

## ICT INFRASTRUCTURE EXPANSION IN SUB-SAHARAN AFRICA: AN ANALYSIS OF SIX WEST AFRICAN COUNTRIES FROM 1995 TO 2002

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### ABSTRACT

A decade has passed since many African countries started consistently investing in the new Information and Communication Technology (ICT). Currently, there is need for more research on the impact of these investments on the expansion of productive capacity necessary for economic and social developments in this region on the world. Presently, the African Telecommunication Union (ATU) is advocating higher levels of investment in ICT in African countries, regional integration and new policies for the ICT sector. High-tech parks are being constructed for the development of the technology and to attract and encourage business initiatives in the sector. However, UNDP agencies for information technology and social development have not yet been able to state firmly whether the adoption of ICT has had a significant impact on less developed countries in general and African countries in particular. In this paper, I demonstrate that the investments in the ICT sector have resulted in technical progress. This study uses a DEA approach and some novel analysis to examine the impacts of investments in the ICT sectors of six West African countries during the period of 1995 and 2002.

**Keywords:** ICT and Development, DEA Analysis, ICT Economics, Information Systems, Economic Development

### 1. INTRODUCTION

Since 1995, many African nations have been increasing investment in ICT infrastructure in response to business and social demands and influence from international development organizations. Scholars have suggested that these investments in ICT will make significant contributions to social and economic development by fostering ‘opportunities of the global digital economy’ to their communities (UNDP, 2001; Pohjola, 2001). Braga et al. (2000) suggest that ICT will help Africa ‘leap frog’ the stages of economic development. These opinions of the potential of ICT to transform the economic and social development of Africa are not universal. Some scholars argue that less developed countries (LDCs), unlike developed countries have little of the supporting infrastructure that is necessary to capitalize on the productive capacity of ICT (UNCSTD 1997; Landauer, 1995). Others argue that it is difficult to provide evidence of the impact of ICT on social and economic development because of the time lag between investment and productivity results (Avgerou, 1998). Nonetheless, the UN ICT task force has advised governments of LDCs to prioritize and focus on ICT infrastructure expansion as an integral part of their poverty eradication strategies (UNICTF 2005). But the range of developmental challenges faced by African policy makers necessitates prudence in the allocation of scarce resources. Are ICT infrastructures providing

an adequate return to warrant continued heavy investment in the face of health pandemics and increasing needs for other civil infrastructure? Empirical evidence on the impact of ICT investment would be useful to policy analysts in deciding this question and to decide on what level of future ICT investments is appropriate within their development strategies. However, there is still limited empirical research in this area (Akpan, 2000; Mwesige, 2004).

The objective of this paper is to report empirical research on ICT expansion in Sub-Saharan Africa. The findings reported here include an analysis of statistical data on the ICT sectors of six African countries, namely Benin, Burkina Faso, Cameroon\*, Côte d'Ivoire, Mali and Senegal. The analysis focuses on three main questions: (1) Are investments in ICT technically efficient with regard to the building and expansion of ICT infrastructure? (2) Do investments in ICT result in revenue growth and contribute to growth in GDP (a component of development). (3) How effectively are these countries managing their investments in ICT? To analyze the relative efficiency of these countries we use Data Envelopment Analysis (DEA), a well known and widely used method for evaluating economic units such as countries, local governments and industries (Shafer and Byrd, 2000; Wang et al., 1997; Chen and Zhu 2004; Färe and Grosskopf, 2005).

## 2. BACKGROUND ON THE COUNTRIES

All six of the countries in the study are considered LDCs and were placed close to the bottom of UN Human Development Index (HDI) rankings in 2002. Two of these countries, Côte d'Ivoire and Cameroon, have the largest populations of the group, 16.4 and 17.1 million respectively and are demographically more similar than the others. Cameroon and Côte d'Ivoire also have the highest literacy rate of the group, 75% and 59.8% respectively. Both countries have fairly large urban populations, comprehensive universities and a very high level of enrollment in primary and secondary education. Senegal which has the fourth highest population also has a high urban population but a relatively lower literacy rate. Senegal also has a comprehensive university, but has lower levels of primary and secondary school enrollment than Cameroon and Côte d'Ivoire. During the period of the study, 1995 to 2002, all six countries participated to differing degrees in programs promoting investments in ICT for African development espoused by UNDP, the World Bank and other international organizations. Consequently they can serve as a meaningful sample for comparative analysis of the performance of their ICT infrastructure expansion programs. Table 1 below summarizes some demographic data and their performance on the HDI measures.

**Table 1: Demographic Background of the Countries, Source: CIA world fact book 2004**

Countries	Population (millions)	%Living in urban Area	Land area (Sq km)	Life Expectancy	GPD per Capita US\$	Literacy Rate %	HDI	HDI Rank 2002
Benin	6.7	45.30	110,620	52.96	1,070.00	55.5	0.411	159
Burkina Faso	13.9	20.50	274,200	43.92	1,100.00	26.6	0.330	173
Cameroon	16.4	51.95	465,400	47.99	2,000.00	75.0	0.499	142
Côte d'Ivoire	17.1	45.35	318,000	45.11	1,520.00	59.8	0.396	161
Mali	10.5	29.20	1,240,198	52.35	930.00	46.4	0.337	172
Senegal	10.5	50.28	192,530	52.31	1,580.00	39.2	0.430	156

\* Although Cameroon is geographically situated in Central Africa, it has always been included in Western African countries for scientific studies.

