2 Telecommunications Infrastructure and Economic Growth: A Cross-Country Analysis

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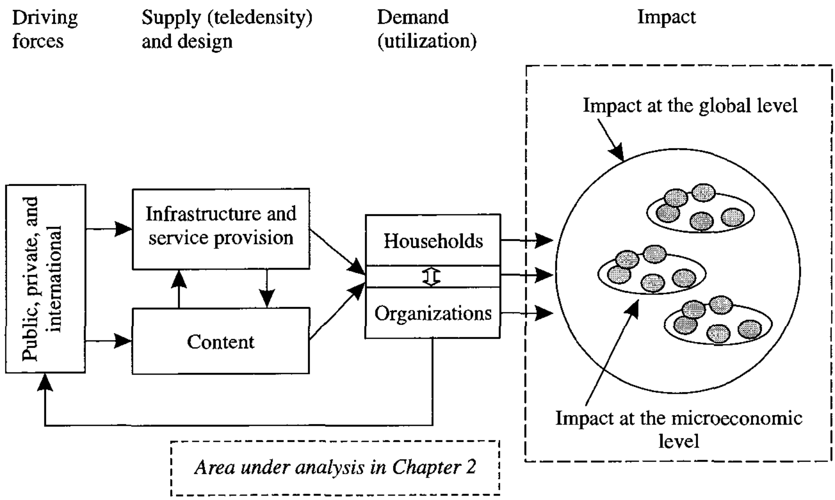
In recent years, the potential of information and communications technologies (ICT) to facilitate economic development, especially in low-income countries, has attracted considerable attention. Several commentators (Pohjola 2001, for example) have argued that development of these new technologies, in terms of proliferation and accessibility, should be integral to country-level development strategies and that ICT investments are essential in the process of enhancing living standards. Nevertheless, detractors also exist. They counter with the primary argument that developing countries have far more pressing investment priorities, and that investing scarce resources in ICT does not fulfill the needs of the poor (Roche and Blaine 1996; Saith 2002).

Whether additional investments in these technologies are justified and whether they have the potential to increase incomes and alleviate poverty can be determined only by empirical investigation. If these new technologies are to command the continued interest of the developing world and justify additional investments, a convincing demonstration of their effects on economic performance is required. On this basis, and given limited existing empirical evidence, this chapter examines the impact of terrestrial telecommunications infrastructure—by far the most prevalent communication technology in developing countries—on aggregate economic output. The conceptual framework that forms the basis of the book is once again presented in Figure 2.1, this time highlighting the area of analysis dealt with in this chapter.

For the purposes of the empirical investigation, a substantial data set covering 113 countries was assembled for the period 1980–2000. The empirical framework explicitly accounts for the two-way relationship between telecommunications infrastructure and economic output (meaning that the framework factors in issues of endogeneity). The four-equation framework used by Röller and Waverman (2001) was adopted and, in the first instance, replicated. However, the estimation methodology and empirical work in this study goes beyond Röller and Waverman's specification. In particular, this study examines the time-series properties of the data set used and corrects for the presence of unit-roots (an attribute of the time series within the statistical model).

FIGURE 2.1 Conceptual framework: Area of analysis dealt with in Chapter 2



NOTE: Teledensity indicates the number of telephone lines per 100 inhabitants.

There are several ways that a country's ICT infrastructure can affect economic growth. Apart from making a direct contribution to gross domestic product (GDP), investments in these technologies are assumed to have pervasive impacts throughout the economy—for example, by reducing transaction costs, improving organizational functioning, and enhancing the spread and development of factor and product markets (along with many other potential effects that have already been outlined by several authors, such as Saunders, Warford, and Wellenius 1983; Leff 1984; and Norton 1992), and therefore are not elaborated on further here. It is worth noting, however, that ICT is unlike other forms of infrastructure in that its expansion generates benefits for both new and existing users. This externality suggests that the effects of ICT on economic growth may be subject to the attainment of a critical mass, meaning that, unless the said infrastructure reaches a certain minimum level within a given country or region, the growth effects may not be discernible. Put in simple economic terms, a nonlinear relationship may exist between telecommunications infrastructure and economic growth. Thus, the empirical work in this chapter addresses two issues. First, does telecommunications infrastructure have an impact on economic growth? Second, if a growth effect does exist, how does it vary with infrastructure and income levels across countries and regions?

This chapter presents a summary of the literature on infrastructure and growth, a description of the data used (presenting correlations between GDP and the availability of ICT), and conclusions. For those interested, the detailed econometric model and empirical results are included in appendix form at the end of the chapter.

A Review of Infrastructure Development and Growth

Overview

Early work on economic growth and development highlighted the necessity of adequate infrastructure. Defining the scope of social overhead capital (SOC), Hirschman (1958, 89) writes "SOC is usually defined as those services without which primary, secondary, and tertiary production activities cannot function." He goes on to write that in its wider sense SOC "includes all public services from law and order through education and public health to transportation, communications, power, and water supply." Although infrastructure implies a wide variety of services, such services have several traits in common. First, while these services yield direct benefits, it is often their indirect contribution—as intermediate inputs enhancing the productivity of all other inputs—that is often considered more important. Second, the development of these services is usually subject to increasing returns to scale. Third, while private-sector participation in the provision of infrastructure has increased, it is still largely funded and provided by the public sector. The rationale for public provision of these services is well known and is usually justified on the basis of a combination of externalities, nonrival consumption, and nonexcludable characteristics of such services.

The appropriate level and composition of public expenditure on different types of infrastructure services is an active area of debate, particularly because of their potential to spark growth and influence economic outcomes. For the purposes of assisting and informing public expenditure decisions, it is important to know the overall impact of infrastructure on economic output, as well as the relative effects of different types of infrastructure. The importance of this question for public policy has motivated a number of authors to examine the macroeconomic link between public capital and output. While there are micro-oriented studies of the infrastructure–growth output link, the economywide effects and potential externalities ascribed to such investments suggest the need for a macroeconomic approach.[1] The infrastructure–output literature consists of several branches; this study, however, reviews only the relevant portions of the existing evidence.

The discussion initially focuses on single countries, either over time or across regions, examining the effect of overall infrastructure capital on private

1. Micro-oriented studies lead to a deeper understanding of how infrastructure enhances output, but when the main goal is to establish the overall effect of infrastructure capital on output and productivity, a macroeconomic analysis is the more logical choice.

output. This is followed by a look at cross-country evidence of the impact of infrastructure capital on economic performance (meaning GDP growth over time). This review of the more general infrastructure literature is followed by a review of studies focusing on the links between telecommunications and output.

General Infrastructure Literature

Despite the existence of estimates of the link between infrastructure and output that predate Aschauer (1989), interest in the effects of public capital on output can be traced to this work. Aschauer used annual U.S. time-series data for the period 1949–85 and estimated that a 1 percent increase in the ratio of public to private capital stock was associated with a 0.39 percent increase in private-sector total factor productivity (TFP). A similar effect was reported by Munnell (1992). Such large effects—at a time when growth in productivity and in the stock of public infrastructure was declining—prompted Aschauer to propose that the declining growth of public infrastructure was an important determinant in the productivity slowdown. To examine whether these results could be extrapolated more generally, Ford and Poret (1991) used time-series data from several countries of the Organisation for Economic Co-operation and Development (OECD) to estimate production function relationships as similar as possible to those studied by Aschauer. Ford and Poret's estimates of the elasticity of output from infrastructure stock spanned a wide and implausible range (from 1.00 for Canada to –0.55 for Norway) and did not support the idea that a decline in infrastructure growth was responsible for the decline in TFP.

Despite this lack of support for the infrastructure–productivity link from studies based on other countries, support for Aschauer (1989) was provided by studies that relied on panel data to examine the effect of publicly provided inputs on the economic performance of U.S. states. Although his results were smaller in magnitude, Munnell (1992) reported that public capital was a statistically significant link in the determination of differences in productivity across U.S. states. Rather than focusing on public capital in its entirety, Garcia-Mila and McGuire (1992) used observations from the 48 contiguous states during 1969–83 to examine the effect of the stock of highway capital and educational expenditure on gross state product. While their results were smaller than the elasticities based on time-series data, they did show that these two variables played a substantial role in explaining statewide productivity differences.

The preceding studies focused exclusively on developed countries; the paucity of data makes it difficult to carry out single-country studies for developing countries. Clues to the link between infrastructure stock and economic development and growth in developing countries stem mainly from cross-country studies. Antle (1983) uses data from a sample of developing and developed countries to examine the extent to which intercountry differences in agricultural productivity can be explained by country-level investments in transportation and communications. For both developing and developed countries, Antle's analysis supports the conclusion that additional investments in infrastructure play a larger role than agricultural research and education in explaining inter-country differences in agricultural productivity.

The broad inference from the above studies is that the stock of public infrastructure plays a causal role in determining growth and productivity in both developing and developed countries. Policy implications drawn from such studies are fairly clear and support the argument for additional investments in physical infrastructure. Nevertheless, policy prescriptions based on the results of these studies have attracted strong criticism, primarily on the basis that they do not adequately account for the possibility of reverse causality and simultaneous determination of output and public capital—meaning that, while it is tempting to infer a causal relationship from public capital to output, it is equally likely that the direction of causality goes from output to public capital. In the context of time-series analysis, the estimated coefficient may reflect a spurious correlation between output and public capital stock that is driven by a common time-trend and not by any underlying relationship between the two variables. In short, the data may be what is economically termed "nonstationary" and inferences based on these data may be misleading. Another problem primarily afflicting panel-data studies stems from omitted variables. The first-generation panel-data studies usually ignore the possibility of unobserved state- or country-specific variables that may influence both output and the stock of public capital. Ignoring such fixed effects is quite likely to lead to an exaggeration of the effect of infrastructure on output.

The more recent literature in this area accounts for both of these problems —simultaneity bias and fixed effects—and presents a rather different picture. Holtz-Eakin (1994) uses panel data from the United States to estimate a variety of production functions in levels and in first differences. These estimates allow for fixed and random effects. Regardless of variations in the specifications, Holtz-Eakin finds no evidence that public capital is involved in productivity differences across states and concludes that the previous large positive findings "appear to be the artifact of an inappropriately restrictive framework" (Holtz-Eakin 1994, 20). In a reconsideration of some of their earlier studies, Garcia-Mila, McGuire, and Porter (1996) use a panel data set drawn from the United States to estimate the effect of public capital investments in highways, water and sewage systems, and all other infrastructure investments on private output. Their results confirm the conclusions reached by Holtz-Eakin (1994). From a cross-country perspective, Craig, Pardey, and Roseboom (1997) control for country-level fixed effects and conclude that, for developing countries, differences in road density are not responsible for differences in agricultural productivity.

Thus, in marked contrast to the first-generation studies, these second-generation studies find no evidence of high returns to investments in infrastructure. Despite these results, it would not be correct to argue that investments in infrastructure are not necessary. These studies show that within the context of a narrow production-function framework there are no indirect productivity effects associated with public capital. These results do not, however, detract from the large direct effects that investments in infrastructure services generate. Furthermore, any investment in public infrastructure calls for a project-specific cost–benefit analysis and should not be based on aggregate analysis.

Telecommunications Infrastructure Literature

Turning to studies more closely related to the topic of this chapter, Jipp (1963) and Hardy (1980) are some of the earliest that focus on the telecommunications–economic growth link.[2] Hardy (1980), for instance, uses data from 15 developed and 45 developing countries for the period 1960–73, regressing per capita GDP on lagged per capita GDP, lagged telephones per capita, and the number of radios. Hardy's results support the idea that the greater availability of telephones has a positive effect on GDP. By demonstrating the strong correlation between teledensity (the number of telephone lines per 100 inhabitants) and GDP, these early studies drew attention to the potential role of telecommunications in influencing growth. However, similar to the first-generation infrastructure literature, these early studies ignored the econometric issues outlined above.

A more sophisticated example of this genre is Norton (1992). Using data from a sample of 47 countries from the post–World War II period until 1977, Norton investigates the effects of telephone infrastructure on growth rates and also attempts to identify the channels through which the availability of this infrastructure leads to growth (that is, the effect of telephone infrastructure on the mean investment ratio, and consequently income growth). The empirical framework replicates Kormendi and Meguire (1985) but includes additional variables to capture telecommunications infrastructure. The inclusion of a more comprehensive set of macroeconomic regressors is designed to reduce the possibility of overestimating the effect of telecommunications infrastructure on growth. The two telecommunications infrastructure measures used are teledensity in 1957 and mean teledensity over the sample timeframe. The use of these two infrastructure variables is an attempt to address the endogenous nature of teledensity and growth. Norton argues that a measure of teledensity prevalent during the early years of the sample is less susceptible to endogeneity bias than a variable that captures the mean teledensity over the entire time period.

2. An emerging body of literature that examines the effect of the stock of computer hardware, software, and labor and other information technology-related measures in influencing economic growth and output. Since the main focus of this study is developing countries, where the stock of such capital is quite small, this body of evidence is not reviewed in detail here. Recent macroeconomic evidence on the United States is provided by Gordon (2000), Oliner and Sichel (2000), and Stiroh (2002). Results based on data from other countries and a cross-country analysis of the effect of information technology expenditure on economic growth are available in Pohjola (2001).

