted with more attention given to both general and technical education by national policies. General education improves health outcomes and technical education improves the potential for technological learning accumulation which is much needed to benefit from ICT expansion (cf. Chapter 8).

9.5 Directions for Future Research

This research has set a foundation upon which future studies can be designed to interrogate the complex reality of ICT4D initiatives in specific empirical situations. The complex relationships among ICT, Health and Education and other civil infrastructure discovered in this research project require further systematic investigation. While there is some understanding of these relationships, more research is needed to better understand the dynamics of the relationships in different empirical situations. Further, there little understanding of the relationships with other economic sectors represented in Figure 9-1 by dashed lines. Interrogation of these latter relationships was not possible in this study. But by extension, the logic of the findings of this study suggests the existence of some important relationships with ICT and other economic sectors that require systematic investigation if the puzzle of ICT4D is to be completely unraveled. The findings of Chapter 5 concerning the relationships between ICT and civil infrastructure such as roads, railways and airports also require further investigation with more complete data. More studies are also necessary to determine the complex relationship with human capital and other variables. The human capital data used in this study was limited to literacy rates and investments in education. Other variables such as national graduation/completion rates at different levels of education and the number of ICT engineers and technicians graduating each year would have been useful to this study. It is clear that technical tertiary graduation rates are directly relevant to the expansion, utilization and innovation of ICT in business and government. It is interesting to note that in this study the countries with more tertiary technical institutions did better on ICT expansion and utilization. However, there were not enough data to rigorously interrogate this *prima facie* relationship. Future studies could investigate more fully the validity of the model. But it is likely that the model would have to be tested with data from developing countries of some other region; e.g. (Latin America or The Caribbean) for which there is more systematic data for a period of more than ten years. My research of data archives of the African continent suggests that more complete data exist only for South Africa. This is a significant setback for systematic empirical research on ICT4D in Africa.

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University of Cape Town

Appendix A. Scale efficiency

DMU	CRS Score	VRS Score	NIRS Score	SE
Benin 1993	59.14%	100.00%	160407.82%	DRS
Senegal 1993	66.08%	100.00%	242288.51%	DRS
Cameroon 1993	68.98%	93003.54%	93832.29%	DRS
Cote d'Ivoire 1993	62.04%	179793.14%	190301.02%	DRS
Burkina Faso 1993	57.73%	100.00%	485731.39%	DRS
Mali 1993	62.88%	66978.75%	113874.96%	DRS
Benin 1994	63.83%	100.00%	34025.69%	DRS
Senegal 1994	73.98%	100.00%	95061.32%	DRS
Cameroon 1994	65.83%	8541.47%	8541.47%	DRS
Cote d'Ivoire 1994	68.53%	9917.06%	10680.42%	DRS
Burkina Faso 1994	64.21%	100.00%	173019.24%	DRS
Mali 1994	100.00%	100.00%	100.00%	MPSS
Benin1995	64.10%	14968.70%	14869.29%	DRS
Senegal1995	73.90%	121574.03%	121477.11%	DRS
Cameroon1995	65.10%	7335.58%	7238.04%	DRS
Cotedivoire1995	71.40%	2169.96%	2078.07%	DRS
Burkina1995	66.00%	100.00%	60417.38%	DRS
Mali1995	56.70%	126.22%	60447.28%	DRS
Benin1996	71.20%	4332.24%	4357.68%	DRS
Senegal1996	76.80%	9590.35%	11069.99%	DRS
Cameroon1996	65.60%	6087.28%	5989.46%	DRS
Cotedivoire1996	71.20%	2087.68%	1994.08%	DRS
Burkina1996	62.30%	3567.79%	27778.84%	DRS
Mali1996	56.10%	9993.99%	27807.92%	DRS
Benin1997	67.40%	3657.12%	3557.15%	DRS
Senegal1997	76.00%	100.00%	1138.11%	DRS
Cameroon1997	66.70%	5139.69%	5040.77%	DRS
Cotedivoire1997	73.80%	765.41%	672.92%	DRS
Burkina1997	61.60%	5357.83%	10187.62%	DRS
Mali1997	55.70%	5966.28%	10214.32%	DRS
Benin1998	64.10%	2178.77%	2552.17%	DRS
Senegal1998	87.00%	342.54%	350.30%	DRS
Cameroon1998	73.40%	4112.26%	4018.14%	DRS
Cotedivoire1998	75.80%	377.46%	284.47%	DRS
Burkina1998	68.20%	2864.75%	5336.01%	DRS
Mali1998	59.00%	3360.07%	5356.85%	DRS
Benin1999	63.20%	1286.45%	2272.62%	DRS
Senegal1999	85.60%	171.32%	91.81%	DRS
Cameroon1999	72.60%	3703.06%	3606.77%	DRS
Cotedivoire1999	72.70%	265.57%	174.77%	DRS
Burkina1999	70.40%	1759.99%	2951.91%	DRS
Mali1999	64.00%	2179.35%	2967.09%	DRS
Benin2000	66.10%	145.03%	367.08%	DRS
Senegal2000	94.30%	100.00%	8.21%	IRS
Cameroon2000	76.94%	473.61%	385.99%	DRS
Cotedivoire2000	83.70%	100.00%	100.00%	DRS
Burkina2000	69.70%	649.36%	685.71%	DRS