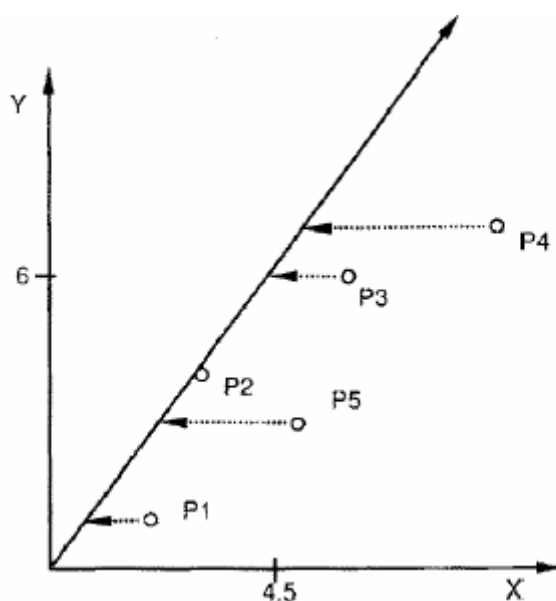
### 3. RESEARCH METHOD

The primary method for this study is data envelopment analysis (DEA), well known for its efficacy in measuring of relative efficiency. DEA originated with Farrell (1957) who drew upon the work of Debreu (1951) and Koopmans (1951). There have been several other significant contributors to the development of DEA, including Charnes et al. (1978, 1979, 1981, 1985, 1989), and Banker et al. (1984). Presently DEA is recognized as an effective method for analyzing the relative efficiency of organizations, industries and countries (Shafer and Byrd, 2000; Wang et al., 1997; Chen and Zhu, 2004; Färe and Grosskopf, 2005). DEA uses a non-parametric linear programming technique and input-output data to compute an efficient production frontier formed by the most efficient units. This is particularly beneficial when the exact relationships between inputs and outputs variables are unknown. Charnes, Cooper and Rhodes (1978, 1979, 1981) formally defined the basic DEA model as:

$$\begin{aligned} \text{maximize: } & h_o = \frac{\sum_{r=1}^s u_r y_{ro}}{\sum_{i=1}^m v_i x_{io}} \\ \text{subject to: } & \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \leq 1; j = 1, 2, \dots, n \\ & \frac{u_r}{\sum_{i=1}^m v_i x_{io}} > \epsilon; r = 1, \dots, s \\ & \frac{v_i}{\sum_{i=1}^m v_i x_{io}} > \epsilon; i = 1, \dots, m \\ & \epsilon > 0 \end{aligned}$$

The efficient production frontier is the set of all technologically feasible production plans (development policies) with the highest efficiency (cf. Figure 1). Consider the points P1 through P5 in Figure 1 as the development policies of five countries; to achieve 100% efficiency these policies P1, P3, P4, and P5 will have to change.

**Figure 1: The Efficient Production Frontier**



An upward or downward shift on the efficient production frontier can cause changes in productivity. Changes in productivity can result from improvements in technical efficiency, economies of scale, and technical change. A technically efficient DMU may still attain a higher level of productivity by moving upward along the efficient production frontier to exploit economies of scale. For the analysis I use both the constant returns to scale (CRS) and the variable returns to scale (VRS) input oriented DEA Model. These models examine the DMUs on the efficient production frontier to determine what reductions can be made to their discretionary inputs while maintaining the same level of output. 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 both ratio analysis and regression analysis. A 100% rating means that the country was operating at maximum performance with regard to the utilization of its inputs in the production of its outputs.

An important feature of DEA is its ability to evaluate the relative performance of any number of decision making units (DMU) responsible for converting inputs into outputs. The  $y_{rj}$ ,  $x_{ij} > 0$  in the DEA model are constants which represent observed amounts of the  $r^{\text{th}}$  output and the  $i^{\text{th}}$  input of the DMU<sub>*j*</sub> for a set of DMUs (where  $j = 1 \dots n$ ) that use  $i$  number of inputs (where  $i = 1 \dots m$ ) produce  $r$  outputs (where  $r = 1 \dots s$ ) outputs (Charnes et al., 1998). The model<sup>1</sup> generates an efficiency score for each DMU with values ranging from 0 to 1.00, where 1.00 represents 100% or maximum efficiency compared to all other DMUs. The most efficient DMU represents the “best practice” or benchmark unit. All inefficient units are meant to compare their practices to efficient ones and possibly improve their performance.

#### 4. DATA COLLECTION

The data on which this analysis is based was gathered from three different sources, the International Telecommunication Union (ITU), the United Nations (UN) and the African Telecommunications Union (ATU). The ITU provides the research community with complete statistical data collected over the years for the telecommunication sector for all countries. The second source is the United Nations provides researchers with reliable data regularly on social and economic indices for a broad set of categories for all countries. The third source is the African Telecommunication Union (ATU). Sibling of the ITU, the ATU has a database of a data specifically concerning the African countries.

**Table 2: List of Variables Used in DEA Analysis**

Input Variables	Output Variables
Population	Revenue from ICT
Number of Households	Number of Internet users
Investment in ICT	Percentage of Households with a Telephone
Number of ICT Staff	Total telephone traffic
	Number of cellular phones
	Number of Main telephone lines

The data of this study were drawn from these sources and covers the period 1995 to 2002. This eight year period has seen the highest investments in ICT and the most of the important changes in the telecommunication sector on the African continent. For example, most of the regulatory policies of these nations were revised to minimize government control

<sup>1</sup> The DEA can be either input or output oriented. An input oriented model defines the efficiency frontier by indicating the maximum reduction in input usage with output levels held constant for the DMU. The output oriented model describes the increase in output production with input levels held constant.

and encourage open market competition. The input and output variables used in the DEA analysis of the ICT sectors of the six countries are given in Table 2.

## 5. FINDINGS AND INTERPRETATIONS

### 5.1 Interpretation of the CRS Input Oriented Model

As stated above, we use the CRS input oriented model to determine the rank of the countries from best practice to worst practice with regard to utilization of ICT investments for infrastructure expansion. As we observe in Table 3, Côte d'Ivoire is by far the most efficient country in the group. It can be considered the 'best practice' country, with an average efficiency score of 98.95% for the entire period of the study. It is important to note that Côte d'Ivoire has ranked first in 6 of the 8 years of the study. It has attained 100% efficiency 4 times in the years 1998, 2000, 2001 and 2002 and has been the benchmark 38 times in the model. Cameroon ranks second with an overall average of 96.51%. However, Cameroon operated at 100% efficiency only twice during the 8 years of the study, in 2001 and 2002. Senegal ranks third in the CRS analysis with an average technical efficiency score of 94.52% for the period of the study. Senegal operated at 100% efficiency in 1997, 2001 and 2002 but was never cited as a benchmark. Burkina Faso, Mali and Benin rank respectively fourth, fifth and sixth with an average score of 91.15% for Burkina Faso, 90.78% for Mali and 80.60% for Benin. Of these three countries, Benin operated at 100% efficiency in 1996, 2001 and 2002, and Burkina Faso in 1999, 2001 and 2002. However, in 2001 and 2002 all of the countries operated at 100% efficiency. Except for Côte d'Ivoire, all of the countries could have been more efficient in their use of ICT investments. More in depth analysis would be needed to determine how exactly these countries could have changed their strategies to optimize ICT expansion.