Norton's results show that the two measures of telecommunications infrastructure are statistically significant and exert positive effects on mean growth rates. For instance, increasing the 1957 teledensity by one standard deviation (9.909) leads to an increase in mean GDP growth of around 0.73 percent. The effect of the average density variable is greater but potentially more susceptible to reverse causality. The second set of estimates examines the effect of the telecommunications infrastructure variables on the mean investment–output ratio, and, similar to the earlier results, the impact is positive. Increasing teledensity by one standard deviation leads to an increase in the investment ratio of around 3.5–4.5 percent. While Norton controls for the endogeneity of telecommunications infrastructure and growth, the large effects reported in the study are reminiscent of the effects reported in early infrastructure literature. Norton does not control for country-level fixed effects, and it is likely that this omission is responsible for the large estimated effects of telecommunications infrastructure.

Madden and Savage (2000) follow the framework used by Mankiw, Romer, and Weil (1992) to estimate the effect of telecommunications on the level and growth of GDP for a cross-section of 43 countries (including 16 developing countries) for the period 1975–90. The authors present estimates based on ordinary least squares (OLS) and mention that they use instrumental variables estimation to control for the possible endogeneity between telecommunications capital and GDP. Their results are not sensitive to alterations in the estimation methodology, and they report large effects of telecommunications capital on the level of GDP. Once again their estimates may be upwardly biased because they do not control for country-level fixed effects.

As mentioned in Chapter 1, Röller and Waverman (2001) present cross-country estimates of the effect of telecommunications on output based on a cross-section of 21 OECD countries over a period of 20 years. They tackle the endogeneity problem by estimating a four-equation model that endogenizes telecommunications infrastructure, and they control for country-level fixed effects. Their results indicate that estimates allowing for fixed effects lead to a reduction in the teledensity elasticity from 0.15 to 0.045. Despite this drop, the growth effect attributed to telecommunications infrastructure is still quite large. The elasticity implies that about one-third of the economic growth in OECD countries between 1971 and 1990 may be attributed to growth in telecommunications infrastructure. An interesting element of Röller and Waverman's work is the investigation of whether a nonlinear relationship exists between teledensity and economic output. They found that teledensity begins to exert an influence on output only when it is universally available—more specifically, when a teledensity threshold or critical mass of about 40 percent is reached.

While the robustness and generality of the threshold effect may be questioned, these results do suggest that enhancements in telecommunications infrastructure may generate higher growth effects in developed countries than in developing countries. In addition, given low teledensity in developing countries (the 1995 average was around 4.0), it appears that marginal improvements in telecommunications infrastructure may not generate the desired growth effects. Thus, developing countries may require substantial investments in telecommunications infrastructure before they can benefit from the growth-generating effects of these technologies.

In this chapter we use a framework and a specification that is as similar as possible to Röller and Waverman (2001). We endogenize telecommunications by estimating a demand and supply model for telecommunication investments and simultaneously estimate a macro-production function. Our primary aim is to examine whether the idea of a critical mass is valid for a larger sample of nations and for a longer timeframe. Our analysis emphasizes an examination of this relationship for developing countries.

Data and Summary Statistics

To construct a comprehensive data set, the inclusion of a country was determined by the availability of time series data of long duration covering the variables required for the analysis. The countries included are presented in Appendix 2A, which also provides details of the income categories and the regional groupings used.[3]

The data set for this chapter is tailored to the needs of the empirical framework and contains information on economic variables such as output, labor force, capital stock, and budget deficit (surplus). The telecommunications-related variables are teledensity, revenue per fixed telephone line, and annual investment in telecommunications. In addition to these telecommunications-related variables, the data set also contains information on the availability of other ICT. Table 2.1 provides a list of the variables and their descriptive statistics, also indicating the sources of the variables.

With respect to variable sources, while most of the variables are readily available from publicly accessible databases, such as the World Development Indicators (WDI) and the International Telecommunications Union (ITU) database (World Bank 2002 and ITU 2002), some of the data—in particular telecommunications capital stock and total physical capital stock—required estimation. Construction of the telecommunications capital stock series is based on annual investment in telecommunications data available in WDI (World Bank

3. In terms of income categories, our data set consists of 36 low-income countries, 27 lower middle-income countries, 21 higher middle-income countries, 8 high-income non-OECD countries, and 21 OECD countries. We divided the countries across six geographic regions based on WDI classifications (World Bank 2002). The data set comprises 40 countries from Africa, 24 countries from the Asian/Middle Eastern region, 4 countries from the Australian region, 23 countries from the European region, 13 from the Central and North American region (including the Caribbean), and 9 countries from South America.

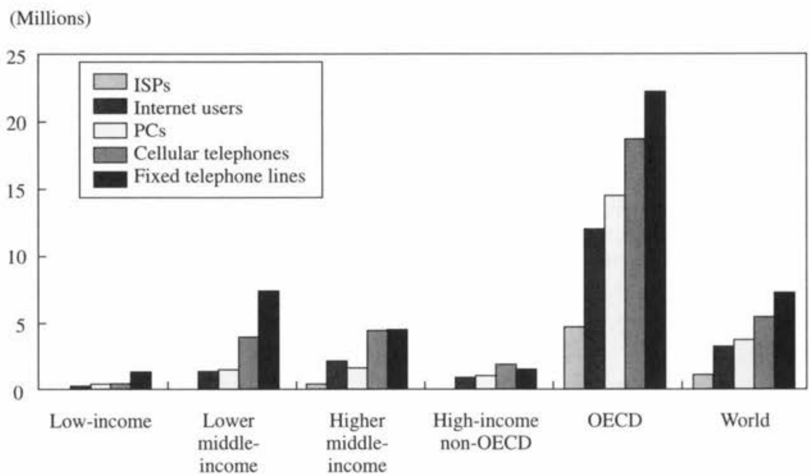
TABLE 2.1 Variables and summary statistics

Variable	N	Minimum	Maximum	Mean	SD
GDP (million 1995 U.S. dollars)	1,829	199.61	7,723,512.50	229,782.90	798,217.13
Total labor force in millions	1,829	0.02	979.67	33.75	113.90
Total physical capital stock (million 1995 U.S. dollars)	1,829	761.49	21,100,000.00	659,167.41	2,300,430.01
Annual investment in telecommunications (million 1995 U.S. dollars)	1,772	0.01	37,080.61	1,240.20	3,888.95
Land area (1,000 square kilometers)	1,819	0.32	9,326.41	838.60	1,891.43
Government budget surplus (deficit) (million 1995 U.S. dollars)	1,404	−309,010.96	84,042.30	−10,406.74	34,965.53
Fixed telephone lines per 100 inhabitants	1,828	0.09	70.69	15.83	18.29
Cellular subscribers per 100 inhabitants	1,791	0.00	47.47	1.17	4.02
Telephone service revenue per fixed line (1995 U.S. dollars)	1,369	58.21	1,314,365.28	3,499.36	51,340.28
Cellular service revenue per fixed line (1995 U.S. dollars)	393	0.00	17,532.79	1,141.04	1,387.06
Waiting list for fixed lines per 100 inhabitants	1,611	0.00	20.73	1.21	2.16
Internet users per 1,000 inhabitants	563	0.00	294.25	12.99	31.68
Internet hosts per 10,000 inhabitants	1,362	0.00	945.82	11.65	56.96
Personal computers per 1,000 inhabitants	689	0.01	406.87	57.65	81.09

SOURCES: Data on gross domestic product (GDP), total labor force, annual investment, land area, and government budget surplus (deficit) are from World Bank (2002); data on total physical capital stock and annual investment in telecommunications are from Nehru and Dhareshwar (1993) and authors' estimations based on World Bank (2002); data on fixed telephone lines, cellular telephones, the Internet, and personal computers are from ITU (2002).

NOTE: N indicates number of observations; SD, standard deviation.

FIGURE 2.2 Availability of ICT in various regions defined by income level, 2000



SOURCE: Calculated by authors from study data set.
NOTES: ISP indicates Internet service provider; OECD, Organisation for Economic Co-operation and Development; PCs, personal computers. For details of the countries within the income groupings, see Appendix 2A.

2002). The telecommunications capital stock is constructed using the perpetual inventory method (PIM). See Appendix 2B for details.

Figure 2.2 shows the availability of different types of ICT for five income groups. The availability of each technology is derived from the country average within each income group. Despite the explosive growth of modern ICT in the 1990s, on average, fixed telephony still predominates in low-income, lower middle-income, and OECD countries. However, cellular telephony has emerged as the second most important communications technology. In some cases, for instance in higher middle-income countries and high-income non-OECD countries, cellular telephony already outnumbers fixed telephony. With the exception of access to fixed telephony, the prevalence of modern ICT, such as Internet hosts and personal computers (PCs), remains very low in low-income countries.

Although countries in all income groups experienced sizable ICT growth in the 1990s (see Table 2.2), the total stock of ICT in low-income countries remained extremely low compared with other income groups. As of 2000, the average number of Internet hosts per low-income country was only 2,432—a mere 0.05 percent of the 4.7 million Internet hosts per OECD country on average. Although the stock in the case of fixed telephony was higher, it still represented only 5.8 percent of the OECD average. In fact, comparatively higher teledensity in certain countries inflated the fixed telephony average for low-income countries. For example, the total number of fixed telephone lines in India

TABLE 2.2 Compound annual growth rate of per capita gross domestic product and fixed telephone lines within income and regional groups

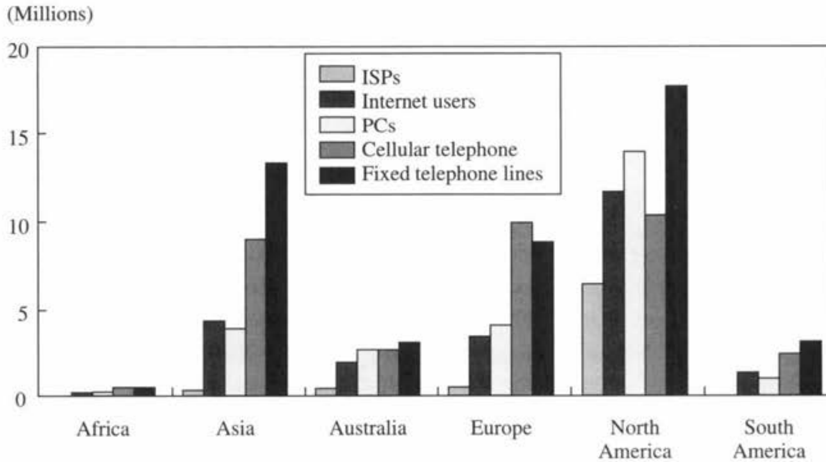
Income/regional group	GDP per capita 1980	GDP per capita 2000	CAGR (%) 1980–2000	Fixed lines per 100 inhabitants 1980	Fixed lines per 100 inhabitants 2000	CAGR (%) 1980–2000	Correlation between growth rates
Income group							
Low-income (36)	388	389	0.04	0.36	1.17	5.94	0.549**
Lower middle-income (27)	1,394	1,642	1.05	2.30	10.21	8.19	0.869**
Higher middle-income (21)	3,964	5,526	1.85	4.86	22.72	7.78	0.817**
High-income non-OECD (8)	13,466	17,147	1.81	16.67	47.84	5.24	0.146
High-income OECD (21)	19,155	29,624	2.11	32.06	58.24	3.12	0.518*
Regional group							
Africa (40)	943	1,150	0.22	0.83	3.61	6.02	0.644**
Asia (24)	6,139	8,104	2.11	6.85	19.17	8.29	0.539**
Australia (4)	8,209	11,193	0.84	18.25	28.02	2.78	–0.515
Europe (23)	14,376	22,712	2.11	23.76	51.82	4.74	0.203
North America (13)	5,225	7,279	1.03	10.08	28.11	6.97	0.404
South America (9)	3,152	3,490	0.31	3.95	14.11	6.12	0.819**
World, 113 countries	5,707	8,263	1.13	8.71	21.25	6.24	0.464**

SOURCE: Calculated by authors from study data set.

NOTES: CAGR indicates compound annual growth rate, where $\text{CAGR} = \left[\left(\frac{\text{Last Value}}{\text{First Value}}\right)^{1/N} - 1\right] \times 100$.

The CAGR was calculated for each of the 113 countries. The number of countries within each income category is shown in parentheses. For details of the countries within the income and regional groupings, see Appendix 2A. Values are unweighted averages; *indicates significance at the 5 percent level; **indicates significance at the 1 percent level. OECD indicates Organisation for Economic Co-operation and Development.

FIGURE 2.3 Availability of ICT in various regions, 2000



SOURCE: Calculated by authors from study data set.
NOTE: For details of the countries within the six regional groupings, see Appendix 2A. ISP indicates Internet service provider; PCs, personal computers.

in 2000 was 25 times the low-income country average, and the number of cellular telephones in Indonesia in 2000 was more than 12 times the low-income country average.