DMU	CRS Score	VRS Score	NIRS Score	SE
Mali2000	65.90%	724.72%	703.71%	DRS
Benin2001	70.60%	100.00%	197.07%	DRS
Senegal 2001	100.00%	100.00%	100.00%	MPSS
Cameroon 2001	73.55%	150.16%	150.16%	DRS
Cote d'Ivoire 2001	84.56%	113.14%	113.14%	DRS
Burkina Faso 2001	71.64%	175.23%	218.56%	DRS
Mali 2001	69.87%	283.42%	309.55%	DRS
Benin 2002	72.93%	104.05%	140.13%	DRS
Senegal 2002	92.68%	106.23%	117.55%	DRS
Cameroon 2002	71.33%	191.93%	191.93%	DRS
Cote d'Ivoire 2002	88.18%	100.00%	100.00%	IRS
Burkina2002	70.90%	219.17%	201.54%	DRS
Mali2002	70.60%	269.45%	213.21%	DRS
Benin2003	61.50%	100.00%	125.99%	DRS
Senegal2003	91.80%	100.00%	100.00%	DRS
Cameroon2003	71.30%	223.47%	124.77%	DRS
Cotedivoire2003	100.00%	100.00%	100.00%	MPSS
Burkina2003	63.30%	100.00%	97.28%	DRS
Mali2003	76.30%	160.01%	87.86%	DRS
Benin2004	79.70%	168.85%	119.86%	DRS
Senegal2004	100.00%	100.00%	100.00%	MPSS
Cameroon2004	82.10%	218.00%	120.36%	DRS
Cotedivoire2004	100.00%	100.00%	100.00%	MPSS
Burkina2004	63.80%	100.00%	57.42%	IRS
Mali2004	86.70%	100.00%	0.00%	MPSS
Benin2005	100.00%	100.00%	100.00%	MPSS
Senegal2005	100.00%	100.00%	100.00%	MPSS
Cameroon2005	100.00%	186.51%	92.52%	DRS
Cotedivoire2005	91.40%	100.00%	100.00%	IRS
Burkina2005	69.30%	100.00%	163.00%	DRS
Mali2005	100.00%	100.00%	100.00%	MPSS

Appendix B Slacks and Factors (CRS_MAX_IN)

