Telecommunications – a means to economic growth in developing countries?

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Karen F. Lomeland Jacobsen

INTRODUCTION

The world economy has experienced enormous growth in the past 50 years, yet the gap between the richest and the poorest countries has increased. In 1960, the 20 percent of the world's population living in the richest countries had 30 times the income of the 20 percent poorest, a ratio that increased to 76:1 in 1997 (Human Development Report, 1999). There have been several attempts to explain the increased difference. Proponents of the endogenous growth theory claim that a technological revolution has created a new growth paradigm. Information and communication technology, which is mainly found in developed countries, has become an engine for long-run economic growth, as railways and electricity once were. Following the information technology revolution seen in the industrialised world in the 90s, ICT has often been advanced as a possible remedy for developing countries and the slow or decelerating growth they have faced. Increased economic growth is seen as necessary to make each country self-supporting and able to continue the development beyond mere everyday survival, as is the case in many least developed countries today.

International organisations such as the World Trade Organization argued for many years for the free trade of goods as the best means of encouraging development, while services were seen as non-tradable. However, in the Uruguay round of negotiations services were brought in, and the General Agreement on Trade in Services (GATS) was signed in 1994.[1] An important feature of the service sector is that services are not only valuable in themselves, but also serve as crucial inputs into the production and trade of most goods. In this paper I will look into one of the service sectors, namely the telecommunications sector.[2] Telecommunications has been enhanced as a development tool because of its broad range. By facilitating the diffusion of information and communication, it increases people's ability to participate more actively in the social, economic and political life of a community. Transparency increases, making corruption among public administrators more difficult. Furthermore, telecommunications has a direct influence on productivity growth. It raises the efficiency of service providers and opens new markets by 'reducing' distances. Telecommunications is a growing sector that creates new activity in itself, contributing to economic growth and employment creation. The positive influence on other sectors is also substantial, with the financial sector as a highlighted example.

The aim of this paper is to investigate whether telecommunications development can serve as a means to achieve economic growth. An empirical approach is adopted, using data from 84 countries over 10 years. The main purpose is to study developing countries, but developed countries are included as a reference group. The paper starts with an overview of earlier research on economic growth and telecommunications. Chapter 3 continues with data description, model specification and empirical implementation. In chapter 4, I use descriptive statistics to look for correlations and tendencies between economic growth and telecommunications. The underlying methodology for the applied econometric method is outlined in chapter 5, along with a discussion of possible methodological problems. Chapter 6 contains the results and interpretation of the econometric analysis and chapter 7 concluding remarks.

[1] An Annex on Basic Telecommunication was signed in February 1997.
[2] Telecommunications can be defines as 'communication of information, in verbal, written, coded or pictorial form, by telephone, telegraph, cable, radio, television' (Information Communications Technology Management Board).

2 THEORETICAL AND EMPIRICAL BACKGROUND

In this chapter, I shall review studies on telecommunications and its relationship to development and economic growth. I shall also discuss some of the features characterising the telecommunication sector. However, I start by discussing general growth theory.

2.1 ECONOMIC GROWTH

Two directions have dominated the theory of long-run economic growth. The traditional neoclassical growth model was developed by Solow and Swan in the 50s (Agénor et al., 1999). They specified a model based on a constant return to scale production function. There are two inputs, capital and labour, the latter with diminishing marginal return. The rates of savings and population growth are taken as exogenous, and these variables are postulated to explain the steady-state level of income per capita. Technology is also assumed to progress at an exogenous rate. The standard Solow Cobb-Douglas production function is given by $Y = AK^{a} L^{1-a}$, $0 < a < 1$, where Y is output, K is the stock of capital, L is labour, and A gives the starting position of a society's technology level. An implication of the model is the concept of convergence, stating that poor countries tend to grow faster than rich ones, and in the long run eventually catch up with them. Due to the diminishing marginal return to capital, countries with low levels of capital stock will have higher marginal product of capital, and thereby grow faster than those with already high levels of per capita capital stock, given similar saving rates.

However, empirical research has given little support to the theory of convergence. It can only be found within the OECD area. Mankiw, Romer and Weil (1992) have introduced an extended Solow model, the augmented Solow model. They aim to explain why convergence has failed to appear, and introduce the notion of 'conditional convergence'. They argue that Solow did not predict that all countries would reach the same level of per capita income, but rather their respective steady state. Convergence is indeed found, as long as differences in the steady state across countries have been controlled for.