In addition to limited variety of ICT available in low-income countries, an imbalance also exists between the availability of fixed telephone lines and the availability of more recent technologies such as the Internet. While the ratio between fixed telephone lines and the Internet was 1.85 to 1 on average in OECD countries in 2000, it was 5 to 1 in low-income countries.

Figure 2.3 shows the availability of ICT across the six different regional categories for the year 2000, based on the country average per region. Like the income groups, there are regional differences in ICT levels. While countries in Africa have the lowest penetration rates on average, countries in the Central and North American region have the highest. For example, while the number of Internet hosts in Africa is 0.59 percent of the world average, the number in the Central and North American region is seven times the world average. In Europe, in contrast to other geographic regions, cellular telephony already outnumbers fixed telephony.

These averages mask individual differences within regions. Not surprisingly, the larger the country (or countries) within a region in terms of area or population, the larger the stock of ICT. In the case of Africa, for example, the number of Internet hosts in South Africa is 35 times the African average, and the number of fixed telephone lines in Egypt is 12 times the African average; in the case of Asia, the outliers are Japan and Korea for all types of ICT and India and China for fixed telephony. Differences in the other regions also follow income and country size (either by area or population). Table 2.2 shows compound annual growth rates (CAGR) of per capita GDP and fixed line teledensity for the period 1980–2000. Over this time, the 113 countries (representing "the world") reported positive growth in both per capita income and fixed telephony. While per capita income grew at 1.1 percent on average, the growth rate for fixed telephony per 100 inhabitants was 6.2 percent. The last column of the table indicates the correlation between the CAGRs for per capita GDP and fixed line teledensity (Table 2.2).

From 1980 to 2000, per capita income in low-income countries virtually stagnated, while all other income groups experienced substantial growth. All income groups achieved growth in fixed telephony per capita, but the growth rate was higher in low-income than in high-income countries. Despite this, the per capita number of fixed telephone lines in low-income countries was only 1.8 in 2000 compared with 58.2 in high-income countries. The growth rate of fixed telephone lines was higher in middle-income countries than in either low- or high-income countries, and per capita GDP growth was also higher for middle-income countries compared with low-income countries. Despite the differences in growth rates among the various income groups, for all groups—with the exception of high-income non-OECD countries—a positive and statistically significant correlation was demonstrated between telecommunications infrastructure and GDP growth (Table 2.2).

Some regional differences were evident. During 1980–2000, per capita GDP in the Asian and European regions grew at a higher rate than in the countries of other regions. African countries lagged behind, followed by the countries of South America. Asian countries displayed high per capita GDP growth, as well as attaining the highest per capita growth in the number of fixed telephone lines. African countries also achieved a high rate of growth in fixed telephony over the same period; nevertheless, in 2000, fixed line teledensity was only 3.6 in Africa compared with 19.2 in Asia. In South American countries the teledensity increased substantially over the 20-year period, reaching 14.1 in 2000. Although there are differences across regions, and with the exception of the Australian region, a high positive correlation exists between per capita GDP growth and per capita fixed telephony growth for all regions (Table 2.2).[4]

Figures 2.4a and 2.4b show the relationship between fixed line teledensity and per capita GDP for the years 1980 and 2000, respectively. In both figures,

4. When the four countries comprising the Australian region—two OECD countries (Australia and New Zealand) and two lower middle-income countries (Papua New Guinea and Fiji)—were separated into their income groups, the result produced a correlation coefficient that was positive, significant, and close to one.

FIGURE 2.4a Fixed telephone lines and per capita gross domestic product, 1980

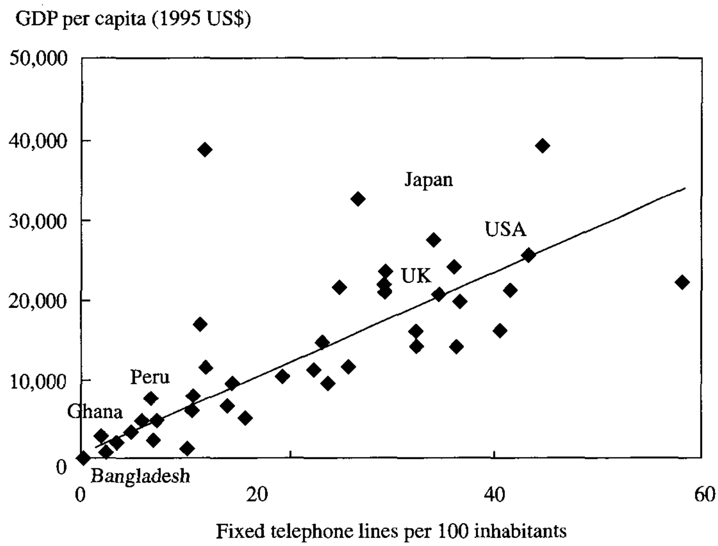
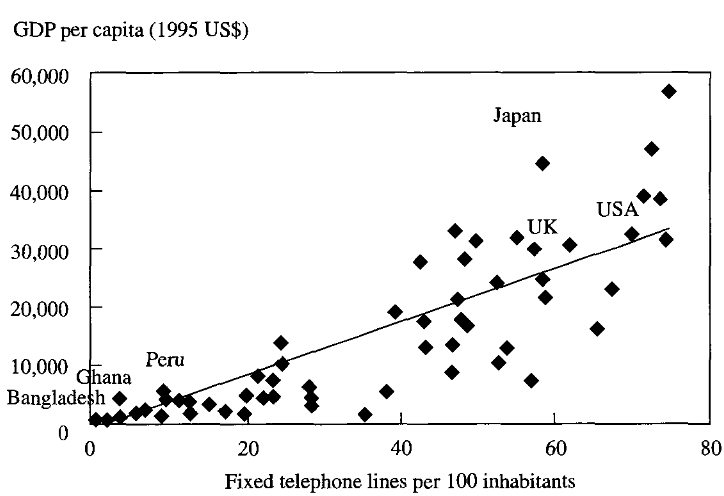


FIGURE 2.4b Fixed telephone lines and per capita gross domestic product, 2000



SOURCE: Calculated by authors from study data set.

per capita GDP expressed in constant 1995 U.S. dollars is the dependent variable, and fixed line teledensity is the independent variable. In 1980, there was a positive relationship between growth of fixed telephony and per capita GDP; a similar positive relationship was found to exist in 2000 as well. Although both per capita GDP and fixed line teledensity grew at different rates (1.1 percent per year and 6.2 percent per year, respectively), the relationship remained strong and positive over the period (Figures 2.4a and 2.4b).[5]

Because there are regional variations in the relative and absolute availability of ICT, as well as among income groups, additional figures detail regional subdivisions based on geographic and income classifications (see Appendix 2C). These supplementary figures show that the relationship between fixed line teledensity and per capita GDP has both regional and income characteristics. While the relationship is relatively weak for low-income countries, it is particularly strong for the lower middle-income and high-income non-OECD countries; in terms of regional groupings, the relationship is relatively high.[6]

As a means of assessing the relationship between the availability of modern forms of ICT and GDP, the relationship between per capita GDP and both PCs per 1,000 inhabitants and Internet users per 1,000 inhabitants was considered (Figures 2.5a and 2.5b). Given limited data availability, results are presented for the year 2000 only. The relationship between PCs per 1,000 inhabitants and per capita GDP is very strong and positive. A linear regression of per capita GDP on PCs per 1,000 inhabitants explains more than 85 percent variation in per capita GDP. Although weaker compared with the relationship to PCs, a positive relationship also exists between per capita GDP and the number of Internet users per 1,000 inhabitants. This regression explains about 73 percent of the variation in GDP.

Table 2.3 provides further evidence on the positive relationship between ICT availability and per capita GDP. In this instance, both traditional and modern forms of ICT are included (fixed and cellular telephones, the Internet, and PCs) for both income and regional groups. In addition, the bottom row of the table presents the combined relationships for the 113 sample countries. With the exception of fixed telephone lines, all the correlation coefficients are for the year 2000.

There is a positive relationship between teledensity and per capita GDP, and, with the exception of high-income non-OECD countries,[7] the correlation

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5. A simple linear regression of per capita GDP on fixed line teledensity explains 75 percent of the variation in per capita GDP in 1980 and 78 percent of the variation in per capita GDP in 2000.

6. A linear regression of per capita GDP on fixed line teledensity explains at least 70 percent of the variation in per capita GDP.

7. Among the eight countries in this group, Kuwait and United Arab Emirates are oil-rich countries that suffered from the decline of oil prices. The exclusion of these two countries would result in a correlation coefficient of 0.9.

FIGURE 2.5a Personal computers and per capita gross domestic product, 2000

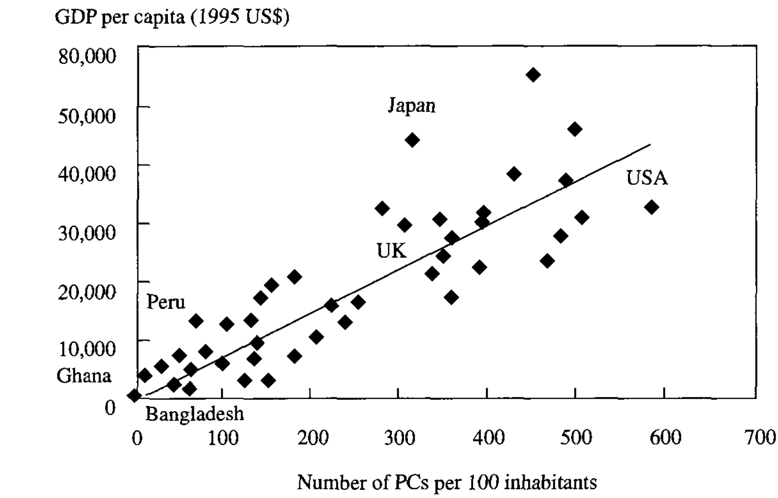
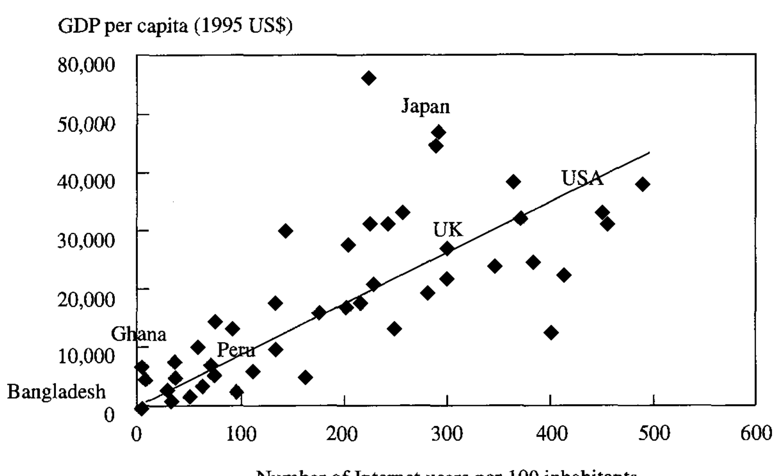


FIGURE 2.5b Internet users and per capita gross domestic product, 2000



SOURCE: Calculated by authors from study data set.

TABLE 2.3 Correlations between per capita gross domestic product and fixed telephone lines, cellular telephones, Internet hosts, and personal computers, 2000

	Correlation coefficients between GDP per capita and					
	Fixed telephone lines per 1,000 inhabitants		Cellular phones per 100 inhabitants	Internet users per 1,000 inhabitants	Internet hosts per 10,000 inhabitants	PCs per 1,000 inhabitants
Income/regional group	1980	2000				
Income group						
Low income (36)	0.34*	0.47**	0.52**	0.32	0.23	0.42*
Lower middle income (27)	0.35	0.22	0.15	0.52**	0.44*	0.57**
Higher middle income (21)	0.70**	0.56**	0.62**	0.66**	0.19	0.72**
High-income non-OECD (8)	–0.26	0.16	0.86**	0.89**	0.84**	0.87**
High-income OECD (21)	0.64**	0.66**	0.15	0.31	0.14	0.63**
Regional group						
Africa (40)	0.88**	0.86**	0.93**	0.86**	0.54**	0.87**
Asia (24)	0.71**	0.91**	0.84**	0.82**	0.90**	0.89**
Australia (4)	0.98**	0.98**	0.92	0.99**	0.96*	0.99**
Europe (23)	0.87**	0.83**	0.76**	0.73**	0.62**	0.91**
North America (13)	0.98**	0.87**	0.90**	0.96**	0.94**	0.97**
South America (9)	0.81**	0.84**	0.56	0.64	0.78*	0.76**
World, 113 countries	0.87**	0.89**	0.88**	0.86**	0.64**	0.93**

SOURCE: Calculated by authors from study data set.