Years	Countries	Score	Factor Invest	Factor Staff	Slacks Cellular	Slacks Landlines
1993	Benin	59.14%	30.68%	10.89%	32219.66	4948.17
	Senegal	66.08%	28.12%	27.15%	100463.03	15134.83
	Cameroon	68.98%	83.26%	18.77%	72632.28	0
	Cote d'Ivoire	62.04%	26.98%	15.66%	114624.43	0
	Burkina	57.73%	26.96%	12.04%	27815.71	0
	Mali	62.88%	66.29%	6.47%	17547.22	0
1994	Benin	63.83%	55.11%	13.28%	36447.12	4851.93
	Senegal	73.98%	69.55%	30.13%	110526.39	14838.51
	Cameroon	65.83%	63.72%	19.54%	72465.62	0
	Cote d'Ivoire	68.53%	60.20%	18.18%	129919.37	0
	Burkina	64.21%	62.36%	14.23%	33465.14	0
	Mali	100.00%				
1995	Benin	64.12%	53.08%	15.52%	40734.55	4627.88
	Senegal	76.81%	79.14%	34.21%	122221.22	14148.05
	Cameroon	65.12%	55.51%	22.24%	80679.07	0
	Cote d'Ivoire	71.47%	73.35%	21.14%	144354.94	0
	Burkina	66.08%	70.70%	16.17%	38162.87	0
	Mali	56.76%	26.78%	8.42%	21763	0
1996	Benin	71.20%	91.47%	18.22%	44153.2	4143.27
	Senegal	76.07%	55.56%	48.58%	136739.49	13488.02
	Cameroon	65.60%	56.09%	23.79%	86292.46	0
	Cote d'Ivoire	71.20%	65.13%	25.01%	151645.31	0
	Burkina	62.34%	45.12%	18.27%	42813.56	0
	Mali	56.17%	20.20%	10.30%	25911.85	0
1997	Benin	67.48%	67.34%	19.90%	45390.7	2589.52
	Senegal	87.07%	98.71%	63.01%	157446.12	13272.5
	Cameroon	66.74%	59.03%	27.13%	91499.9	0
	Cote d'Ivoire	73.88%	78.02%	26.19%	145119.69	0
	Burkina	61.68%	39.87%	19.12%	44639.12	0
	Mali	55.79%	15.77%	11.68%	27948.68	0
1998	Benin	64.16%	46.94%	20.62%	44352.61	1437.3
	Senegal	83.99%	61.80%	73.24%	164731.09	11494.01
	Cameroon	73.47%	99.01%	24.66%	114523.06	0
	Cote d'Ivoire	75.86%	79.57%	30.65%	125132.13	0
	Burkina	68.20%	75.29%	21.65%	49724.25	0
	Mali	59.04%	32.91%	13.41%	29967.51	0
1999	Benin	63.25%	38.26%	23.08%	48287.88	0.01
	Senegal	85.65%	54.68%	81.83%	134193.81	8628.55
	Cameroon	72.65%	91.04%	28.06%	114387.16	0
Years	Countries	Score	Factor Invest	Factor Staff	Slacks Cellular	Slacks Landlines