Still, the neoclassical theories have been attacked for failing to appreciate technological progress as an important input for economic growth. They do point out that it is important, but treat technological progress as exogenous. As a result, a new direction in growth theory has emerged. This new direction has been called the endogenous growth theories, and dismisses the concept of convergence entirely. Endogenous growth theories are based on either constant or increasing returns to scale in capital, postulating a growth in the gap between rich and poor countries. The model is based on the standard Cobb-Douglas production function given above, but the focus is directed to the technological progress, given by the A. Bernard and Jones (1996b) emphasise a model of endogenised technological change, where each country's composition of products and industry, and its ability to adapt the leading technology, determine its long run growth. Similar population growth and investment rates across countries have no impact on the relative position between them. Similar steady state outcomes are the exceptions rather than the rule. It is technology that determines the countries' rate of convergence, or lack of convergence, to their own steady state. By studying 14 OECD countries Bernard and Jones discovered that there is a substantial variation in technology across countries, and that this variation in magnitude corresponds roughly with the variation in labour productivity. They also find that the dispersion of labour productivity over time corresponds closely to the change in dispersion of technology. According to Bernard and Jones (1996a) the highest convergence rates are found in the service sector, when it comes to both labour productivity and multifactor productivity. Labour productivity is said to be an important input for economic growth, indicating that telecommunications, as part of the service sector, might lead to economic growth.

Romer (1986) has been another important contributor to the endogenous growth theory. He has specified an equilibrium model of endogenous technological change. Crucial in the model is the departure from the assumption of diminishing returns to capital. Romer argues that the rate of investment and the rate of return on capital may increase rather than decrease with a rise in the capital stock. The reason is externalities, an important notion within the endogenous growth theories. Increased investment and capital stock lead to productivity gains that offset any tendency towards diminishing returns. If an increase in the investments rate generates strong externalities, the output elasticity, a , in the Solow model grows to be one, and we are left with the model $Y = AK$ (Pack, 1994). A competitive equilibrium with externalities is present in the model. The equilibrium is not Pareto optimal, but according to Romer is capable of explaining historical growth in the absence of government intervention.

The model applied in this study is an endogenous growth model. As a result, an increasing return to capital is assumed, and I expect to find divergence between the growth rates of the respective countries. This implies that countries with low initial capital, in this case the stock of telecommunications, will grow at a slower rate than countries with a high stock of telecommunications.

2.2 TELECOMMUNICATIONS AND EXTERNALITIES

What justifies the confidence placed in ICT[3] as a development tool, and what are the channels through which ICT is expected to promote development? A common feature of most of the telecommunications studies is their emphasis on network externalities. Network externalities exist when the value of a product to any user is greater the larger the number of other users of the same product (Besen, 1999). There are increasing returns to capital, as Romer postulates in his endogenous growth model.

Telecommunications' contribution to aggregated growth arises both from the private return to capital and from the output generated via externalities. Such externalities are not only limited to network externalities, as defined above, but consist also of indirect externalities: Telecommunications lowers transaction costs, both the fixed costs of acquiring information that is needed for competent decision-making, and the variable costs of participating in markets. The existence of a well functioning telecommunication sector is essential for other product and factor markets as well. The size of the latter markets expands as the increasing returns to communication generate cost-saving externalities. This is, among others, stressed by Leff (1984). He uses social benefit analysis to analyse the welfare effects of investment in telecommunications in developing countries. Leff argues that investment in the telecommunication sector leads to improved organisational performance. It lowers communication costs, increases access to information and enhances the quality of the information obtained. This permits the transformation of uncertainty into risk, and gives ground to more informed and improved decision-making. It is true for both the private and the public sector, giving the latter the potential to increase the efficiency, transparency and accountability of governments. Furthermore, by lowering the transaction costs, ICT may enhance the efficiency and promote the spread of factor and product markets in developing countries. If a market is non-existent, the two key elements that determine the emergence of one are the costs associated with acquiring information and the cost of negotiating transactions (Leff, 1984). The spread of ICT is expected to lower these costs, thereby

[3] Telecommunications and the notion of Information and Communication Technology (ICT) incorporate much of the same, and are looked upon as equivalent in this study.

contributing to the emerging of markets, as well as the development of those already in existence.