NOTES: The number of countries within each category is shown in parentheses. For details of the countries within each category, see Appendix 2A. *Indicates significance at the 5 percent level; **indicates significance at the 1 percent level. GDP indicates gross domestic product; OECD, Organisation for Economic Co-operation and Development; PC, personal computer.

coefficients between fixed telephone lines and per capita GDP remained positive and significant for all income groups and for all geographic regions. In fact, for some income groups (such as the higher middle-income countries) and for all geographic regions, the correlation coefficient between fixed telephone lines and per capita GDP is very high, ranging from 0.56 to 0.98. Though there is a negative correlation between the CAGR of per capita GDP and the CAGR of fixed telephone lines for the Australian region, the correlation coefficient between per capita GDP and fixed line teledensity is as high as 0.98; it is also statistically significant both for 1980 and 2000. The correlation coefficient for all 113 countries is very high, at 0.87 in 1980 to 0.89 in 2000.

An important development in ICT in recent times is the tremendous surge in the penetration rate of cellular telephones. In fact, in the case of some low-income countries, the cellular penetration rate has surpassed that of fixed lines. Not surprisingly, a positive correlation exists between the growth rate of cellular telephones and per capita GDP. For low-income countries, the correlation is greater for cellular phones than for fixed line telephones; there is no observable pattern, however (that is, the correlation coefficient does not increase or decrease with the per capita GDP). In the case of regional groups, all regions show a strongly positive correlation between cellular phone penetration and per capita GDP—albeit at varying magnitudes. Similarly, a strongly positive correlation exists between cellular telephone penetration and per capita GDP for the world, represented by our 113-country sample.

Turning to more modern ICT, a similar pattern emerges. Similar to the relationship between fixed and cellular teledensity and per capita GDP, the availability of modern ICT—specifically, the Internet and personal computers—shows a strong correlation with per capita GDP. With the exception of the OECD countries, there is a correlation between GDP and Internet users and PCs, although the trend is stronger for high-income than for low-income countries. For the geographic regions, however, there is no observable trend. Among the different types of ICT, the strongest relationship exists between per capita GDP and the PC penetration rate. The correlation coefficients are significant for all income groups and all geographic regions; for Australia, the European and Central/North American regions, and the 113-country sample as a whole, the correlation coefficient is higher than 0.9.

Econometric Model and Empirical Results

To identify the effect of telecommunications on economic growth, we chose to adopt the model used by Röller and Waverman (2001), with two major differences. The first main difference is that we extend their database to include developing countries and not only 21 OECD counties, and second we correct our estimates for the presence of unit roots by estimating the model in first differences following the two-step Arrellano and Bond (1991, 1998) generalized method of moments (GMM) estimator. Appendix 2D provides further details on the model and the econometric techniques used.

Empirical Results

As discussed above, differencing the data and using Arellano and Bond's (1991, 1998) instrumentalization technique is the preferred estimation methodology, first because it may increase the efficiency of the parameters in terms of ordinary least squares (OLS) or GMM in levels, but most importantly because it tackles the problem of unit roots. Table 2.4 shows the results of the Phillips–Perron test for unit roots for GDP, capital, and the real investment in telecommunications infrastructure (TTI). The results clearly show the presence of unit roots in practically all the series for all the countries. It also shows how this problem is significantly reduced when differences are used instead of levels, and when the Hodrick–Prescott filter is applied to the series. From this result it is clear that OLS or even GMM estimates in levels (such as the ones carried out by Röller and Waverman 2001) may lead to spurious results.

Table 2.5 presents estimates of the output equation (1′) using different estimation methods. Equations (2′)–(4′) have been used to instrumentalize this equation (see Appendix 2D for details on the equations). Models (1)–(3) present the results for different estimation methods using the variables in levels, while models (4) and (5) present the results following Arrellano and Bond's (1991, 1998) dynamic panel data estimation. The presence of unit root problems results in an overestimation of the impact of the penetration rate on aggregate output. For example, if we use model 3, a 1 percent increase in the penetration rate is associated with a 0.11 percent increase in output. On the other hand, if we correct for the unit root problem using GMM with the data in first differences, the impact of the penetration rate on economic output is substantially smaller. In this sense, models (4) and (5) show that a 1 percent increase in the penetration increases economic output by 0.03 percent, which is clearly a more realistic coefficient.

Tables 2.6 through 2.9 show the results using Arrellano and Bond (1991, 1998) dynamic GMM techniques for each of the four equations outlined above. A regression for each income group is presented in each table. It should be emphasized that the focus of the empirical analysis is not the estimation of demand and supply relationships in the telecommunications industry but rather the impact of telecommunications infrastructure on economic development, and the best way to estimate this impact. In this respect, the results of the demand, supply, and production equations are inputs for the output equation.

From Table 2.6, it is clear that, although telecommunications penetration has a significant impact on output growth when we include all the countries in our sample, there are differences across regions. Consistent with the results of our simple regression analysis, the impact of telecommunications is statistically significant for lower and higher middle-income countries only, while it is

TABLE 2.4 Phillips–Perron test for unit roots by country

	Level			Differenced			Filtered[a]		
Country	GDP	TTI	KNT	GDP	TTI	KNT	GDP	TTI	KNT
1. Argentina	0.707	0.000	0.591	0.004	0.000	0.503	0.006	0.000	1.000
2. Australia	0.741	0.251	0.872	0.001	0.001	0.070	0.104	0.007	0.026
3. Austria	0.287	0.625	0.106	0.001	0.082	0.088	0.318	0.002	0.019
4. Bahrain	0.154	0.246	0.999	0.004	0.001	0.593	0.000	0.000	0.008
5. Bangladesh	0.430	0.167	0.844	0.000	0.000	0.333	0.039	0.000	0.865
6. Barbados	0.404	0.000	0.637	0.040	0.000	0.228	0.076	0.000	0.006
7. Belgium	0.395	0.451	0.570	0.000	0.000	0.182	0.142	0.000	0.113
8. Belize	0.571	0.000	0.945	0.103	0.000	0.660	0.102	0.000	1.000
9. Bolivia	0.965	0.688	1.000	0.035	0.149	1.000	0.053	1.000	1.000
10. Botswana	0.987	0.264	0.985	0.039	0.000	0.567	0.030	0.000	0.000
11. Bulgaria	0.637	0.811	0.998	0.509	0.003	0.582	0.004	0.000	0.000
12. Burkina Faso	0.004	0.093	0.495	0.000	0.002	0.743	0.000	0.000	0.000
13. Burundi	0.937	0.103	0.990	0.007	0.000	0.402	0.001	1.000	0.000
14. Cameroon	0.775	0.998	0.000	0.023	0.010	0.113	0.000	0.179	0.000
15. Chile	0.854	0.174	0.784	0.071	0.001	0.530	0.078	0.000	0.115
16. China	0.024	0.533	0.469	0.036	0.001	0.047	0.073	0.000	0.085
17. Colombia	0.602	0.225	0.659	0.140	0.000	0.541	0.024	0.000	0.000
18. Costa Rica	0.916	0.974	0.213	0.001	0.000	0.630	0.087	0.000	0.026
19. Côte d'Ivoire	0.416	0.413	0.998	0.025	0.000	0.591	0.003	0.000	1.000
20. Cyprus	0.846	0.339	0.967	0.000	0.000	0.043	0.000	0.004	0.000
21. Denmark	0.391	0.725	0.455	0.002	0.048	0.003	0.005	0.103	0.000
22. Ecuador	0.289	0.048	0.000	0.000	0.000	0.180	0.001	0.000	0.000
23. Egypt	0.001	0.284	0.012	0.004	0.069	0.000	0.001	0.000	0.000
24. Ethiopia	0.693	0.765	0.432	0.005	0.157	0.000	0.000	0.000	0.000
25. Fiji	0.037	0.048	0.000	0.000	0.000	0.016	0.000	0.015	0.000
26. Finland	0.765	0.405	0.002	0.344	0.042	0.000	0.319	0.057	0.000
27. France	0.233	0.507	0.707	0.077	0.167	0.094	0.565	0.133	0.003
28. Gabon	0.434	0.000	0.728	0.000		0.006	0.042	1.000	1.000
29. Gambia	0.070	0.006	0.822	0.000	0.000	0.072	0.051	0.000	0.000
30. Ghana	0.746	0.005	0.000	0.038	0.003	0.000	0.040	1.000	1.000
31. Greece	0.155	0.648	0.653	0.050	0.074	0.008	0.179	0.025	0.017
32. Hungary	0.625	0.621	0.011	0.144	0.003	0.454	0.248	0.000	0.000
33. India	0.222	0.214	0.969	0.000	0.003	0.001	0.008	0.033	0.077
34. Indonesia	0.967	0.580	0.986	0.015	0.000	0.014	0.004	0.002	0.002
35. Iran (Islamic Rep. of)	0.915	0.151	0.951	0.003	0.000	0.623	0.023	0.000	0.212
36. Ireland	0.999	0.465	0.562	0.067	0.202	0.347	0.979	0.008	0.175
37. Israel	0.436	0.073	0.280	0.070	0.000	0.000	0.041	0.001	0.002
38. Italy	0.118	0.581	0.998	0.047	0.160	0.217	0.032	0.004	0.000
39. Japan	0.969	0.624	0.940	0.013	0.034	0.444	0.023	0.008	0.001
40. Jordan	0.109	0.000	0.278	0.004	0.074	0.870	0.001	0.000	0.283
41. Kenya	0.908	0.374	0.003	0.064	0.000	0.018	0.006	0.000	0.000
42. Korea (Rep. of)	0.762	0.002	0.976	0.007	0.000	0.061	0.074	0.000	0.008
43. Kuwait	0.888	0.014	0.987	0.359	0.000	0.033	0.002	0.000	1.000
44. Lesotho	0.465	0.020	0.729	0.118	0.000	0.337	0.030	0.000	0.239

TABLE 2.4 *Continued*

	Level			Differenced			Filtered[a]		
Country	GDP	TTI	KNT	GDP	TTI	KNT	GDP	TTI	KNT
45. Luxembourg	0.913	0.691	0.431	0.003	0.001	0.000	0.571	0.003	0.001
46. Madagascar	0.843	0.768	0.875	0.001	0.005	0.406	0.011	1.000	1.000
47. Malawi	0.039	0.758	0.463	0.000	0.348	0.251	0.000	0.000	0.000
48. Malaysia	0.510	0.675	0.680	0.013	0.044	0.283	0.057	0.024	0.248
49. Mali	0.824	0.552	0.974	0.000	0.167	0.379	0.001	1.000	1.000
50. Malta	0.257	0.124	0.934	0.669	0.006	0.090	0.823	0.039	0.011
51. Mauritania	0.986	0.846	0.998	0.000	0.431	0.471	0.000	1.000	0.130
52. Mauritius	0.335	0.287	0.569	0.000	0.000	0.065	0.001	0.000	0.000
53. Mexico	0.602	0.690	0.568	0.000	0.000	0.494	0.000	0.004	0.004
54. Mongolia	0.562	0.000	0.008	0.608	0.000	0.671	0.001	0.000	0.000
55. Morocco	0.011	0.309	0.873	0.000	0.000	0.174	0.000	0.000	0.000
56. Nepal	0.575	0.443	1.000	0.000	0.060	0.625	0.000	0.000	0.146
57. Netherlands	0.987	0.824	0.223	0.014	0.103	0.012	0.668	0.123	0.058
58. New Zealand	0.468	0.854	0.770	0.008	0.205	0.541	0.048	0.003	0.005
59. Niger	0.440	0.164	0.858	0.011	0.000	0.070	0.012	1.000	1.000
60. Norway	0.223	0.839	0.419	0.078	0.000	0.000	0.127	0.000	0.010
61. Oman	0.741	0.002	0.528	0.087	0.000	0.630	0.044	0.000	1.000
62. Pakistan	0.999	0.922	0.918	0.000	0.282	0.002	0.000	0.000	1.000
63. Panama	0.560	0.611	0.618	0.033	0.124	0.558	0.012	0.001	0.016
64. Papua New Guinea	0.602	0.118	0.843	0.050	0.000	0.500	0.019	0.000	0.000
65. Paraguay	0.478	0.242	0.105	0.227	0.049	0.199	0.064	0.060	0.000
66. Peru	0.481	0.108	0.712	0.034	0.000	0.000	0.028	0.000	0.000
67. Philippines	0.327	0.564	0.971	0.219	0.044	0.080	0.139	0.000	0.087
68. Poland	0.493	0.954	1.000	0.149	0.000	1.000	0.000	0.000	1.000
69. Portugal	0.281	0.274	0.562	0.144	0.000	0.018	0.319	0.000	0.032
70. Romania	0.286	0.636	0.204	0.277	0.000	0.575	0.018	0.000	0.000
71. Rwanda	0.313	1.000	0.843	0.000		0.802	0.000	1.000	1.000
72. Senegal	0.600	0.225	0.869	0.000	0.001	0.000	0.000	0.000	0.000
73. Seychelles	0.231	0.000	0.891	0.000	0.000	0.103	0.000	1.000	1.000
74. Sierra Leone	0.837	0.000	0.000	0.000		0.000	0.000	1.000	1.000
75. Singapore	0.535	0.159	0.256	0.095	0.000	0.039	0.244	0.002	0.000
76. South Africa	0.399	0.620	0.276	0.011	0.014	0.129	0.008	0.004	0.000
77. Spain	0.902	0.752	0.419	0.105	0.282	0.577	0.799	0.043	0.027
78. Sri Lanka	0.779	0.027	0.000	0.012	0.000	0.944	0.710	0.000	0.000
79. Swaziland	0.499	0.613	0.093	0.137	0.000	0.142	0.002	0.025	0.004
80. Switzerland	0.594	0.515	0.673	0.031	0.001	0.009	0.100	0.003	0.002
81. Syria	0.692	0.875	0.008	0.000	0.002	0.627	0.001	0.001	0.000
82. Thailand	0.967	0.453	0.437	0.472	0.000	0.536	0.093	0.000	0.000
83. Togo	0.151	0.552	0.446	0.000	0.406	0.783	0.001	0.061	0.000
84. Trinidad and Tobago	0.262	0.700	0.100	0.001	0.160	0.838	0.000	0.000	0.514
85. Tunisia	0.160	0.496	0.562	0.000	0.000	0.120	0.065	0.000	0.061
86. Turkey	0.290	0.540	0.778	0.000	0.002	0.000	0.001	0.013	0.001
87. Uganda	0.580	0.191	0.004	0.230	0.248	0.000	0.000	1.000	1.000