	Cote d'Ivoire	72.73%	40.68%	38.70%	21926.64	0
	Burkina	70.49%	84.45%	24.74%	55206.58	0
	Mali	64.05%	58.19%	16.39%	36599.09	0
2000	Benin	66.18%	49.00%	27.68%	10246.48	0.01
	Senegal	94.31%	75.27%	98.83%	19099.49	5764.86
	Cameroon	62.77%	31.95%	28.18%	17618.48	0
	Cote d'Ivoire	83.79%	90.96%	45.09%	0	0
	Burkina	69.78%	76.12%	27.47%	42479.23	0
	Mali	65.92%	65.51%	18.98%	39517.39	0
2001	Benin	70.62%	68.82%	32.38%	0.07	0
	Senegal	100.00%				
	Cameroon	73.06%	67.55%	41.81%	0	0
	Cote d'Ivoire	84.56%	82.91%	51.98%	0	0
	Burkina	71.62%	83.80%	29.70%	0	0
	Mali	69.87%	80.55%	24.58%	19653.21	0
2002	Benin	72.93%	79.34%	34.71%	0	0
	Senegal	92.68%	65.86%	96.27%	0	257.04
	Cameroon	70.58%	51.72%	44.01%	0	0
	Cote d'Ivoire	88.18%	90.08%	60.74%	0	0
	Burkina	70.81%	72.09%	34.16%	0	0
	Mali	70.68%	84.57%	24.24%	19394.27	0
2003	Benin	61.57%	9.57%	36.55%	0	0
	Senegal	91.83%	59.76%	96.85%	0	0
	Cameroon	69.85%	29.78%	45.83%	0	0
	Cote d'Ivoire	91.97%	100.00%	63.10%	0	0
	Burkina	63.35%	29.34%	32.55%	0.09	0
	Mali	74.35%	86.31%	33.86%	0	0
2004	Benin	80.00%	100.00%	47.65%	0	1320.7
	Senegal	100.00%	100.00%	100.00%	0	0
	Cameroon	82.34%	100.00%	54.11%	0	17341.1
	Cote d'Ivoire	100.00%	100.00%	100.00%	0	0
	Burkina	63.86%	23.17%	38.17%	0	0
	Mali	76.28%	100.00%	34.97%	0	0
2005	Benin	100.00%	100.00%	100.00%	0	0
	Senegal	100.00%	100.00%	100.00%	0	0
	Cameroon	100.00%	100.00%	100.00%	0	0
	Cote d'Ivoire	90.58%	85.82%	83.55%	0	103537.25
	Burkina	69.30%	47.05%	40.49%	0	0
	Mali	100.00%	96.08%	63.80%	0	0

Appendix C: Comparison of Productivity ratio (PR) and Technical change (TC) rate.

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Benin	PR	0.1	1.78	1.58	3.12	1.71	1.23	1.59	1.91	1.63	1.4	0.66	2.63	1.24
	TC	0.1	1.78	1.58	3.12	1.71	1.23	1.59	1.91	1.63	1.4	0.66	2.63	1.24
Senegal	PR	0.1	1.11	1.5	4.38	1.87	1.58	1.86	1.71	1.7	1.07	1.34	1.73	1.18
	TC	0.1	1.11	1.5	4.38	1.87	1.58	1.86	1.71	1.7	1.07	1.34	1.73	1.18
Cameroon	PR	0.1	3.28	1.28	4.37	1.03	1.24	1.44	0.99	2.22	1.14	1.2	1.23	1.34
	TC	0.1	3.28	1.28	4.37	1.03	1.24	1.44	0.99	2.22	1.14	1.2	1.23	1.34
Cote d'Ivoire	PR	0.1	2.38	1.21	3.49	1.82	1.68	1.32	2.06	1.18	1.21	1.39	1.21	0.89
	TC	0.1	2.38	1.21	3.49	1.82	1.68	1.32	2.06	1.18	1.21	1.39	1.21	0.89
Burkina Faso	PR	0.1	1.68	1.21	1.41	2.65	2.54	1.22	1.07	1.41	0.85	0.62	1.01	1.2
	TC	0.1	1.68	1.21	1.41	2.65	2.54	1.22	1.07	1.41	0.85	0.62	1.01	1.2
Mali	PR	0.1	2.79	0.34	2.38	1.22	1.87	1.67	1.23	1.19	1.15	1.37	2.25	0.99
	TC	0.1	2.79	0.34	2.38	1.22	1.87	1.67	1.23	1.19	1.15	1.37	2.25	0.99

Appendix D: Costs of Telecommunication services

Appendix D-1: Residential hook up telephone costs (US\$)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Benin	211.8	157.9	193.3	188.6	165.3	163.5	156.7	135.5	131.64	138.4	166.0	182.6	182.9
Senegal	162.15	100.8	112.19	109.4	115.13	39.66	38.01	32.87	31.92	61.71	74.00	81.41	44.36
Cameroon	105.9	54.03	60.10	58.65	51.40	50.85	48.73	42.14	40.93	43.04	68.82	75.72	75.83
Cote d'Ivoire	148.3	75.65	84.14	82.10	71.96	71.19	56.85	49.16	47.75	28.69	34.41	37.86	37.92
Burkina	63.57	38.90	43.27	42.22	37.01	36.61	41.40	41.17	39.99	42.05	50.43	55.48	47.40
Mali	162.4	91.86	102.17	99.70	87.38	86.45	91.81	79.39	77.11	81.10	85.78	94.37	37.99