But the spread of ICT might also yield negative effects. Telecommunications investment may influence the distribution of income, and the equality of access to information and communications. It has been argued that access to ICT depends on the prevailing income and wealth distribution, and that only small segments of the population will benefit from the development of ICT. However, others claim that access to information is already unequal in developing countries, and that these inequalities will only persist if one restricts investments based on such an argument. Leff finds that an expansion in telecommunications may well have an equalising effect, both on the distribution of income and on access to information.

The latter view is maintained by Bedi (1999). He identifies distinct features that help us to understand the development potential of ICT and the arguments above. According to Bedi, ICT has the capability to separate information from its physical repository, meaning that the utility of ICT is not limited by locality. He also emphasises the content- and size-related externalities of ICT, and that its use is not restricted to a particular sector of the economy. Dudley (1997) elaborates the theory that the development of telecommunications infrastructures and economic growth is positively linked due to network externalities. He argues that communication technology should be given more attention compared to other technologies. Based on the assumption that technological progress is a result of combining old ideas in a new way, communications technology may influence the degree to which previous ideas in other technologies are synthesized. Communications technology may also increase the speed of diffusion of other technologies. Accordingly, in addition to the growth effect from communications in itself, it has substantial externality effects.

However, it is assumed that the least developed countries cannot benefit from network externalities at the same extent as industrialised countries: They have a larger rural population, causing development costs to be higher, they have poor institutions, and they lack human capital. Furthermore, even though telecommunications might contribute to growth, it can never be the complete answer to the question of underdevelopment.

2.3 EMPIRICAL STUDIES ON TELECOMMUNICATIONS

The empirical results of telecommunications and economic growth have been ambiguous. An early study was performed by Norton (1992). Using the average telephone stock between 1957 and 1977 as a variable for telecommunications, he estimated the effect on the average growth rate for 47 countries, controlling for several macroeconomic variables. He found a positive and significant result, arguing that telecommunications reduces transaction costs in numerous markets and thereby raises output. However, opponents have argued that his results seem implausibly high, attributing them to the difficulty of separating the direct effect of telecommunications with the growth of the industries that telecommunications encourages.

Rodrígues and Wilson (2000) have conducted a study on the relationship between information technology and economic growth. They perform a cross-sectional analysis for 110 countries, with economic growth rates between 1988 and 1997 as dependent variable. They construct an index of technological progress (ITP), and use levels of this index as an explanatory variable, while controlling for traditional determinants of economic growth. They do not succeed in establishing a causal link between technology and economic growth.

Dewan and Kraemer (1998)[4] and Pohjola (2000)[5] do find positive and significant returns from investments in IT capital in developed countries, but neither succeeds in

[4] Dewan and Kraemer's panel data study consists of 36 countries, between 1985 and 1993.

[5] Pohjola's report contains data for 39 countries, of which 23 are OECD countries, in the period 1980-1995.

detecting a significant correlation between IT investment and growth in developing countries. They attribute the difference between developed and developing countries to the developing countries difficulty in benefiting from modern advances in technology, due to a lack of complementary factors such as physical infrastructure and human capital, which enhance and amplify the effects of IT investment in developed countries. Still, Dewan and Kraemer find that non-IT capital generates substantial returns in developing countries. Even though non-IT capital seems to have a higher payoff in developing countries, they do not advise against investing in IT capital in these countries, since there might be learning effects that require a certain level of experience before IT investments start to yield profit.

In a later study, Pohjola (2002) even fails to detect growth effects from ICT in the sub-sample of developed countries. The low level of investment in ICT and the lack of complementary organisational and human capital, used to explain the lack of returns in developing countries, cannot explain the inability to detect growth effects in the sub-sample of developed countries. Pohjola therefore attacks the neoclassical method in use. According to him, growth effects should be looked for in the demand-side of the economy, not the supply-side. The benefits of ICT consist of increased welfare for consumers of knowledge products.

The same view is espoused by Bayoumi and Haacker (2002). They find that it is the users of IT, not the producers, who receive the welfare benefit due to falling relative prices. They stress that earlier studies on how IT production affects real GDP are less valuable in assessing welfare distribution, though they serve as useful instruments in detecting overall benefits.

Haacker and Morsink (2002) investigate 20 developed countries over the period 1985-2000, looking for the impact of IT on total factor productivity growth. A large and significant effect is found for IT expenditure, with a smaller, yet significant, effect for IT production. They postulate that the increase in IT expenditure in the sample for 1995-2000 will lead to an annual increase in total factor productivity growth of 1/3 percent. Their results also indicate that total factor productivity accelerates more in high-income countries due to a better capability for extracting the efficiency gains, and that the impact of IT expenditure on growth increases over time, suggesting that spillovers materialise gradually.