**Table 3: CRS Technical Efficiency Scores and Ranking**

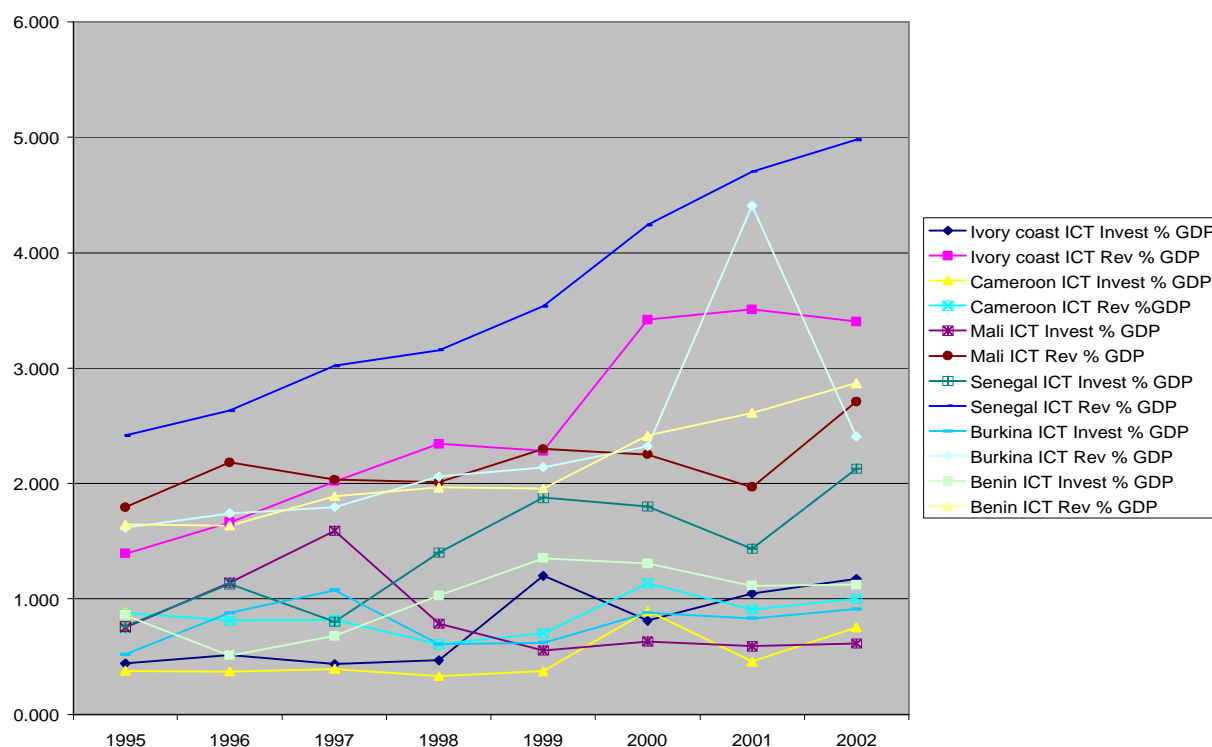
Rank	DMU	1995	1996	1997	1998	1999	2000	2001	2002	Average score
1	Côte D'Ivoire	100.00%	95.24%	96.34%	100.00%	100.00%	100.00%	100.00%	100.00%	<b>98.95%</b>
2	Cameroon	95.59%	95.42%	94.65%	97.98%	97.54%	90.90%	100.00%	100.00%	<b>96.51%</b>
3	Mali	83.27%	83.03%	82.91%	87.35%	93.00%	96.95%	99.69%	100.00%	<b>90.78%</b>
4	Senegal	89.76%	87.82%	100.00%	91.23%	91.38%	95.93%	100.00%	100.00%	<b>94.52%</b>
5	Burkina Faso	88.67%	83.27%	81.68%	90.19%	100.00%	89.40%	100.00%	96.01%	<b>91.15%</b>
6	Benin	82.90%	100.00%	86.83%	83.10%	84.14%	87.05%	92.80%	100.00%	<b>89.60%</b>

### 5.2 ICT Revenue Performance Analysis

As a general observation, all six countries show improvements in ICT revenue relative to their ICT investments over the period of time (1995 – 2002) of this study. We can separate the countries into two groups based on revenue performance, high performance and moderate performance. The high performance group is composed of the three countries namely, Côte d'Ivoire, Senegal and Cameroon. These countries have invested considerable amounts of capital and ICT labor. Of these three, Senegal has the highest investment rate relative to its GDP. The moderate performance group of countries is composed of Burkina Faso, Mali and Benin, had relatively low investments in both ICT capital and ICT personnel. The second observation that stands out from this analysis is that of the general trend of the investment curves is rising. They rise constantly from 1996, until 1999 when they slow down slightly, and then continue to rise with some ups and downs. In terms of ICT revenue performance,

Senegal has highest rate of revenue relative to GDP. In 1995, Senegal's revenue as a percentage of GDP was 2.4 %; it rose consistently to attain 4.9% in 2002.