(continued)

TABLE 2.4 *Continued*

Country	Level GDP	Level TTI	Level KNT	Differenced GDP	Differenced TTI	Differenced KNT	Filtered[a] GDP	Filtered[a] TTI	Filtered[a] KNT
88. United Arab Emirates	0.383	0.539	0.000	0.074	0.000	0.163	0.001	0.000	0.000
89. United Kingdom	0.583	0.221	0.853	0.221	0.215	0.476	0.363	0.011	0.030
90. United States	0.907	0.352	0.914	0.040	0.069	0.001	0.465	0.079	0.238
91. Uruguay	0.747	0.007	0.569	0.167	0.000	0.745	0.115	0.000	0.314
92. Venezuela	0.517	0.572	0.324	0.002	0.092	0.000	0.002	0.000	0.000
93. Yemen	0.956	0.437	1.000	0.000	0.999	0.013	1.000	1.000	1.000
94. Zambia	0.084	0.000	0.149	0.000	0.136	0.000	0.001	0.000	0.000
95. Zimbabwe	0.342	0.523	0.858	0.066	0.021	0.038	0.030	0.799	0.000

SOURCE: Compiled and calculated by authors from study data set.

NOTES: The figures report MacKinnon approximated *p*-values to test for the presence of unit roots in the Phillips–Perron test. The null hypothesis indicates that the variable contains a unit root; the alternative is that the variable was generated by a stationary process. *P*-values larger than 0.1 mean that the Phillips–Perron test lies inside the acceptance region at 1, 5, and 10 percent; hence we cannot reject the presence of unit roots. GDP indicates gross domestic product; KNT, stock of capital net telecommunication; TTI, telecommunications infrastructure.

[a]Hodrick–Prescott filter.

not significant for OECD and high-income non-OECD countries or for low-income countries.

This result is consistent with the idea that high-income countries have reached a critical mass of telecommunications infrastructure, so marginal increases in telecommunications infrastructure have limited impact on output. In direct contrast, telecommunications infrastructure is expanding in lower and higher middle-income countries, and this has a positive effect on aggregate output. Finally, for low-income countries, our results indicated no impact on aggregate output from telecommunications infrastructure. On a technical note, Sargan's test of overidentifying restrictions does not reject the validity of instruments when we subdivide the countries by income groups.

This differentiated result across income groups could be reflecting the characteristic of network externalities. As mentioned in several studies, an implication of network externalities is that the impact of telecommunications infrastructure on growth may not be linear. The piecewise linear regressions presented here show that in poor countries lacking a critical mass of telecommunications infrastructure (the mean penetration rates for this group of countries is 0.58 percent), marginal increases in the penetration rate do not spark economic growth. On the other hand, in lower and higher middle-income countries, where mean penetration rates range from 5 to 11 percent, telecommunications infrastructure has a positive and statistically significant impact on aggregate output. In OECD and other high-income countries, where penetration rates are about 40 percent (which may be considered universal coverage), the effect is muted. These results are contradictory to the results reported in

TABLE 2.5 Output equation

Dependent variable: $\log(\text{GDP})_{it}$	Two-stage least squares (1)	Three-stage least squares (2)	Generalized method of moments-IV (3)	A-bond dynamic panel data[a] (4)	(5)
$\log(\text{GDP})_{i(t-1)}$	—	—	—	0.793	0.959
				(38.11)**	(27.87)**
$\log(\text{GDP})_{i(t-2)}$	—	—	—	—	−0.188
					(7.20)**
$\log(\text{PEN})_{it}$	0.113	0.173	0.113	0.033	0.033
	(9.87)**	(18.78)**	(9.57)**	(3.33)**	(2.96)**
$\log(\text{KNT})_{it}$	0.468	0.370	0.468	0.028	0.057
	(29.41)**	(27.51)**	(28.52)**	(1.96)*	(3.68)**
$\log(\text{TLF})_{it}$	0.061	0.114	0.061	−0.004	−0.009
	(2.89)**	(6.43)**	(2.81)**	(0.41)	(0.73)
Trend	0.008	0.009	0.008	—	—
	(9.58)**	(13.76)**	(9.29)**		
Constant	5.188	6.769	4.135	0.003	0.003
	(10.66)**	(16.55)**	(8.69)**	(6.36)**	(5.68)**
Number of observations	1,655	1,655	1,655	1,639	1,596
Number of countries	95	95	95	95	95
R^2	0.9983	0.9982	0.9669		
Sargan test	88.818**			816.70**	687.57**

SOURCE: Compiled and calculated by authors from study data set.

NOTES: Absolute values of z statistics are shown in parentheses. All models include fixed effects. *Indicates significance at the 5 percent level; **indicates significance at the 1 percent level. GDP indicates gross domestic product; KNT, stock of capital net telecommunication; PEN, penetration rate; TLF, total labor force.

[a] Generalized method of moments estimates, all variables in first differences. The estimations underlying the results in columns (4) and (5) differ slightly in the variables used.

Röller and Waverman (2001), who find a strong causal link between telecommunications infrastructure and economic output in OECD countries. It is possible that their results were driven by the presence of unit roots in the GDP, the investment in telecommunications infrastructure, and the nonresidential capital stock net of telecommunications capital.

Turning to the demand, supply, and production equations, all of which are used as instruments for the output equation, most of the estimated coefficients display the expected indications and are statistically significant. For the demand equation shown in Table 2.7, the effective demand is inversely related to telephone price for the full sample. There are differences in this effect across income groups, but for the three lowest income groups the price effect is negative.

TABLE 2.6 Output equation—generalized method of moments estimates (all variables in first differences)

Dependent variable: $\log(\text{GDP})_{it}$	All countries	OECD	OECD and high non-OECD	Higher middle-income	Lower middle-income	Low-income
$\log(\text{GDP})_{i(t-1)}$	0.959	1.34	1.24	1.054	1.046	0.952
	(27.87)**	(29.37)**	(29.11)**	(19.90)**	(19.06)**	(18.41)**
$\log(\text{GDP})_{i(t-2)}$	–0.188	–0.382	–0.39	–0.24	–0.339	–0.115
	(7.20)**	(7.96)**	(8.85)**	(4.69)**	(6.46)**	(2.29)**
$\log(\text{PEN})_{it}$	0.033	0.012	0.015	0.064	0.032	0.017
	(2.96)**	(1.16)	(0.91)	(3.98)**	(2.36)*	(1.24)
$\log(\text{KNT})_{it}$	0.057	–0.033	0.074	0.016	0.073	0.031
	(3.68)**	(1.53)	(2.62)**	(0.82)	(6.07)**	(1.41)
$\log(\text{TLF})_{it}$	–0.009	–0.045	–0.008	0.211	0.211	–0.018
	(0.73)	(1.07)	(0.27)	(4.49)**	(4.46)**	(1.50)
Constant	0.003	0.002	0.002	–0.004	–0.005	0.003
	(5.68)**	(2.69)**	(2.45)*	(2.79)**	(3.35)**	(2.67)**
Number of observations	1,596	395	518	321	372	385
Number of countries	95	19	26	20	21	28
Sargan test	687.57**	326.81	400.31	363.27	365.54	371.98

SOURCE: Compiled and calculated by authors from study data set.

NOTES: Absolute values of z statistics are shown in parentheses. In all models, PEN is instrumentalized according to models of equations (2′)–(4′). *Indicates significance at the 5 percent level; **indicates significance at the 1 percent level. GDP indicates gross domestic product; KNT, stock of capital net telecommunications; OECD, Organisation for Economic Co-operation and Development; PEN, penetration rate; TLF, total labor force.

Moreover, the elasticity is less than one, implying inelastic demand for telecommunications. This result is consistent with many other studies, such as those of Doherty (1984), Zona and Jacob (1990), Duncan and Perry (1994), Levy (1996), Gatto, Kelejian, and Stephan (1988), Gatto et al. (1988), and Pascó-Font, Gallardo, and Fry (1999).[8]

Demand for telecommunications infrastructure is positively correlated with income, and income elasticity is considerably higher than the price elasticity.

With respect to the supply equation, neither geographic area nor government surplus (deficit) is significant in explaining telecommunications investment. Although government surplus has the expected positive indication—implying that telecommunications infrastructure investment would be positively

8. These studies found elasticities ranging from –0.21 to –0.475. See Pascó-Font, Gallardo, and Fry (1999) for further details.

TABLE 2.7 Demand equation—generalized method of moments estimates, all variables in first differences

Dependent variable: $\log(\text{PEN+WL})_{it}$	All countries	OECD	OECD and high-income non-OECD	Higher middle-income	Lower middle-income	Low-income
$\log(\text{PEN+WL})_{i(t-1)}$	0.729	0.944	0.925	0.820	0.695	0.649
	(37.76)**	(160.60)**	(139.07)**	(31.18)**	(20.23)**	(20.12)**
$\log(\text{GDP/POP})_{it}$	0.636	0.021	0.017	0.123	0.618	0.234
	(14.99)**	(10.78)**	(5.75)**	(3.33)**	(9.60)**	(3.20)**
$\log(\text{TELP})_{it}$	−0.035	0.425	2.048	−0.035	−0.030	−0.080
	(3.07)**	(0.13)	(0.32)	(2.20)*	(1.31)	(3.28)**
Constant	0.001	0.000	0.001	0.007	0.013	0.020
	(0.51)	(0.01)	(3.18)**	(3.39)**	(5.44)**	(6.56)**
Number of observations	1,366	451	597	266	288	346
Number of countries	95	19	26	20	21	28
Sargan test	882.82**	862.11**	663.75**	435.86	519.01	507.75

SOURCE: Compiled and calculated by authors from study data set.

NOTES: Absolute values of *z* statistics are shown in parentheses. *Indicates significance at the 5 percent level; **indicates significance at the 1 percent level. GDP indicates gross domestic product; OECD, Organisation for Economic Co-operation and Development; PEN, penetration rate; POP, population; TELP, total labor force in millions; WL, waiting list for fixed lines per capita.

affected by a government surplus—this result is not significant in any of the regressions. As expected, the waiting list for fixed lines (per capita) is positively related to the supply of telecommunications infrastructure, suggesting that countries with excess demand tend to invest more in telecommunications infrastructure. Finally, price is positively correlated with investment in telecommunications infrastructure.

The last table reported, Table 2.9, showed the production function, relating investment to penetration rates. As expected, the relationship is positive and significant for the panel of all countries and across all income groups, with the exception of low-income countries. The elasticity is about 0.024, indicating that a one-time 10 percent increase in investment would result in about a 0.2 percent increase in the penetration rate. This is consistent with observations in historic series. Although the geographic area is not significant, this could be because the lagged penetration rate could already be incorporating this effect.

Conclusion

While the empirical approach presented in this chapter mirrors the work of Röller and Waverman (2001), some notable differences exist. Unlike those

TABLE 2.8 Supply equation—generalized method of moments estimates, all variables in first differences

Dependent variable: $\log(\text{TTI})_{it}$	All countries	OECD	OECD and high-income non-OECD	Higher middle-income	Lower middle-income	Low-income
$\log(\text{TTI})_{i(t-1)}$	0.261	0.635	0.626	0.152	0.344	0.394
	(6.82)**	(19.30)**	(17.86)**	(2.50)*	(6.30)**	(5.35)**
WL_{it}	0.104	0.024	–0.005	0.094	0.110	0.076
	(3.56)**	(2.20)*	(0.43)	(2.35)*	(3.55)**	(0.27)
$\log(\text{GA})_{it}$	–238.924	–96.720	31.892	—	—	—
	(0.48)	(0.99)	(0.22)	—	—	—
GD_{it}	0.000	0.000	0.000	0.000	0.000	0.000
	(0.11)	(0.44)	(0.39)	(1.44)	(1.23)	(0.52)
$\log(\text{TELP})_{it}$	0.116	0.477	0.075	0.654	–0.062	0.115
	(2.21)*	(7.58)**	(3.64)**	(3.77)**	(0.47)	(0.62)
Constant	0.047	0.000	0.018	0.053	0.062	0.023
	(9.90)**	(0.00)	(6.19)**	(5.65)**	(5.30)**	(1.99)*
Number of observations	889	290	365	200	189	135
Number of countries	83	19	24	19	20	20
Sargan test	495.63	383.14	421.97	205.16	272.86	154.96

SOURCE: Compiled and calculated by authors from study data set.