Röller and Waverman (2001) investigate the effects of investment in telecommunications on economic growth in 21 OECD countries from 1970 to 1990, finding a positive and significant link. By allowing for country-specific effects, they find that one-third of the OECD growth can be attributed to telecommunications, perhaps an unreasonably high result. It is also worth noticing that they find a strong positive and significant relation between demand for telecommunications infrastructure and real GDP, indicating that there exists a two-way causality between growth and telecommunications. Network externalities open a possibility that the growth effects from the industry might not be linear. Röller and Waverman find that growth is twice as large in countries with a high penetration rate[6] than for those at a medium and low level. The result is substantial and significant. This implies that the existence of a critical mass of telecommunications infrastructure is necessary before substantial growth effects are noticed. The critical mass seems to be equal to universal service[7]. In an earlier study, Röller and Waverman (1996) included 14 developing or newly industrialised countries. These countries only had an average penetration rate of 4 percent, suggesting that the rich developed countries benefit most from telecommunications investments and that developing countries need substantial investment before they earn profit. It also means that there might be

[6] Low penetration rate is classified as a penetration rate below 0.2 main telephone lines per capita. Medium penetration rate ranges from 0.2 to 0.4 main lines per capita, and high penetration rate above 0.4 main lines.
[7] Computing 2 - 2.5 persons per household and more than 40 telephones per 100 inhabitant, a high penetration rate can also be looked upon as universal service.

a tendency for economic divergence between developed and non-developed countries. This corresponds with the view of the endogenous growth theoreticians discussed in section 2.1.

In a case-study on Namibia and IP telephony, Aochamub et al. (2002) have not been able to confirm the bi-directional causality between GDP growth and telecommunications found by Röller and Waverman. Only the unilateral causality from growth to telecommunications has been corroborated. They attribute it to the small sample size, but cannot reject the possibility that it is the due to lower network externalities in Namibia than in OECD countries, as postulated by Röller and Waverman.

By reviewing empirical studies on ICT and development, both macroeconomic and microeconomic, Bedi (1999) concludes that it is difficult to identify a clear causal link between ICT development and economic growth, or to quantify the impact of ICT on growth. It is clear that there is a positive association between them, but the chain of causality may go both ways. He stresses that most of the studies are based on data from developed countries, and more evidence from developing countries is needed.

Conclusion

The theoretical studies indicate that telecommunications has an effect on economic growth, but this relationship is difficult to establish empirically. Where a relationship has been found it is mostly based on data from developed countries. However, the lack of empirical evidence is often attributed to the quality of data sets. By including recent, more complete data, I hope to be able to reveal whether the earlier findings are due to the problem of qualified data, or simply a lack of connection between telecommunications and growth. While Röller and Waverman incorporate fixed effects, and account for reverse causality by specifying a system of equations that endogenises telecommunications investment, the other studies use a more reduced form model. With that in mind I have chosen to adapt the model outlined by Röller and Waverman. By expanding the analysis to include developing countries I wish to test the hypothesis of a critical mass, and investigate more precisely the impact telecommunication infrastructures have on economic growth in these countries.

3 DATA DESCRIPTION AND THE EMPIRICAL MODEL

The data used in this analysis are collected from World Development Indicators 2001 (WDI) published by The World Bank, and ITU World Telecommunication Indicators 2002 (ITU) published by the International Telecommunication Union.

3.1 TIME SPAN

I have chosen to use data from 1990 to 1999. There has been an accelerating development in the telecommunication sector in recent years, with cellular telephones and personal computers as examples. My analysis is meant to capture these novelties and the effect they have had on economic development. This can be done by a cross-sectional study, where the stock of telecommunications is measured alongside economic growth at a single point of time. However, this approach fails to acknowledge the dynamics of the development. It is especially true when it comes to studying economic growth, since economies are complex structures that tend to react to delay, with the effects of initiatives appearing later. When earlier incidents influence the outcome in subsequent periods, we are faced by a dynamic model. Lagged variables can help estimate such effects by intercepting occurrences in the past. A dynamic approach can be obtained by using a panel data analysis, which combines a cross-sectional with a time-series approach. This increases the degrees of freedom and takes collinearity between the explanatory variables into consideration, thus improving the accuracy of the estimates.