**Figure 2: ICT Revenue performance to ICT Investments as a percentage of GDP**



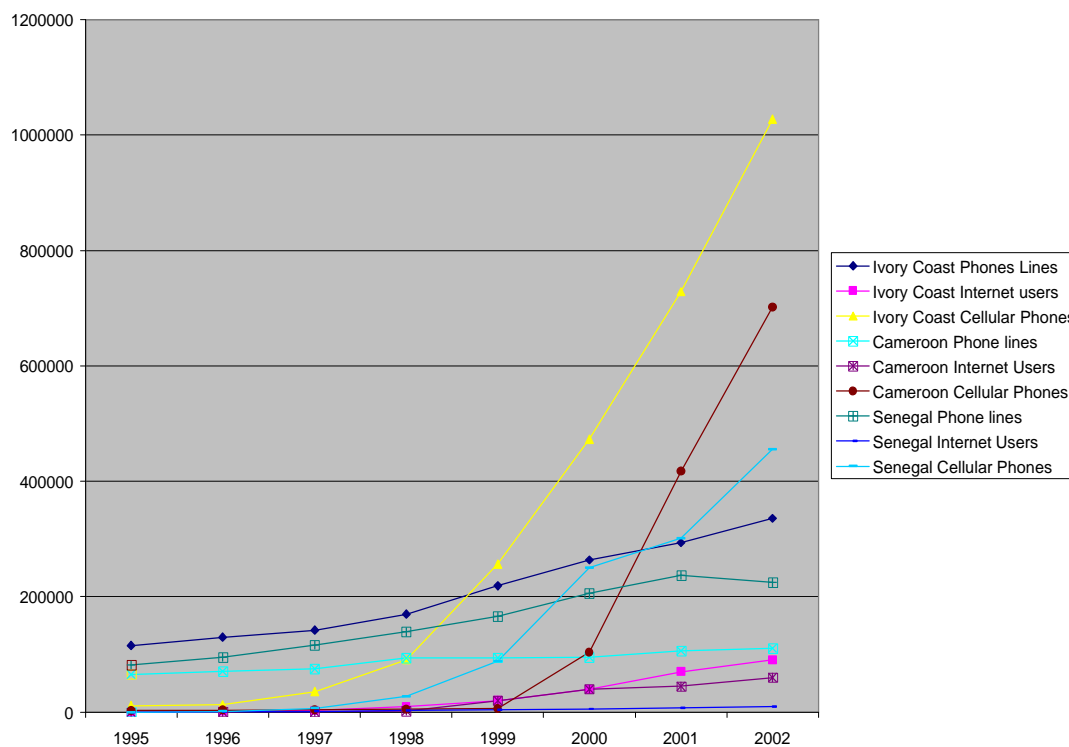
The country with the second highest revenue as a percentage of GDP is Benin. Although Benin has a relatively weak investment in ICT, the revenue from ICT rose consistently between 1996 and 2002. Benin's ICT investments range from 0.8% of the GDP in 1996 to 1.1% in 2002. Likewise Benin's ICT revenue rose from 1.6% to 2.8% over the same period. Although Cameroon is the second largest investor in ICT after Côte d'Ivoire in terms of capital (constant dollars) and ICT staff (see Table 3), it earned surprisingly low revenue from its ICT investments compared to the others. Cameroon has the lowest rate of ICT revenue relative to ICT investments for the period 1995 to 2002. Côte d'Ivoire has a fairly good ratio of returns on ICT investments compared to its investments (in dollars); however, one might expect better returns given the level of its investments. It is not clear why Senegal has a higher return on ICT investments than Côte d'Ivoire. Further investigation in the way investments are use and the very structure of the overall economy of the two countries will help us understand this.

### 5.3 ICT Infrastructure Expansion

With regard to ICT infrastructure expansion, the performance of the countries vary more widely. Three of them, Côte d'Ivoire, Benin and Cameroon, have been more successful than the others (Figure 3). However, Côte d'Ivoire stands out for its explosive expansion in the number of cellular telephones and considerable expansion in the area of landline capacity. Starting from 0 cellular telephones in 1995 this segment grew gradually to just under 100,000 in 1998 then skyrocketed to just over 1 million in 2002, 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 1995 to above 350,000 in 2002. Since 1993 the number of telephone mainlines have been increasing at an average rate of

1.2% each year and outgoing telephone traffic been almost doubling every 3 years. Cameroon, the country with the second most rapid expansion in cellular telephones, had very low numbers of cellular telephones between 1995 and 1999. In 1999 this sub sector 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 telephones.

**Figure 3: ICT Infrastructure Expansion in Côte d'Ivoire, Cameroon and Senegal**

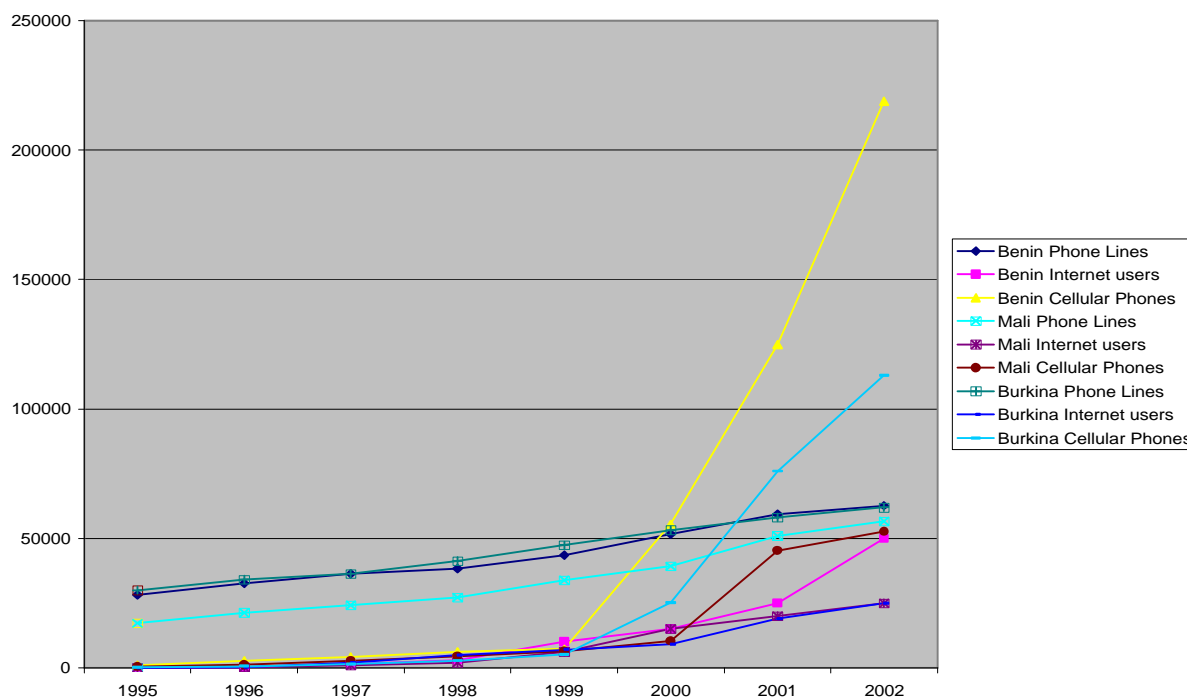


Senegal had the second fastest expansion of telephone land lines, behind Côte d'Ivoire, but the third largest expansion in the number of cellular telephones. In 1995 Senegal had just under 100,000 landlines but increased slowly doubling its capacity by 2000 when it leveled off. In the area of cellular telephones, Senegal started from a negligible number of cellular in 1995 to around 240,000 in 2000 then climbed higher to around 450,000 in 2002. Expansion of internet users has been significantly slower for all three of these countries. All of them report less than 100,000 internet users in 2002.