NOTES: Absolute values of *z* statistics are shown in parentheses. *Indicates significance at the 5 percent level; **indicates significance at the 1 percent level. GA indicates geographic area in thousands of square kilometers; GD, goverment surplus (deficit) in billions of U.S. dollars; OECD, Organisation for Economic Co-operation and Development; TELP, total labor force in millions; TTI, telecommunications infrastructure; WL, waiting list for fixed lines per capita.

of Röller and Waverman (2001), our estimates are corrected for the presence of unit roots. Estimates based on the entire set of countries indicated a positive causal relationship between telecommunications infrastructure and GDP. These estimates suggested that a 1 percent increase in the telecommunications penetration rate could be expected to lead to a 0.03 percent increase in GDP. Piecewise regression models for different country groups revealed a nonlinear effect of telecommunications infrastructure on economic output. The impact was particularly pronounced for lower and higher middle-income countries and was muted for other country groups. These results imply that telecommunications networks need to reach a critical mass, or threshold level, of connectivity before impact on economic output is discernible. Of note, growth effects were strongest for telecommunications penetration rates of between 5 and 15 percent. Outside this range, growth effects were limited.

TABLE 2.9 Production equation—generalized method of moments estimates, all variables in first differences

Dependent variable: $\log(\text{PEN})_{it}$	All countries	OECD	OECD and high-income non-OECD	Higher middle-income	Lower middle-income	Low-income
$\log(\text{PEN})_{i(t-1)}$	0.941	0.944	0.883	0.916	0.971	0.885
	(119.56)**	(160.60)**	(61.59)**	(81.08)**	(87.08)**	(47.38)**
$\log(\text{TTI})_{it}$	0.024	0.021	0.013	0.038	0.046	0.005
	(7.27)**	(10.78)**	(3.02)**	(9.95)**	(10.33)**	(1.10)
$\log(\text{GA})_{it}$	−1.91	0.425	—	−294.542	0.000	0.000
	(0.13)	(0.13)		(0.56)		
Constant	0.002	0.000	0.010	0.003	0.002	0.011
	(3.64)**	(0.01)	(8.39)**	(3.20)**	(2.14)*	(6.99)**
Number of observations	1,671	451	724	350	379	345
Number of countries	95	19	49	20	21	28
Sargan test	984.73**	862.11**	648.38**	483.67	485.22	482.14

SOURCE: Compiled and calculated by authors from study data set.

NOTES: Absolute values of z statistics are shown in parentheses. *Indicates significance at the 5 percent level; **indicates significance at the 1 percent level. GA indicates geographic area in thousands of square kilometers; OECD, Organisation for Economic Co-operation and Development; PEN, penetration rate; TTI, telecommunications infrastructure.

While there are some similarities between the results presented here and those of Röller and Waverman (2001), some differences also exist. Röller and Waverman (2001) report a similar positive relationship, but their estimate of the impact of telecommunications infrastructure on economic output is about 50 percent larger than our estimate (0.045 versus 0.03). They also report a critical mass for telecommunications infrastructure, estimating the level to be close to a universal penetration rate of about 40 percent, and suggest that growth effects are strongest in OECD countries. While we also detect a critical mass, our results suggest that this threshold is reached at a much lower penetration level and that growth effects are strongest for countries in the low- and middle-income categories.

Notwithstanding these differences, considering that the average telecommunications penetration rate in low-income countries is below 1, our estimates imply that developing countries need continued investment in their telecommunications networks if they are to reap positive growth effects. Marginal improvements in telecommunications infrastructure are unlikely to yield discernible growth effects. Moreover, given the even lower penetration level of other forms of ICT, growth effects will remain elusive without widespread increases in access to these technologies in low-income countries.

Appendix 2A: Additional Data Set Details

See tables on pages 49–53.

Appendix 2B: Construction of Physical Capital Stock and Telecommunications Capital Stock

The telecommunications capital stock is constructed using PIM, which may be represented by the following equation:

$$K_t = (1 - \delta)^t K(0) + \sum_{i=0}^{t-1} I_{t-i}(1 - \delta)^i. \tag{1}$$

In this equation, K_t is the stock of capital at time t, δ is the rate of depreciation, $K(0)$ is the initial stock of capital in period 0, and I_{t-i} is investment. Since we did not know the initial stock of telecommunications capital, we estimated the initial stock using

$$K_{t-1} = I_t/(g + \delta), \tag{2}$$

where g is the growth rate of fixed telephone lines. For the stock of telecommunications capital, we used the growth rate of fixed telephone lines. Following Röller and Waverman (2001) we used a three-year average for investments in telecommunications and growth in fixed telephone lines and adopted a 10 percent rate of depreciation for capital. Given the high depreciation rate for telecommunications capital, the initial stock plays only a minor role in the 1990s.

To construct the physical capital stock series, we built on the work by Nehru and Dhareshwar (1993), who provide a data set on physical capital stock for a group of 92 developing and industrial countries covering the period 1960–90. Following their methodology, and using data on gross domestic fixed investment from the World Bank (2002), we extended the physical capital stock series to cover, as far as possible, the period 1980–2000 and the 113 countries in our data set. We employed the same measure for constructing the initial stock of physical capital for the countries for which data on output growth and gross domestic fixed investment were available. For construction of the stock of physical capital we used PIM and adopted a rate of depreciation of 4 percent for all countries. To avoid short-term variations in growth in aggregate output and investment, we used a three-year average for investment and output following Harberger (1978).

TABLE 2A.1 Countries included in the study

Country income group	Regional groupings[a]					
	African region	Asian region	Australian region	European region	Central and North American region, including Caribbean	South America
Low-income	Benin Burkina Faso Burundi Cameroon Central African Republic Comoros Congo Côte d'Ivoire Ethiopia Gambia Ghana Kenya Lesotho Madagascar Malawi	Bangladesh India Indonesia Mongolia Nepal Pakistan Yemen			Nicaragua	

(continued)

TABLE 2A.1 *Continued*

	Regional groupings[a]					
Country income group	African region	Asian region	Australian region	European region	Central and North American region, including Caribbean	South America
	Mali					
	Mauritania					
	Mozambique					
	Niger					
	Nigeria					
	Rwanda					
	Senegal					
	Sierra Leone					
	Tanzania					
	Togo					
	Uganda					
	Zambia					
	Zimbabwe					
Lower middle-income	Algeria	China	Fiji	Bulgaria	Belize	Bolivia
	Cape Verde	Iran	Papua New Guinea	Romania	El Salvador	Colombia
	Egypt	Jordan			Honduras	Ecuador
	Morocco	Philippines			Jamaica	Paraguay
	Namibia	Sri Lanka				Peru
	Swaziland	Syria				
	Tunisia	Thailand				

Higher middle-income	Botswana Gabon Mauritius Seychelles South Africa	Bahrain Korea, Republic of Malaysia Oman		Hungary Poland Turkey	Costa Rica Mexico Panama Saint Kits Trinidad Barbados	Argentina Chile Uruguay Venezuela
High-income non-OECD		Hong Kong Israel Kuwait Singapore United Arab Emirates		Cyprus Malta		
OECD (high-income)		Japan	Australia New Zealand	Austria Belgium Denmark Finland France Greece Ireland Italy Luxembourg Netherlands Norway Portugal Spain Sweden Switzerland United Kingdom	Canada United States	

NOTE: OECD indicates Organisation for Economic Co-operation and Development.

[a]Regional groupings are based on world development indicators categories (World Bank 2002).

TABLE 2A.2 Variables and summary statistics for different income groups

	Income groups				
Variable	Low-income	Lower middle-income	Higher middle-income	High-income non-OECD	OECD
GDP (million 1995 U.S. dollars)	15,755.73	35,727.42	68,404.39	33,132.12	752,551.27
	(49,554.76)	(92,365.61)	(101,965.25)	(35,844.59)	(1,445,354.68)
Total labor force (millions)	38.19	27.18	6.30	1.21	26.25
	(123.06)	(112.88)	(8.41)	(0.99)	(34.05)
Total physical capital stock	41,855.14	94,706.70	183,438.61	89,215.31	2,180,765.34
(million 1995 U.S. dollars)	(121,767.55)	(203,262.88)	(247,650.52)	(94,773.50)	(4,064,327.04)
Annual investment in telecommunications	2,166.63	2,798.31	6,028.50	2,131.78	67,653.58
(million 1995 U.S. dollars)	(5,857.52)	(9,199.73)	(9,978.45)	(2,672.64)	(134,908.30)
Land area	559.85	815.71	500.43	16.70	1,430.49
(1,000 square kilometers)	(619.05)	(1,765.74)	(697.60)	(26.48)	(2,992.91)
Government budget surplus (deficit)	–985.72	–781.10	–1,833.62	135.19	–25,797.30
(million 1995 U.S. dollars)	(3,313.11)	(1,909.74)	(4,852.64)	(3,967.68)	(53,174.59)
Fixed telephone lines per 100 inhabitants	0.58	4.70	10.87	28.47	41.75
	(0.67)	(5.21)	(9.34)	(14.88)	(14.90)

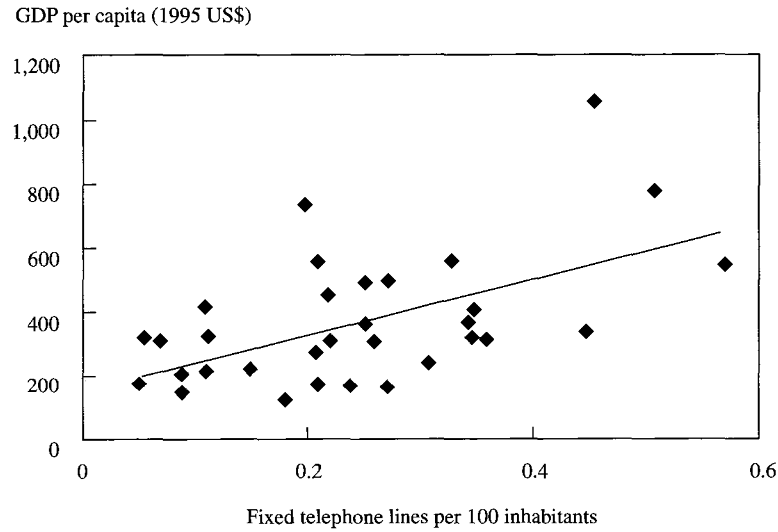
Cellular phone subscribers per 100 inhabitants	0.11	0.78	2.63	8.05	9.57
	(0.51)	(2.56)	(7.55)	(17.15)	(19.37)
Telephone service revenue per fixed line	995.48	667.79	791.89	28,335.73	648.76
(1995 U.S. dollars)	(642.18)	(516.73)	(632.76)	(162540.96)	(216.80)
Telephone service revenue per cellular line	701.33	609.23	977.35	1,172.61	1,079.01
(1995 U.S. dollars)	(1,957.44)	(487.91)	(976.53)	(1,188.79)	(1,174.86)
Waiting list for fixed lines per 100 inhabitants	0.28	1.98	1.58	1.52	0.63
	(0.41)	(3.01)	(1.71)	(2.20)	(1.63)
Internet users per 1,000 inhabitants	1.28	8.42	31.17	85.59	112.25
	(2.66)	(15.97)	(61.41)	(112.47)	(138.20)
Internet hosts per 10,000 inhabitants	0.06	0.86	8.57	41.25	208.38
	(0.27)	(3.15)	(24.23)	(95.79)	(403.95)
Personal computers per 1,000 inhabitants	3.31	17.63	44.12	126.05	184.81
	(3.67)	(19.89)	(45.69)	(106.70)	(138.17)

SOURCES: Data on 1995 GDP, total labor force, annual investment, land area, and government budget surplus (deficit) are from World Bank (2002); data on total physical capital stock and annual investment in telecommunications are from Nehru and Dhareshwar (1993) and authors' estimations based on World Bank (2002); data on fixed telephone lines, cellular telephones, the Internet, and personal computers are from ITU (2002).

NOTES: Standard deviations are shown in parentheses. GDP indicates gross domestic product; OECD, Organisation for Economic Co-operation and Development.