Appendix D-2: Residential telephone monthly charges

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Benin	7.24	4.05	5.07	4.84	4.24	4.20	4.02	3.48	3.38	4.22	5.06	5.57	5.57
Senegal	6.71	4.17	4.64	4.53	3.97	4.09	3.92	3.39	3.29	3.46	4.16	4.57	4.58
Cameroon	3.75	3.60	3.51	3.42	3.00	2.97	2.84	2.46	2.39	2.51	5.16	5.68	5.69
Cote d'Ivoire	12.29	6.27	6.97	6.80	5.74	5.68	6.20	5.37	5.73	7.17	10.32	11.36	11.38
Burkina	6.14	3.76	4.18	4.08	3.58	3.54	3.39	4.97	4.83	5.08	6.09	6.70	4.74
Mali	4.77	3.40	3.79	3.69	3.24	3.20	3.12	2.70	2.62	2.75	7.74	8.52	8.53

Appendix D-3: Telephone business monthly charges

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Benin	339.0	287.7	354.0	345.4	302.7	299.5	287.0	248.2	241.0	279.8	335.5	332.6	333.1
Senegal	162.1	100.9	112.2	109.5	115.1	39.7	38.0	32.9	31.9	101.9	122.2	134.4	44.4
Cameroon	105.9	54.0	60.1	58.6	51.4	50.9	48.7	42.1	40.9	43.0	68.8	75.7	75.8
Cote d'Ivoire	148.3	75.6	84.1	82.1	80.0	79.1	68.2	49.2	47.7	28.7	34.4	37.9	37.9
Burkina	63.6	38.9	43.3	42.2	37.0	36.6	41.4	41.2	40.0	42.1	50.4	55.5	47.4
Mali	162.5	91.9	102.2	99.7	87.4	86.4	91.8	79.4	77.1	81.1	85.8	94.4	38.0

Appendix D-4: Telephone business hook-up costs

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Benin	339.0	287.7	354.0	345.4	302.7	299.5	287.0	248.2	241.0	279.8	335.5	332.6	333.1
Senegal	162.1	100.9	112.2	109.5	115.1	39.7	38.0	32.9	31.9	101.9	122.2	134.4	44.4
Cameroon	105.	54.0	60.1	58.6	51.4	50.9	48.7	42.1	40.9	43.0	68.8	75.7	75.8
Cote d'Ivoire	148.	75.6	84.1	82.1	80.0	79.1	68.2	49.2	47.7	28.7	34.4	37.9	37.9
Burkina	63.6	38.9	43.3	42.2	37.0	36.6	41.4	41.2	40.0	42.1	50.4	55.5	47.4
Mali	162.	91.9	102.	99.7	87.4	86.4	91.8	79.4	77.1	81.1	85.8	94.4	38.0

Appendix E: Raw data for the DEA analysis (US\$)