The countries, Benin, Burkina Faso and Mali realized only modest expansion in their ICT infrastructure for the period of the study (Figure 4). In the area of cellular telephones, Benin is the leader in this group. From 1995 to 1999 it reported less than 5,000 cellular telephones; but expansion took off in 1999 resulting in a rapid rise to about 225,000 cellular telephones in 2002. It is important to note here that Benin has about 1/3 the population and about 2/3 the GDP per capita of Côte d'Ivoire. The second most cellular telephone expansion for this group took place in Burkina Faso. This country has just about 2.2 times the population of Benin and about 3 times the GDP. Between 1995 and 1999 cellular telephone expansion in Burkina Faso was slow reaching only a few thousand, but between 1999 and 2002 it rose to about 110,000. Mali had the third most increase in cellular telephones moving from just below 5,000 in 1999 to just above 50,000 in 2002. Mali does have a higher population than Benin, but the lowest GDP per capita of the countries in the study. In all three countries there has been limited expansion of telephone land through the period of this study. Benin almost doubled its telephone landline capacity from about 30,000 in 1995 to just

under 60,000 in 2002. Burkina Faso had an almost identical performance over the same period, moving from about 31,000 landlines in 1995 to about 60,000 in 2002. Mali had a more rapid growth in telephone landlines than Benin and Burkina Faso, but started lower with just under 20,000 in 1995 but jumped to about 55,000 in 2002. All three of these countries had low expansion of internet users, while Benin hit the 50,000 mark in 2002, the others achieved only around 25,000 internet users by 2002.

**Figure 4: ICT Infrastructure Expansion in Benin, Mali and Burkina**



#### 5.4 The Benchmark and Best Practice Country

The CRS input oriented model suggests that Côte d'Ivoire is the best practice country with 98.95% CRS technical efficiency (see Table 3); it has also been the benchmark 38 of the 48 times in the model. As such Côte d'Ivoire merits a closer examine as the reference model for the other five countries. We would need do conduct more research to determine all the factors that contribute the excellent performance of Côte d'Ivoire. However, the present analysis and data does offer some important insights into the structure of its ICT expansion strategy: (1) The sustained level of ICT investments; (2) the structure of its agreements with FCR; (3) landscape features and development of other civil infrastructure (4) its capacity for training of ICT engineers and technicians; (5) the cost structure of its services. First of all, Côte d'Ivoire has been continually investing in ICT at a sustained rate of about 1% of its GDP annually, which in dollars is significant sum of capital investment. It also has the second highest GDP per capita (behind Cameroon) among the countries being studied. Cameroon and the other countries which have lower GDP's have been investing proportionally smaller amounts of their GDP in ICT. The exception to this trend is Senegal, which has been investing more than Côte d'Ivoire as a proportion of GDP. However, since Côte d'Ivoire has a much higher GDP than Senegal, Senegal's investment in dollar terms is much less than that of Côte d'Ivoire. For the period of the study Côte d'Ivoire had the second highest ICT revenue per dollar of investment behind Senegal. From the CRS analysis we observe that it has the best good utilization of ICT investments and returns. All the other countries have exhibited levels of inefficiency in the utilization of their ICT investments.

Second, relative to the other five countries Côte d'Ivoire had developed a unique ICT expansion strategy. In 1997 CI-Telecom was fully privatized, with the state retaining 35% of its shares while 51% were bought by France Cable and Radio (FCR). As part of the deal, FRC committed to invest USD 417 million to the expansion of the telecommunications infrastructure over five years which led to the addition of 290 000 landlines to the existing 140 000. The other countries made no such deals when they privatized their telephone sectors. Consequently, ICT capital reinvestment has been a low priority in these countries, limited to network maintenance and incremental growth. A third factor that favors Côte d'Ivoire's landline expansion is its excellent civil infrastructure, relatively small land area (318,000 sq km) and high density of urban population (45.4%). Côte d'Ivoire has 68,000 km of roads of which 6,500 are paved. Cameroon is a bit larger in land area (465,400 sq km) than Côte d'Ivoire and has the highest urban population (51.96%). However, it ranks behind Côte d'Ivoire in developed civil infrastructure, having 50,000 km of roads of which only 4,300 are paved. In contrast to these two, countries such as Senegal, Mali and Burkina Faso have relatively lower levels of civil infrastructure development and smaller urban populations which are both impediments to the expansion of ICT landlines. Although Senegal has the second highest urban population (50.28%) and the second smallest land area (192,530 sq km), it has only 2,678 km of roads of which 395 km are paved. Burkina Faso has a little larger land area (274,000 sq km) than Senegal but the lowest urban population (20.5) of all the countries in the study. Its civil infrastructure comprises of 15,272 km of roads of which 2,416 are paved. Mali on the other hand has a vastness and in-hospitality landscape that is a formidable impediment to the development of a large landline network. Mali comprises of some 1,240,198 square kilometers of mostly desert and has only 29.25 of its population living in urban areas. Benin is the smallest country of the six with a total land area of 110,620 sq km, the fourth largest urban population (45.3%), a total of 3500 km of roads of which 1195 km are paved. It is clear that the level of civil infrastructure development was a factor that aided ICT expansion in Côte d'Ivoire. Further, the electricity distribution sector of Côte d'Ivoire is now developing and testing approaches to ICT signal transmission over their infrastructure.