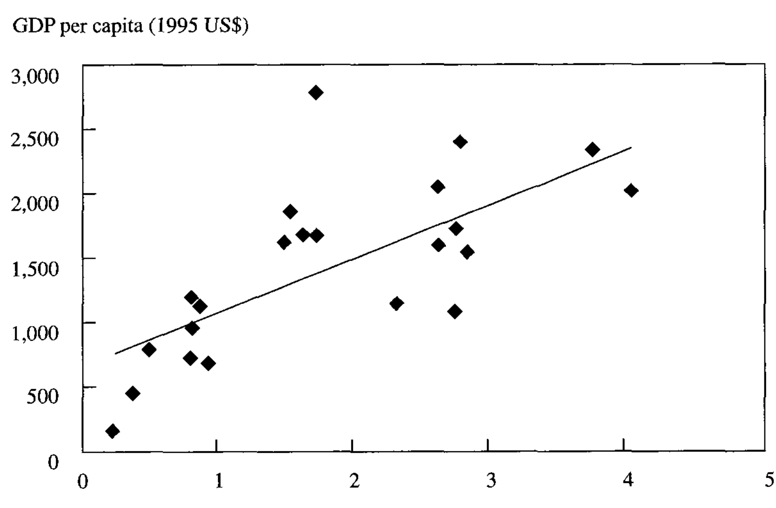
Appendix 2C: Supplementary Figures

FIGURE 2C.1 Fixed telephone lines and gross domestic product in low-income countries, 1980



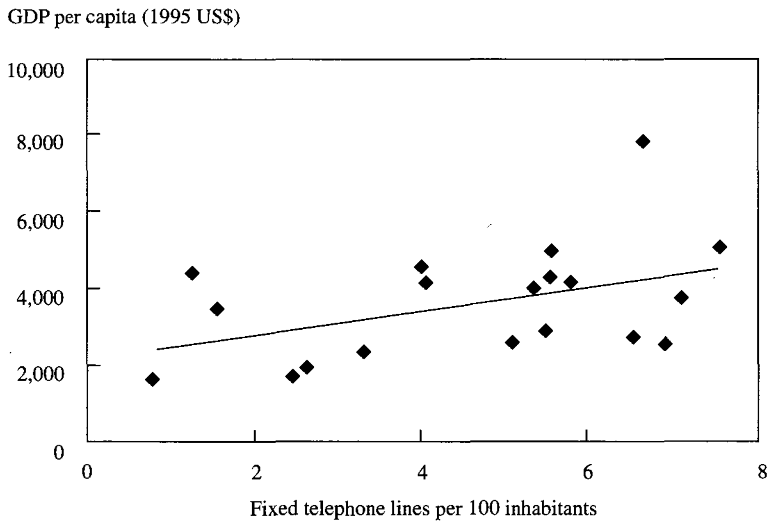
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.2 Fixed telephone lines and gross domestic product in lower middle-income countries, 1980



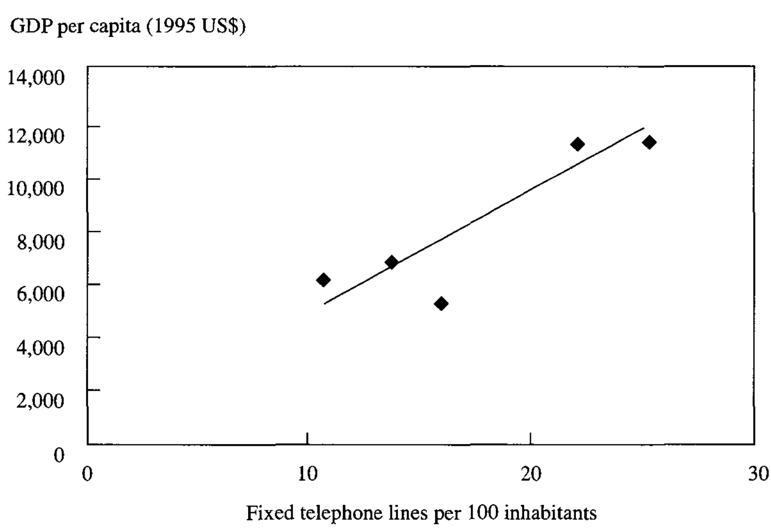
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.3 Fixed telephone lines and gross domestic product in higher middle-income countries, 1980



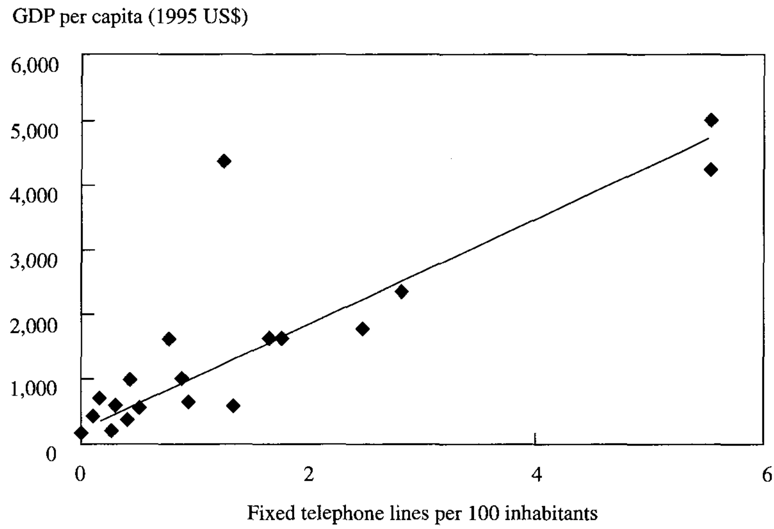
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.4 Fixed telephone lines and gross domestic product in non–Organisation for Economic Co-operation and Development countries, 1980



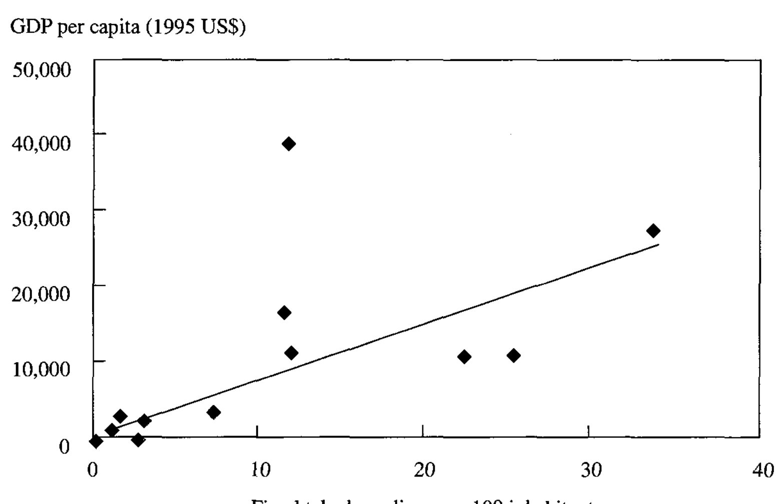
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.5 Fixed telephone lines and gross domestic product in Africa, 1980



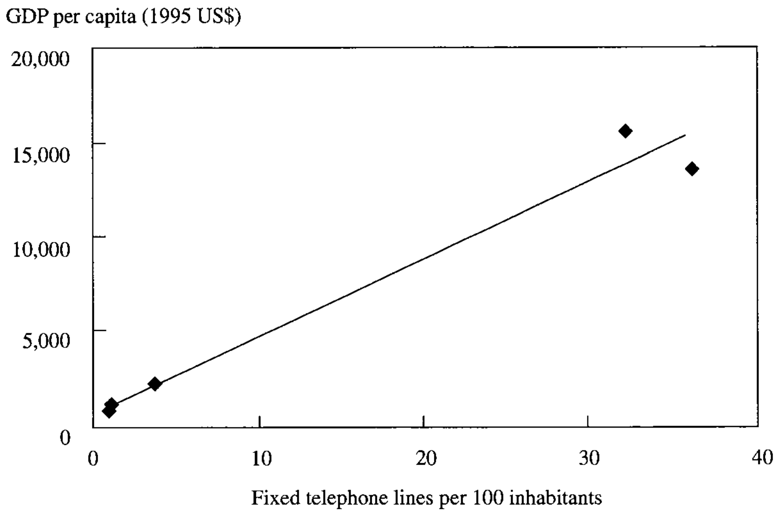
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.6 Fixed telephone lines and gross domestic product in the Asian region, 1980



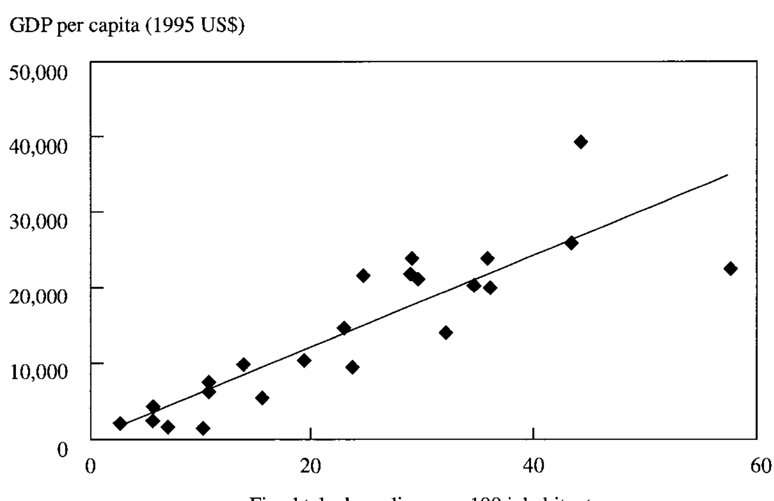
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.7 Fixed telephone lines and gross domestic product in the Australian region, 1980



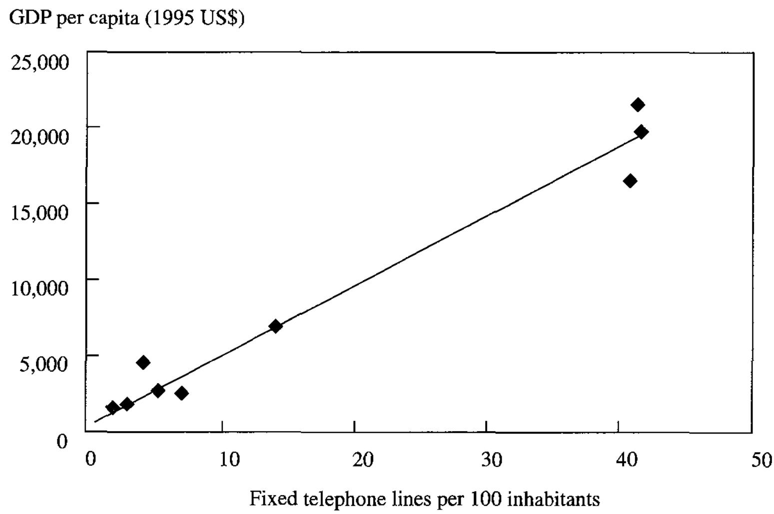
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.8 Fixed telephone lines and gross domestic product in the European region, 1980



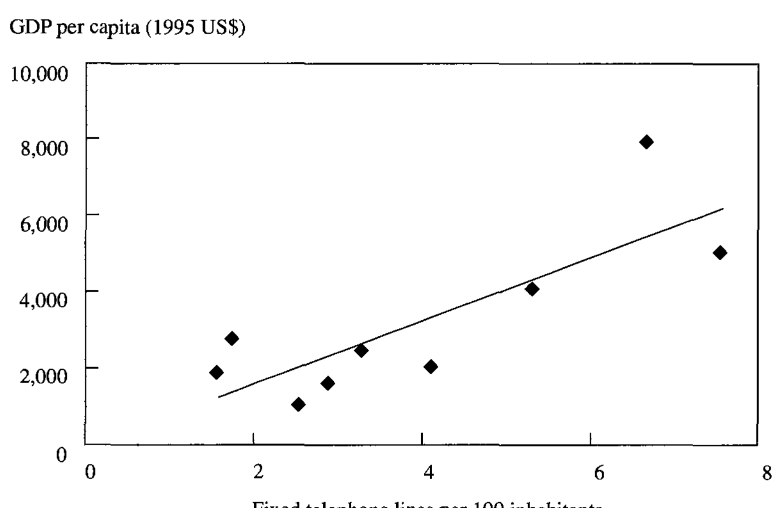
SOURCE: Calculated by authors from the study data set.

FIGURE 2C.9 Fixed telephone lines and gross domestic product in the Central and North American region, including the Caribbean, 1980



SOURCE: Calculated by authors from the study data set.

FIGURE 2C.10 Fixed telephone lines and gross domestic product in South America, 1980



SOURCE: Calculated by authors from the study data set.

Appendix 2D: Econometric Model and Empirical Results

Econometric Model

The Röller and Waverman (2001) four-equation system consists of an aggregate production function equation in which the coefficient on *TELECOM* estimates the one-way causal relationship between the stock of telecommunications, measured through the penetration rate, and economic output:

$$GDP_{it} = f(K_{it}, HK_{it}, TELECOM_{it}, t). \tag{1}$$

This equation is empirically estimated as follows:

$$\log(GDP_{it}) = a_{0i} + a_1 \log(K_{it}) + a_2 \log(TLF_{it}) + a_3 \log(PEN_{it}) + a_4 t + u^1_{it}, \tag{1'}$$

where *GDP* is the real gross domestic product, *K* is a measure of the real capital stock net of telecommunication capital as mentioned in the data section. *TLF* is the total labor force, which is a proxy for human capital, and *t* is a linear time trend. The variable *PEN,* that is, the penetration rate, is defined by the number of fixed lines per hundred inhabitants. This variable is a proxy for the stock of telecommunications infrastructure (*TELECOM*).