Key: BEN = Benin, SEN = Senegal, CAM = Cameroon, CIV=Cote d'Ivoire, BUR=Burkina

DMU	ICT INVEST	Staff ICT	ICT Revenue	ICT invest % GDP	GDP \$US
BEN1993	23,121,204	1,528	33,756,676	1.10	2,106,264,960
SEN1993	78,584,544	1,910	134,499,936	1.46	5,374,700,032
CAM1993	19,205,997	2,000	36,000,000	0.17	11,037,929,472
CIV1993	93,494,840	3,779	229,552,192	0.90	10,406,130,688
BUR1993	22,691,010	1,193	47,735,380	0.77	2,941,093,376
MAL1993	5,828,116	1,402	42,848,144	0.23	2,514,832,640
BEN1994	14,615,929	1,424	23,647,520	0.98	1,496,820,992
SEN1994	34,961,548	1,894	103,548,880	1.04	3,357,648,384
CAM1994	25,548,892	1,955	66,864,788	0.37	6,819,041,280
CIV1994	47,983,644	3,730	122,476,184	0.63	7,665,928,192
BUR1994	11,809,946	1,215	26,882,072	0.66	1,790,133,504
MAL1994	1,393,687	1,350	30,673,898	0.08	1,762,756,480
BEN1995	17,303,216	1,389	33,012,060	0.80	2,169,628,416
SEN1995	33,977,764	1,845	107,460,680	0.76	4,452,969,984
CAM1995	33,056,196	1,936	77,030,952	0.38	8,745,868,288
CIV1995	44,159,072	3,596	139,256,736	0.44	9,992,186,880
BUR1995	11,886,207	1,220	37,100,492	0.52	2,292,898,048
MAL1995	17,928,398	1,338	42,704,468	0.75	2,378,243,072
BEN1996	11,260,874	1,327	36,169,504	0.48	2,361,118,208
SEN1996	54,657,412	1,467	127,330,664	1.13	4,839,018,496
CAM1996	35,187,176	1,947	76,737,368	0.37	9,454,599,168

CIV1996	55,748,216	3,408	180,766,304	0.51	10,845,860,864
BUR1996	21,112,306	1,224	41,847,032	0.88	2,400,547,328
MAL1996	29,490,920	1,357	56,335,276	1.14	2,579,024,640
BEN1997	16,218,362	1,288	40,480,064	0.72	2,268,302,336
SEN1997	36,604,588	1,346	137,118,576	0.78	4,672,160,768
CAM1997	35,636,576	1,820	73,894,496	0.39	9,122,894,848
CIV1997	51,027,120	3,567	236,306,480	0.44	11,709,356,032
BUR1997	25,439,032	1,245	42,407,524	1.08	2,362,979,072
MAL1997	42,918,088	1,360	54,878,252	1.59	2,697,757,184
BEN1998	23,713,874	1,267	45,350,784	0.97	2,455,106,304
SEN1998	68,370,200	1,354	153,733,360	1.36	5,030,935,040
CAM1998	26,535,102	2,500	57,565,828	0.27	9,827,815,424
CIV1998	59,761,336	3,641	299,464,352	0.47	12,782,608,384
BUR1998	15,313,162	1,250	51,985,760	0.61	2,521,739,008
MAL1998	23,000,014	1,325	58,747,936	0.79	2,921,434,112
BEN1999	31,918,142	1,242	46,114,992	1.28	2,488,890,624
SEN1999	89,265,880	1,400	168,033,136	1.74	5,143,738,880
CAM1999	29,064,105	2,213	68,597,160	0.29	10,022,105,088
CIV1999	150,774,720	3,720	286,940,064	1.20	12,561,474,560
BUR1999	15,679,714	1,256	53,846,028	0.62	2,515,673,344
MAL1999	16,237,166	1,353	67,348,424	0.55	2,927,886,848
BEN2000	29,479,760	1,225	54,396,192	1.25	2,359,111,168
SEN2000	78,652,488	1,406	185,064,192	1.68	4,679,906,816
CAM2000	83,163,856	2,213	132,484,056	0.90	9,287,325,696