The fourth important factor in Côte d'Ivoire's ICT expansion performance is its capacity to educate annually some 30,000 ICT engineers and technicians at its ten tertiary institutions for technological education<sup>2</sup>. 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 have 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 seek training in Côte d'Ivoire where most of them remain and work after completing their studies. Perhaps this is why its ICT sector has ten times the number of specialists employed that Benin, twice that of Cameroon and three times of that of Senegal. The ability of Côte d'Ivoire to train its own staff gives it an advantage over the other five countries. It is no surprise that Côte d'Ivoire leads these countries in the low level of failures per 100 telephone circuits. Further as it has been reported elsewhere complementary investments in education, healthcare and other civil infrastructure leads to higher impact of ICT on human development (Ngwenyama et al., 2005).

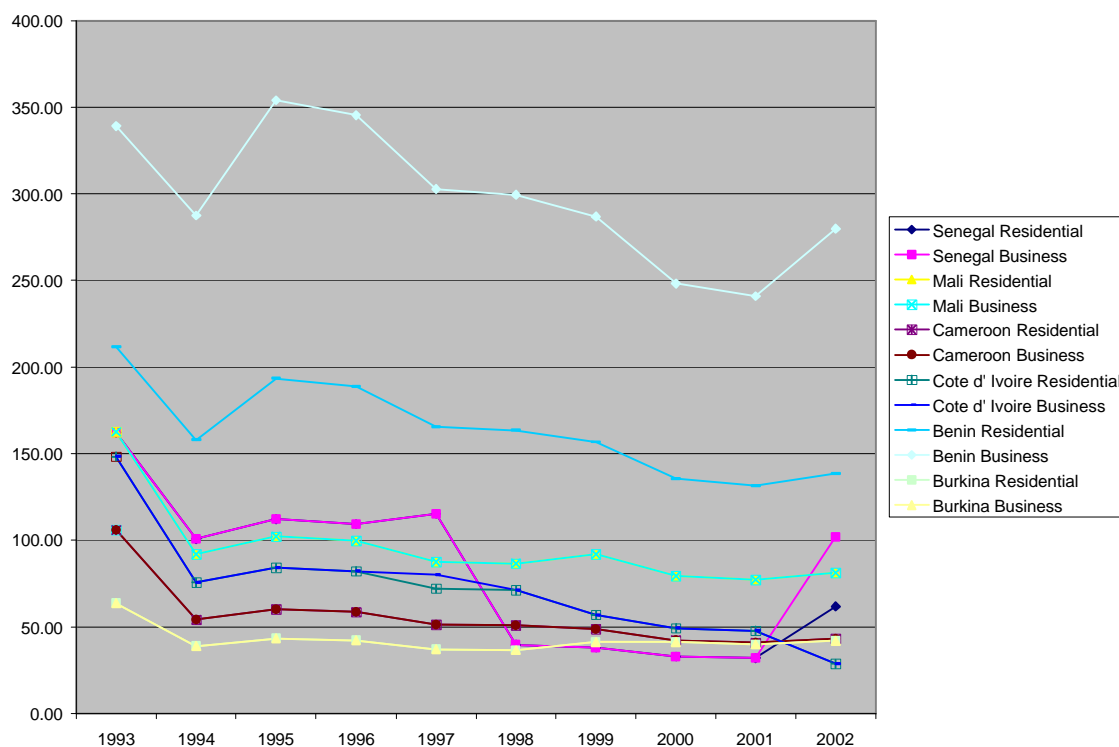
A fifth important factor that differentiates Côte d'Ivoire from the other countries is its service-cost structure. All the countries in the study are economically challenged; their GDP per capita during the period of the study did not rise above U\$2500 (see Appendix A).

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<sup>2</sup> For example: Ecole Nationale Supérieure d'Ingenieurs, Ecole de Technologie Tertiaire, Ecole Nationale des Techniciens Supérieurs, the Centre de Formation Continue, Ecole Supérieure Interafricaine de l'Electricite, Institut National Polytechnique Houphouët-Boigny, Ecole National Supérieure des Travaux Publics and Ecole Préparatoire.

Consequently, any change in the service-cost structure is likely to cause dramatic shifts in consumer response. For example, in Côte d'Ivoire the cost to acquire business or residential telephone line has dropped from U\$150 in 1995 to less than U\$50 in 2002 (Figure 5). While in the other countries it has stayed the same or rose during the same period. In the case of Cameroon these costs have remained unchanged for the entire period; in Senegal it went up by 50% between 1995 and 1999 then dropped back down by about 60% then rose again to just below the 1995 levels. In Benin and Burkina Faso, these charges rose 50% from 1995 to 2002, and for Mali they went up 20% over the period. This decline in telephone hook-up costs in Côte d'Ivoire has undoubtedly led to increasing demand for telephone landline service. 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 initiating cellular telephone service dropped by 24% then again by another 31% between 1999 and 2000. Following the reductions in 1998, the number of 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.

**Figure 5: Hook-up Cost for Business and Residential Telephone Lines**



It is clear that the price structure of ICT services over the period of the study assisted the rapid expansion in Côte d'Ivoire. On the other, Cameroon which had the second highest growth in cellular telephone service, also had 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 this same period it realized an increase in cellular telephones subscribers from 5,000 to 417,295. Benin however, had a contrary experience; from 1999 to 2002 its cellular service connection charges increased by 500% 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 rose from 2,730 in 1998 to 5,036 in 1999, 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 then 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.

### 5.5 Analysis of Performance Management

To answer our third question: How well are these countries are managing their ICT investments? I performed variable returns to scale (VRS) analysis. The chosen VRS model is radial distance input oriented. This model indicates the necessary improvements when all relevant factors are improved by the same factor equiproportionally. This model yields slacks and factors (see Appendix C) for DMUs that don't attain the 100% efficiency to allow the interpreter of the model to perform some simulations to determine better resource allocations. For the present analysis, I ran an input oriented version which quantifies the input reduction necessary to optimize efficient holding the outputs constant.