The demand for telecommunications infrastructure is treated as a function of per capita GDP and the price of telephone service:

$$TELECOM_{it} = h(GDP_{it}/POP_{it}, TELP_{it}). \tag{2}$$

Given that the objective is to measure the demand for telecommunications, in this equation *TELECOM* is approximated by the sum of the penetration rate and the waiting list per hundred habitants (*WL*). The price for telephone service is approximated by the total service revenue per fixed line (*TELP*) and per capita GDP measures income. The empirical counterpart of (2) is given by

$$\log(PEN_{it} + WL_{it}) = b_0 + b_1 \log(GDP_{it}/POP_{it}) + b_2 \log(TELP_{it}) + u^2_{it}. \tag{2'}$$

The third equation corresponds to the supply of telecommunications investment. It is treated as a function of the price of telephone service (*TELP*) and other variables specific to the country:

$$TTI_{it} = g(TELP_{it}, Z_{it}). \tag{3}$$

The empirical counterpart of this equation is given as:

$$\log(TTI_{it}) = c_0 + c_1 \log(GA_{it}) + c_2 GD_{it} + \log(TELP)_{it} + u^3_{it}, \tag{3'}$$

where (as in the demand equation) service revenue per fixed line is used as a proxy for price. The scale of the country and the economic well-being of the country is measured by the geographic area in thousands of square kilometers (*GA*) and the government surplus (deficit) in billions of 1985 U.S. dollars (*GD*), respectively.

Finally the telecommunications infrastructure production function measures the relationship between investment in telecommunications infrastructure and the change in the stock of telecommunications infrastructure:

$$TELECOM_{it} - TELECOM_{i,t-1} = (TTI_{it}, R_{it}). \tag{4}$$

To empirically estimate this equation, the change in the stock of telecommunications is approximated by the change in penetration as a function of investment in telecommunications infrastructure and the geographic area:

$$\log(PEN_{it}/PEN_{t,t-1}) = d_0 + d_1 \log(TTI_{it}) + d_2 \log(GA_{it}) + u^4_{it}. \tag{4'}$$

Since Equations (2)–(4) involve the demand for and supply of telecommunications infrastructure, they endogenize telecommunications infrastructure. All four equations may be estimated as a system or using a two-step estimation procedure.

Röller and Waverman (2001) estimate the empirical model outlined above using variables in levels, and with and without country-level fixed effects. An issue that Röller and Waverman do not take into account is that variables such as GDP and capital may follow a random walk. If these variables do follow a random walk, then a regression of one on the other may lead to spurious results. De-trending the variables before running the regression may not help because the de-trended series may still be nonstationary. It is likely that only first-differencing will yield stationary series.

We attempt to solve this problem by estimating equations in first differences, and in our empirical work we assume that the error terms in the four equations follow an error component model,

$$u_{it} = \mu_i + v_{it}, \tag{5}$$

where $\mu \sim \mathrm{IID}(0, \sigma^2\mu)$ and $v_{it} \sim \mathrm{IID}(0, \sigma^2 v)$ are independent of each other and represent unmeasured time-invariant country and country/year effects, respectively. Given this error structure, lagged values of the dependent variable (let's call the generic dependent variable Y[9]) will be correlated with the error terms in equations (1)–(4). Even though the first difference transformation mitigates this correlation problem by eliminating the individual effect, μ_i, OLS estimation of the differenced model would also be inconsistent because now ΔY_{it-1} and Δv_{it} are correlated (given that Y_{it-1} and u_{it-1} are correlated). Anderson and Hsiao (1981) observed that as long as u_{it} is not serially correlated, ΔY_{it-2} (which depends on the second and further lags of u_{it}) is clearly correlated with ΔY_{it-1} but not with Δv_{it} (which only depends on v_{it} and v_{it-1}). Therefore, ΔY_{it-2} is a valid instrument for ΔY_{it-1} and may be used to estimate the model consistently.

9. *Y* represents the four dependent variables in the four equations: $\log(GDP)$, $\log(PEN + WL)$, $\log(TTI)$ and $\log(PEN_t/PEN_{t-1})$.

Arellano and Bond (1991) observed that, when the number of periods is small and the number of groups in the panel is large, in order to gain efficiency, the number of valid instruments grows with the number of available periods. For example, for $t = 3$ the only valid instrument is Y_{it-1}, but for $t = 4$ both Y_{it-1} and Y_{it-2} are valid instruments. Consequently, for any given period T, the set of valid instruments becomes $(Y_{i1}, Y_{i1t-1}, \ldots, Y_{iT-2})$. Because the exogenous variables (called x_{it} for simplicity, though they actually include the model's other explanatory variables such as capital and labor force) may be predetermined and correlated with μ_I, the valid set of instruments is $[x_{i1'}, x_{i2'}, \ldots, x_{i(s-1)'}]$, given that $E(x_{it}v_{is}) \neq 0$ for $s < t$ and otherwise equals zero.

With the instruments obtained from the lagged Y and the lagged explanatory variables, a matrix of instruments W[10] can be obtained, so that $E(W_i'\Delta v_i) = 0$. Using generalized method of moments (GMM), the one-step estimators of α and δ would be

$$\begin{pmatrix}\hat{\alpha}_1\\ \hat{\delta}_1\end{pmatrix} = ([\Delta Y_{-1}\Delta X]'WV_N^{-1}W'[\Delta Y_{-1}\Delta X])^{-1}([\Delta Y_{-1}\Delta X]'WV_N^{-1}W'\Delta Y), \quad (6)$$

where

$$V_N = \sum_{i=1}^{N} W_i'(\Delta v_i)(\Delta v_i)'W_i. \quad (7)$$

This GMM estimator does not require any knowledge of the initial conditions or distributions of v_i and μ_i. However, to correct for the presence of unobserved firm heteroskedasticity, we operationalize this procedure by replacing Δv with differenced residuals obtained from the preliminary consistent estimator δ_1. This yields the more efficient, two-step GMM estimator (Arellano and Bond 1991, 1998) used in our study. This second-step estimation provides robust standard errors. In the absence of such standard errors, test statistics could be highly misleading, especially in long panel data sets such as the ones with which we are working.[11]

References

Anderson, T. W., and C. Hsiao. 1981. Estimation of dynamic models with error components. *Journal of the American Statistical Association* 76 (375): 598–606.

Antle, J. M. 1983. Infrastructure and aggregate agricultural productivity: International evidence. *Economic Development and Cultural Change* 31 (4): 609–619.

10. The transformed W_i are deviations from individual means.

11. For the hypothesis that there is no second-order serial correlation for the disturbances of the first-differenced equation, we follow the test by Arellano and Bond (1991, 282), which assumes the consistency of the GMM estimation because it relies on the following: $E[\Delta v_{it}\Delta v_{i,t-2}] = 0$. Finally, we performed Sargan's (1958) test of overidentifying restrictions, suggested by Arellano and Bond (1991).

Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58 (2): 277–297.

———. 1998. Dynamic panel data estimation using DPD98 for Gauss. Working Paper No. 88/15, Institute for Fiscal Studies, London.

Aschauer, D. A. 1989. Is public expenditure productive? *Journal of Monetary Economics* 23 (2): 177–200.

Craig, B. J., P. G. Pardey, and J. Roseboom. 1997. International productivity patterns: Accounting for input quality, infrastructure, and research. *American Journal of Agricultural Economics* 79 (4): 1064–1076.

Doherty, A. 1984. Empirical estimates of demand and cost elasticities of local telephone service. In *Changing patterns in regulated markets and technology: The effect of public utility pricing.* East Lansing, Mich., U.S.A.: Michigan State University Institute of Public Utility Pricing, Institute of Public Utilities.

Duncan, G., and D. Perry. 1994. IntalLATA toll demand modelling a dynamic analysis of revenue and usage data. *Information Economics and Policy* 6: 163–178.

Ford, R., and P. Poret. 1991. Infrastructure and private-sector productivity. *OECD Economic Studies* 17 (Autumn): 63–89.

Garcia-Mila, T., and T. J. McGuire. 1992. The contribution of publicly provided inputs to states' economies. *Regional Science and Urban Economics* 22 (2): 229–241.

Garcia-Mila, T., T. J. McGuire, and R. H. Porter. 1996. The effect of public capital in state-level production functions reconsidered. *Review of Economics and Statistics* 78 (1): 177–180.

Gatto, J. J., H. Kelejian, and S. Stephan. 1988. Stochastic generalizations of demand systems with an application to telecommunications. *Information Economics and Policy* 3 (4): 283–309.

Gatto, J. J., L. Hooper, P. Robinson, and H. Tyan. 1988. Interstate switched access demand analysis. *Information Economics and Policy* 3 (4): 333–358.

Gordon, R. J. 2000. Does the new economy measure up to the great inventions of the past? *Journal of Economic Perspective* 14 (4): 49–74.

Harberger, A. 1978. Perspectives on capital and technology in less developed countries. In *Contemporary Economic Analysis,* M. J. Artis and A. R. Nobay, eds. London: Croom Helm.

Hardy, A. 1980. The role of the telephone in economic development. *Telecommunications Policy* 4 (4): 278–286.

Hirschmann, A. O. 1958. *The strategy of economic development.* New Haven, Conn., USA: Yale University Press.

Holtz-Eakin, D. 1994. Public-sector capital and the productivity puzzle. *Review of Economics and Statistics* 76 (1): 12–21.

ITU (International Telecommunications Union). 2002. Online database. <www.itu.int/home/index.html> (accessed February 2002).

Jipp, A. 1963. Wealth of nations and telephone density. *Telecommunications Journal* 20: 199–201.

Kormendi, R., and P. Meguire. 1985. Macro-economic determinants of growth: Cross-country evidence. *Journal of Monetary Economics* 16: 141–163.

Leff, N. H. 1984. Externalities, information costs, and social benefit–cost analysis for economic development: An example from telecommunications. *Economic Development and Cultural Change* 32 (2): 255–276.

Levy, A. 1996. Semi parametric estimation of telecommunications demand. Ph.D. dissertation, University of California–Berkeley, Berkeley, Calif., USA.

Madden, G., and S. J. Savage. 2000. Telecommunications and economic growth. *International Journal of Social Economics* 27 (7–10): 893–906.

Mankiw, N. G., D. Romer, and D. N. Weil. 1992. A contribution to the empirics of growth. *Quarterly Journal of Economics* 107: 407–437.

Munnell, A. H. 1992. Policy watch: Infrastructure investment and economic growth. *Journal of Economic Perspectives* 6 (4): 189–198.

Nehru, V., and A. Dhareshwar. 1993. A new database on physical capital stock: Sources, methodology and results. *Revista de Análisis Económico* 8 (1): 37–59.

Norton, S. W. 1992. Transaction costs, telecommunications and the microeconomics of macroeconomic growth. *Economic Development and Cultural Change* 41 (1): 175–196.

Oliner, S. D., and D. E. Sichel. 2000. The resurgence of growth in the late 1990s: Is information technology the story? *Journal of Economic Perspectives* 14 (4): 3–22.

Pascó-Font, A., J. Gallardo, and V. Fry. 1999. La demanda residencial de telefonía básica en el Perú. In *Estudio en Telecomunicac*iones No. 4. Lima: Organismo Supervisor de la Inversión Privada en Telecomunicaciones (OSIPTEL).

Panzar, J. C. 2000. A methodology for measuring the costs of universal service obligations. *Information Economics and Policy* 12 (3): 211–220.

Pohjola, M., ed. 2001. *Information technology, productivity and economic growth: International evidence and implications for economic development.* World Institute for Development Economics Research, United Nations University, Studies in Development Economics. Oxford and New York: Oxford University Press.

Roche, E. M., and M. J. Blaine. 1996. *Information technology, development and policy.* Avebury, UK: Aldershot.

Röller, L.-H., and L. Waverman. 2001. Telecommunications infrastructure and economic growth: A simultaneous approach. *American Economic Review* 91 (4): 909–923.

Saith, A. 2002. ICT: Hope or hype. Paper presented at ICTs and Indian Development, held in Bangalore, India, December.

Saunders, R. J., J. J. Warford, and B. Wellenius. 1983. *Telecommunications and economic development.* Baltimore: Johns Hopkins University Press.

Stiroh, K. J. 2002. Are ICT spillovers driving the new economy. *Review of Income and Wealth* 48 (1): 33–57.

Torero, M., S. Chowdhury, and V. Galdo. 2003. Willingness to pay for the rural telephone service in Bangladesh and Peru. *Information Economics and Policy* 15 (3): 327–361.

World Bank. 2002. *World development indicators.* Online database <www.worldbank.org/data/countrydata/countrydata.html> (accessed February 2002).

Zona, J. D., and R. Jacob. 1990. The total bill concept: Defining and testing alternative views. Presented at the Bellcore/Bell Canada Industry Forum, "Telecommunications Demand Analysis with Dynamic Regulation," held in Hilton Head, S.C., in April 1990. Cambridge, Mass., USA: National Economic Research Associates.