The increase in observations that features the panel data approach may also increase the danger of missing observations. The number of missing observations, for both the economic variables and the telecommunication variables, increases as more years from the past are included. However, the more years you include in a time-series, the more accurate and valid the estimates become. Finding a relationship that is consistent over 10 years is a stronger implication of *de facto* than if it were indicative over 4 years only. Also, including several years takes out business cycles. Studying a panel of less than five years risks finding spurious correlations that are due to economic trends, rather than an actual relationship between GDP and telecommunications. Hence, one has to counterbalance the drawback of missing observations against the advantage of a long time-series when choosing which time span to use. My first intention was to include 20 years in my sample, but this resulted in a large quantity of missing observations. It turned out that there was a large leap from 1989 to 1990 in the number of countries that had observations for all variables. Excluding the countries with several missing observations could have been another solution to the problem. Then a long time span would have been kept, and the missing observations eliminated at the same time. However, this implied leaving out mostly developing countries. Since the study of developing countries is my main purpose, and a broad sample is of value, I have chosen to sacrifice a long time span. My final sample for the econometric analysis covers 10 years, i.e. 1990 to 1999. The 80s are covered to a small extent in the descriptive statistics.

3.2 SELECTION OF COUNTRIES

The countries are selected from a total sample of 207 economies. Small countries are omitted from the analysis; that is, all countries with fewer than 1.5 million inhabitants. Those countries with large differences between minimum and maximum value of GDP growth, and large fluctuations between years, are also left out. I checked all the countries that had a variation between minimum and maximum values for GDP growth of more than 20 percent. If there was a smooth development they were kept, if not they were dropped. A large variance can be a sign of inconsistency in statistical methods applied over years, or it can depict a real situation due to war and so on. In any case, including these countries in the sample would make inference difficult, since no seemingly logical pattern exists across time. The estimates could in reality measure something that is excluded from the model. I have also left out countries with insufficient data. A panel where at least one observation for at least one unit is missing is called an unbalanced panel. Missing data in panel data sets are very common. An unbalanced panel can give inconsistent and invalid estimates if the model is specified without considering this difficulty.[8] I have only kept those countries that have observations for all the variables for at least five years[9]. The ideal would have been to eliminate all missing observations. However, since I am studying developing countries that often have imperfect statistical reports, this would leave us with too small a sample. The selection criterion is chosen in order to allow for both the missing observations and the sample size.

Finally, I am left with a sample of 84 countries, representing all income groups and regions. My prime objective is to investigate the effect telecommunications has had on growth in developing countries, but I will use high-income countries as a reference group. I have categorized the countries into four income groups based on initial income, measured as GDP per capita in 1990.

Table 3.1 Income groups

Income group	Low	Middle low	Middle high	High	Total
1990 GDP per capita	<= 534$	<534$ - 2119$	<2119$ -10 692$	10 692$ <	
Observations	21	21	21	21	84

GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant U.S. dollars.

By categorising the countries by income, it is possible to investigate whether initial income has any effect on the subsequent growth rate. Initial income is a variable frequently used to explain economic growth. The variable is often found to be significant, and it might explain the growing gap in income observed between low and high-income countries. This is the same as the conditional convergence effect discussed in section 2.1. The question of a link between initial income and growth is also important in light of the discussion of globalisation. Opponents of world liberalisation and globalisation have argued that liberalisation only favours the industrialised world, since the developing countries have neither the means nor the goods to compete on a worldwide market. Even if the countries have low-cost production as a result of low wages, they are not able to enter a market where traditional expensive marketing is crucial for selling products, malfunctioning financial institutions make international trade complicated and expensive, and corruption takes much of the profit. Investigating the growth effects from telecommunications in developed and developing countries separately might add further understanding to this debate. If lower growth effects are found in the developing countries than in developed countries the arguments of the

[8] By applying a fixed-effect model with a full set of dummy variables for each of the countries represented in the sample (minus one to avoid the dummy trap), missing observations are measured in these interceptions, thereby reducing the problem of an unbalanced panel. The model is elaborated in section 5.2

[9] That is, all variables but the budget deficit. This variable has a lot of missing variables for all the countries. The sample would be too small if this variable set the standard. In the analysis I will investigate whether this variable can be excluded all together. It is included so far since it can be looked upon as negative saving, and saving is an important variable in economic growth theory.

opponents of liberalisation are strengthened, and vice versa. The country sample and its distribution by income and region are specified in table 3.2 below.