**Table 4: VRS model scores**

Countries	Rank	1995	1996	1997	1998	1999	2000	2001	2002	Score Average
Benin	1	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Burkina Faso	2	100.00%	94.79%	93.02%	99.12%	100.00%	98.40%	100.00%	100.00%	98.17%
Côte d'Ivoire	3	92.92%	92.74%	94.81%	100.00%	100.00%	100.00%	100.00%	100.00%	97.56%
Mali	4	96.76%	92.68%	90.77%	100.00%	100.00%	100.00%	100.00%	100.00%	97.53%
Senegal	5	92.42%	92.21%	100.00%	96.05%	94.63%	100.00%	100.00%	100.00%	96.91%
Cameroon	6	96.40%	96.40%	97.17%	95.74%	96.62%	91.78%	100.00%	100.00%	96.76%

The empirical results of the model suggest that Benin is the best managed of the group. Benin, at the current level of the technology, uses the most efficient combination of inputs to produce current levels of output relative to all countries under study. Benin realizes a 100% score throughout the entire period of our study. It is followed by Burkina Faso with an average score of 98.17%, Côte d'Ivoire 97.56%, Mali 97.53, Senegal 96.91 and Cameroon holds the tail with 96.76%. Two observations stand out from the results of this model. (1) Côte d'Ivoire which led in the CRS analysis ranks third under the VRS analysis, whereas Benin which performed poorly in CRS analysis ranked first in the VRS analysis; and (2) Two members of the small investors group in our CRS analysis now lead in the VRS analysis, namely Benin and Burkina Faso; while two members of the big investors group rank at the bottom in the VRS model. This situation calls for deeper investigation the overall performance of the technology for the six countries under study and a closer look at the investment patterns. The ideal situation would be for a country to be both technically efficient according to the CRS model and at the production frontier on the VRS model. That would mean that this country is efficiently transforming one unit of input to the highest value possible of output on the one hand, and on the other hand, the country is using the best possible combination of its input variable to produce a given amount of output according to its level of achievement in the technology. As Table 4 shows, Côte d'Ivoire was fully efficient from 1998 onwards. For Côte d'Ivoire, the observation of the slacks and factors table suggests that in 1995, the country could have achieved the same level of output with only 88.23% of the investments in ICT and 62.21% of the staff in ICT for that year. Had Côte d'Ivoire policy makers been aware of this situation it could have reallocated these over investments to other sectors such as education or healthcare. The same observation applies

for the following years where only 78.46% and 70% of the input ICT investments and ICT staff respectively were needed to achieve its 1996 level of output; in 1997, only 93.56% and 70.13% of the current input would have sufficed to produce the output for that year. Mali, Senegal and Burkina Faso did very badly in 1996. For Mali for instance, 50% of its 1996 investment in ICT would have been enough to achieve the level of output, while for Senegal 47% of its investments could have been reallocated to other sectors. In the case of Burkina Faso, 37% of its ICT investment could have been reallocated to other sectors. Mali's worse performance occurred in 1997 when it could have reallocated 70% of its investments in ICT to other sectors and still achieved the same level of output.

## 6. CONCLUSIONS

This research provides some interesting empirical evidence concerning the impact of ICT investments on the expansion of the ICT sectors of these African countries. The choice of DEA for this analysis was deliberate because I did not have enough data to conduct reliable regression analysis to determine the exact correlations between the different factors and the expansion in ICT infrastructure. However, with the DEA method I was able to clearly answer the three basic questions of this research: (1) Are investments in ICT technical efficient with regard to the building and expansion of ICT infrastructure? (2) Are investments in ICT resulting in revenue growth and contributing to growth in GDP (a component of development)? (3) How well are these countries managing their ICT investments? For Côte d'Ivoire the evidence is clear on both questions, investments their investments in ICT are clearly technically efficient with regard to ICT infrastructure expansion and are contributing to GDP growth. This analysis also demonstrated that Côte d'Ivoire outperformed the others in ICT expansion. However, it could have managed its ICT investments more efficiently. Although Cameroon and Senegal also showed some noteworthy gains in ICT expansion from their investments, the performance management analysis revealed that the level of investment has been too high each year for the level of output they have achieved. Therefore, more in depth investigations into the ICT strategies and social conditions of these countries could yield important insights that would help to reformulate their ICT investment strategy and policies with a view to improving the technical efficiency of their ICT sectors. Further, Benin, Mali and Burkina Faso are not efficiently utilizing their investments in ICT to achieve any significant returns in terms of infrastructure expansion and consequent social development. However, it is worth noting that these countries have been prudent in their ICT investments and have managed to demonstrate better use of these investments. These three countries should benchmark Côte d'Ivoire and find a good balance between performance management and expansion of the ICT infrastructure. Knowing that the sector is growing very fast, a more aggressive attitude and sustained investments in the ICT sector are necessary to remain in the race. Nonetheless, to their credit, some of the reason for not achieving higher technical efficiency might have to do with their cost structure of their ICT services and/or limited civil infrastructure of some of these countries. In the case of Mali its vast inhospitable landscape, low GDP per capita and low urban population are likely to be continued obstacles to ICT expansion. Presently we are not in a position to verify that these factors are significant obstacles to ICT expansion. More research is needed to verify the validity of this hypothesis. However, many of these countries face at least five obstacles to ICT expansion (1) financial resources for sustaining the level of ICT investments; (2) the structure of its agreements with FCR; (3) landscape features and development of other civil infrastructure (4) lack of capacity for training of ICT engineers and technicians; (5) the cost structure of its services.

## 6.1 Implications for Policy Makers

This research also makes a contribution to African ICT policy makers both by providing evidence and an approach to analysis that could inform their work as they embark on the formulation of new development strategies. Presently, African policy makers are faced with the difficult task of balancing investment priorities for its critical sectors (health, education, civil infrastructure, ICT, etc.) in order to alleviate poverty and improve the general well being of their citizens. While ICT is an attractive investment due to falling cost and potential for social and economic impact, it is widely known that there is a lack of research in ICT for the African continent (Akpan, 2000; Mwesige, 2004). There is also little support for policy makers who must face these difficult and complex decisions. Relying on ICT investment benchmarks from developed countries would certainly lead to mistakes given the differences in transformative capacities among the developed and developing countries. Therefore, African policy makers should look for benchmarks and best practices from other developing countries. They could also adopt more sophisticated modeling and analysis methods (such as those used here). The DEA analytical approach used in this paper offers at least two advantages: (1) the countries could learn from their own mistakes based on their past data and performances and (2) each country could compare its performance relative to its immediate neighbors and other countries facing similar constraints and similar level of economic and social development.