CIV2000	85,957,472	3,897	362,369,728	0.81	10,599,314,432
BUR2000	19,555,324	1,272	51,509,804	0.88	2,218,180,352
MALI2000	16,747,078	1,357	59,559,648	0.63	2,644,877,568
BEN2001	26,424,206	1,231	79,130,744	1.06	2,499,263,232
SEN2001	66,338,808	1,557	216,855,840	1.36	4,871,494,144
CAM2001	43,936,212	2,213	201,300,064	0.46	9,633,089,536
CIV2001	112,861,520	3,837	376,891,744	1.05	10,735,430,656
BUR2001	19,372,750	1,289	102,534,648	0.83	2,328,522,240
MALI2001	17,734,366	1,364	59,196,224	0.59	3,006,384,384
BEN2002	27,748,253	1,261	80,224,968	0.99	2,807,644,416
SEN2002	108,609,880	1,586	253,764,048	2.03	5,337,235,968
CAM2002	80,154,664	2,225	266,025,344	0.74	10,879,754,240
CIV2002	122,852,072	3,702	396,942,656	1.05	11,692,133,376
BUR2002	24,013,258	1,266	63,256,288	0.91	2,630,166,784
MALI2002	18,721,654	1,533	91,823,416	0.57	3,304,064,512
BEN2003	280,048,736	1,214	84,132,832	7.87	3,557,226,496
SEN2003	133,653,511	1,647	400,894,688	1.95	6,858,963,968
CAM2003	111,164,832	2,821	387,241,920	0.82	13,621,747,712
CIV2003	76,925,152	3,408	539,503,168	0.55	14,044,907,520
BUR2003	80,381,968	1,433	116,369,584	1.90	4,233,310,464
MALI2003	19,708,942	1,580	137,544,736	0.47	4,222,298,624
BEN2004	35,395,344	1,264	62,037,964	0.87	4,050,824,448
SEN2004	94,644,984	1,761	548,940,928	1.18	8,014,291,456
CAM2004	129,296,408	3,130	477,148,928	0.82	15,775,199,232

CIV2004	95,160,544	2,850	667,594,176	0.61	15,481,080,832
BUR2004	169,982,400	1,501	165,963,776	3.36	5,060,477,952
MALI2004	20,696,230	1,620	214,365,216	0.42	4,982,112,256
BEN2005	20,966,334	1,331	54,618,524	0.48	4,358,008,320
SEN2005	149,772,112	1,815	678,714,176	1.73	8,651,311,104
CAM2005	146,055,696	3,223	515,866,304	0.88	16,587,805,696
CIV2005	236,981,200	2,950	815,215,360	1.45	16,353,978,368
BUR2005	107,001,752	1,647	191,789,840	1.88	5,697,407,488
MALI2005	21,683,518	1,750	405,711,808	0.41	5,304,454,656

Appendix F: Utilization rates of Investments in ICT and ICT Staff (%)

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	AVG
Benin	Invest	30.6	55.1	53.0	91.4	67.3	46.9	38.3	49	68.8	79.3	9.57	76.9	100	58.9
	Staff	10.8	13.2	15.5	18.2	19.9	20.6	23.1	27.6	32.4	34.7	36.5	50.7	76.9	29.2
Senegal	Invest	28.1	69.5	79.1	55.5	98.7	61.8	54.7	75.2	100	65.8	59.7	100	100	72.9
	Staff	27.1	30.1	34.2	48.2	63	73.2	81.8	98.8	100	96.2	96.8	100	100	73.1
Cameroon	Invest	83.2	63.7	55.5	56.0	59	99.0	91	31.9	67.6	51.7	29.7	28.5	50.9	59.1
	Staff	18.7	19.5	22.2	23.7	27.1	24.6	28.1	28.1	41.8	44.0	45.8	52.9	75.1	34.7
Cote d'Ivoire	Invest	26.9	60.2	73.3	65.1	78	79.5	40.7	90.9	82.9	90.0	100	100	58.9	72.8
	Staff	15.6	18.1	21.1	25.0	26.2	30.6	38.7	45.0	52	60.7	63.1	81.9	84.5	43.3
Burkina	Invest	26.9	62.3	70.7	45.1	39.9	75.2	84.5	76.1	83.8	72.0	29.7	23.1	47.0	56.6
	Staff	12.0	14.2	16.1	18.2	19.1	21.6	24.7	27.4	29.7	34.1	32.5	38.1	40.4	25.2
Mali	Invest	66.2	100	26.7	20.2	15.8	32.9	58.2	65.5	80.6	84.5	86.3	100	96.0	64.1
	Staff	6.4	100	8.4	10.3	11.7	13.4	16.4	18.9	24.6	24.2	33.8	100	63.8	33.2