Table 3.2 Country sample by income and region

Income group	Sub-Saharan Africa	Asia and Oceania	Europe and Central Asia	Middle East and North Africa	Americas
Low	Benin Burundi Guinea Kenya Lesotho Madagascar Mauritania Mozambique Niger Nigeria Tanzania Uganda Zambia	Bangladesh China India Mongolia Nepal Pakistan		Yemen, Rep.	Nicaragua
Total: 21	**13**	**6**	**0**	**1**	**1**
Middle low	Namibia Cote d'Ivoire Cameroon Senegal Zimbabwe	Philippines Sri Lanka Thailand	Bulgaria Romania	Algeria Egypt, Arab Rep. Iran, Islamic Rep. Jordan Syrian Arab Rep. Tunisia	Colombia Ecuador Honduras Jamaica Peru
Total: 21	**5**	**3**	**2**	**6**	**5**
Middle high	Botswana South Africa	Korea, Rep. Malaysia	Hungary Poland Greece Portugal Turkey Russian Fed.	Oman Saudi Arabia	Argentina Brazil Chile Mexico Panama Puerto Rico Uruguay Venezuela Costa Rica
Total: 21	**2**	**2**	**6**	**2**	**9**
High		Australia Hong Kong, China Japan New Zealand Singapore	Austrian Belgium Denmark Finland France Germany Italy Netherlands Norway Spain Sweden Switzerland United Kingdom	Israel	Canada United States
Total: 21	**0**	**5**	**13**	**1**	**2**

3.3 HOW TO MEASURE TELECOMMUNICATIONS INFRASTRUCTURE

Telecommunication can be defined as "communication of information, in verbal, written, coded or pictorial form, by telephone, telegraph, cable, radio, television" (Information Communications Technology Management Board). I have chosen to limit my scope to instruments used in activities directly connected to productivity growth, and will not look at radio and television. One can argue that information spread by radio and television enhances the average knowledge in a population, thereby raising output, but still I choose to make this limitation in order to simplify the analysis. Fax is still widely used, but its importance will diminish in the future, and therefore this variable is omitted, as is the telegraph, which today is outdated. I will indirectly include these factors in telecommunications by looking at the total investment in telecommunications. Earlier studies on telecommunications have focused on the fixed telephone line and its influence on economic growth.[10] However, there has been a large increase in people connected to the telephone network since the introduction of cellular telephones in the worldwide market. While credit constraints limited the number of fixed telephone subscribers, the introduction of cash cards for cellular telephones made the market accessible for substantially more people. In that regard, I find it natural to include both cellular telephones and fixed telephones in my study.

Due to the importance of the Internet in today's society, I would also like to include a variable that measures this development. I have chosen to use the number of personal computers as a proxy variable. Measuring Internet accessibility is quite difficult. There is a shortage of publicly available data, especially for the developing countries. There has not yet been established a worldwide methodology for collecting data, but several different indicators have been used. The most commonly used indicator to measure Internet development is the number of host computers (Minges, 2000). A host is a domain name that has an IP address record associated with it. The problem is that the country where the computer is hosted and the place where it is physically situated are not necessarily the same. For example, the United States, which is normally looked upon as one of the countries with the highest Internet connection density in the world, is only number 44 on the Internet penetration rank due to the fact that many of the computers located in the United States are hosted elsewhere. Another problem is the variable's lack of information on accessibility, since it does not measure the number of users. An alternative variable is the number of Internet users, which is an estimated variable. However, there is no standard definition of frequency (e.g. daily, weekly, monthly) or services used (e.g. e-mail, world wide web), thereby making comparisons of the data misleading. The number of Internet subscribers could also be used. It is a more precise indicator of access than users, but it does not capture the fact that numerous people obtain their access through work, school, as a member of a household or from community locations such as cyber cafés. Several people might use a single subscription.

The latter is also a problem when using the number of personal computers as an indicator of Internet accessibility. However, the data are more complete for this variable than for Internet subscribers. Combined with the number of telephone lines, which is how most people connect in the developing world, the number of personal computers gives us a picture of the Internet infrastructure. However, the number of personal computers is only an estimate. ITU base their estimates on sales and import data, with a tendency towards underestimation since a significant portion of imported computers in developing countries is unreported (e.g. smuggling, grey market, local assembly). This should be kept in mind when interpreting the results.