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**APPENDIX A****GDP Per Capita, Current International Dollar, Source: UN Statistics Division Database**

<b>COUNTRIES</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>
Benin	800.00	840.00	880.00	900.00	930.00	980.00	1030.00	1070.00
Burkina Faso	850.00	900.00	950.00	950.00	1000.00	1020.00	1060.00	1100.00
Cameroon	1540.00	1600.00	1680.00	1720.00	1770.00	1880.00	1960.00	2000.00
Côte d'Ivoire	1440.00	1510.00	1560.00	1610.00	1630.00	1590.00	1590.00	1520.00
Mali	640.00	660.00	700.00	740.00	780.00	740.00	890.00	930.00
Senegal	1230.00	1260.00	1310.00	1360.00	1420.00	1490.00	1570.00	1580.00

**APPENDIX B****Cost of Business and Residential Telephone Line Connection Charges  
Source: ITU Yearbook**

<b>COUNTRIES</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>
Senegal Residential	162.15	100.86	112.19	109.47	115.13	39.66	38.01	32.87	31.92	61.71
Senegal Business	162.15	100.86	112.19	109.47	115.13	39.66	38.01	32.87	31.92	101.88
Mali Residential	162.45	91.86	102.17	99.70	87.38	86.45	91.81	79.39	77.11	81.10
Mali Business	162.45	91.86	102.17	99.70	87.38	86.45	91.81	79.39	77.11	81.10
Cameroon Residential	105.95	54.03	60.10	58.65	51.40	50.85	48.73	42.14	40.93	43.04
Cameroon Business	105.95	54.03	60.10	58.65	51.40	50.85	48.73	42.14	40.93	43.04
Côte d' Ivoire Residential	148.33	75.65	84.14	82.10	71.96	71.19	56.85	49.16	47.75	28.69
Côte d' Ivoire Business	148.33	75.65	84.14	82.10	79.95	71.19	56.85	49.16	47.75	28.69
Benin Residential	211.89	157.99	193.31	188.63	165.32	163.56	156.72	135.53	131.64	138.45
Benin Business	339.03	287.67	353.99	345.41	302.73	299.50	286.98	248.17	241.04	279.77
Burkina Residential	63.57	38.90	43.27	42.22	37.01	36.61	41.40	41.17	39.99	42.05
Burkina Business	63.57	38.90	43.27	42.22	37.01	36.61	41.40	41.17	39.99	42.05

## APPENDIX C

## Use Factors and Slacks from the VRS Model

COUNTRIES	Year	Score	Use factor for ICT Invest	Use factor for ICT Staff	Slack for ICT Revenue	Slack for Internet	Slack for Telephone	Slack for Cellular
CÔTE D'IVOIRE	1995	92.92%	88.23%	62.21%	20618530.91	23543.94	0	141570.06
CAMEROUN	1995	96.40%	84.69%	90.13%	27761444.04	22987.94	17447.81	106851.58
MALI	1995	96.76%	79.22%	98.11%	5529472.26	7587.75	18095.2	5401.69
SENEGAL	1995	92.42%	73.68%	73.25%	0.87	4043.44	0	68224.94
BURKINA	1995	100.00%						
BENIN	1995	100.00%						
CÔTE D'IVOIRE	1996	92.74%	78.46%	70.72%	910.67	23816.54	947.25	170351.4
CAMEROUN	1996	96.40%	82.92%	91.88%	33311715.26	22854.72	16172.98	113565.87
MALI	1996	92.68%	50.87%	97.87%	4.49	9580.39	15222.47	6112.64
SENEGAL	1996	92.21%	53.08%	92.42%	0.4	1945.65	0	92865.83
BURKINA	1996	94.79%	63.54%	100.00%	0.09	1451.01	0	7334.79
BENIN	1996	100.00%						
CÔTE D'IVOIRE	1997	94.81%	93.56%	70.13%	0.07	23616.29	0	181533.51
CAMEROUN	1997	97.17%	81.88%	98.29%	36154581.1	22354.72	11530.98	112865.88
MALI	1997	90.77%	36.53%	98.85%	20626.94	10989.26	13546.06	5850.71
SENEGAL	1997	100.00%						
BURKINA	1997	93.02%	52.08%	99.03%	710936.66	522.2	0	435.93
BENIN	1997	100.00%						
CÔTE D'IVOIRE	1998	100.00%						
CAMEROUN	1998	95.74%	98.81%	71.35%	57901135.87	20680.85	0	121237.96
MALI	1998	100.00%						
SENEGAL	1998	96.05%	72.36%	100.00%	0.67	2636.78	0	71850.24
BURKINA	1998	99.12%	94.30%	99.52%	10.34	0	0	4800.91
BENIN	1998	100.00%						
CÔTE D'IVOIRE	1999	100.00%						
CAMEROUN	1999	96.62%	89.55%	86.79%	57222757.39	4394.63	3189.9	133304.32
MALI	1999	100.00%						
SENEGAL	1999	94.63%	62.43%	100.00%	0.29	0	0	51803.52
BURKINA	1999	100.00%						
BENIN	1999	100.00%						
CÔTE D'IVOIRE	2000	100.00%						
CAMEROUN	2000	91.78%	58.78%	83.68%	80.77	0	0	245548.72
MALI	2000	100.00%						
SENEGAL	2000	100.00%						
BURKINA	2000	98.40%	89.08%	99.73%	15408810.39	445.8	0	0
BENIN	2000	100.00%						
CÔTE D'IVOIRE	2001	100.00%						
CAMEROUN	2001	100.00%						
MALI	2001	100.00%						
SENEGAL	2001	100.00%						
BURKINA	2001	100.00%						
BENIN	2001	100.00%						
CÔTE D'IVOIRE	2002	100.00%						
CAMEROUN	2002	100.00%						
MALI	2002	100.00%						
SENEGAL	2002	100.00%						
BURKINA	2002	100.00%						
BENIN	2002	100.00%						