3.4 MODEL SPECIFICATION

The model used to investigate the relationship between development of telecommunications infrastructure and economic growth is an endogenous growth model. In order to recognise the reverse causality discussed in section 2.4, one needs to single out two effects: the increase in economic growth due to development in telecommunications infrastructure, and the income elasticity of telecommunications demand. One would expect a reverse causality, leaving the estimates of the effect of telecommunications development on economic growth biased if the income elasticity is not included in the model. The solution is to build a more structural model where the telecommunications infrastructure investments are endogenised into the aggregated economy. This is done by specifying a micro-model of supply and demand for telecommunications investments, and estimating it together with an

[10] E.g. Norton (1992) and Röller & Waverman (2001).

aggregated production function in a system. However, consumers demand stocks of telecommunications rather than investments. Consequently, the demand function is specified as demand for the stock of telecommunications infrastructure. In order to acknowledge the relationship between the change in the telecommunications infrastructure stock, as specified in the demand equation, and telecommunications investment, as specified in the supply equation, a telecommunications infrastructure production function is outlined. The macro function of aggregated production and the micro functions of supply, demand and production of telecommunications are estimated in a simultaneous equation system, originally developed by Röller and Waverman. The four equations are specified as follows:

The aggregated production / output function:
(3.1) $GDP_{it} = f(K_{it}, HK_{it}, TELECOM_{it}, t)$
Demand for telecommunications infrastructure:
(3.2) $TELECOM_{it} = h(GDP_{it} / POP_{it}, TELP_{it})$
Supply of telecommunications investment:
(3.3) $TTI_{it} = g(TELP_{it}, Z_{it})$
Telecommunications infrastructure production function:
(3.4) $TELECOM_{it} - TELECOM_{i,t-1} = (TTI_{i,t}, R_{it})$

The income elasticity is given in equation 3.2. The subscripts i and t are defined for $i = 1,...,n$ and $t = 1,...,T$, and refer to countries and time respectively. The first equation states that economic growth, measured by real GDP, is a function of the stock of capital net of telecommunication capital (K), the stock of human capital (HK) and the stock of telecommunications infrastructure (TELECOM). A time trend (t) is also included in order to capture economical fluctuations, like business cycles, common across countries. The demand equation states that the demand for the stock of telecommunications infrastructure is a function of the price of telephone service (TELP) and GDP per capita, thus showing us the income elasticity of the demand for telecommunications services. In the third equation we see that the telecommunications infrastructure investment (TTI), i.e. the supply, is a function of the telephone price (TELP) and exogenous variables affecting supply. The fourth equation gives us the relationship between the change in the stock of telecommunications infrastructure and investment in telecommunications infrastructure (TTI). The three equations 3.2-3.4 are meant to differentiate the effect of TELECOM on GDP from the income elasticity of telecommunications, in other words testing for reverse causality.

3.5 EXPLANATORY VARIABLES

As described in the previous section, the standard production - or output - function includes the level of technology (TELECOM), the stock of telecommunications capital (K), and the stock of human capital (HK). The level of technology is given by the penetration rate of main lines and cellular telephones, and the number of personal computers. I expect to find a positive relationship between the technology level and output. I also expect to find a positive correlation between the stock of telecommunication and output. The stock of human capital is measured as the total labour force. The labour force is related to economic growth through a scale effect. The endogenous growth theories of knowledge accumulation predict that technological progress is an increasing function of population size. The larger the population, the more people there are to make discoveries, leading to more rapid knowledge accumulation, which again stimulates growth.

The explanatory variables in the demand equation are GDP per capita (GDP/POP) and telephone revenue. A high income in the population will presumably lead to higher demand for telecommunications. In a poor country, income barely covers the basic needs, and demand would accordingly be smaller. There is a positive correlation between demand and GDP per capita. Telephone revenue is a proxy for the telephone service price (TELP). The higher the price, the lower the demand, indicating a negative correlation between them.

The supply equation consists of the geographic area, the budget deficit (surplus), the waiting list for main lines (all three representing Z) and the telephone revenue per main line (TELP). It is expected that large countries invest more than small countries, thereby increasing the supply of telecommunications. This is the reason for including the geographic area variable, and a positive coefficient is anticipated. The effect of a budget deficit is ambiguous. One could expect that a budget deficit puts constraints on investments, thereby finding a positive relationship between this variable and investment (the higher the surplus, the more investments there are). But large investments in telecommunications can just as well be the direct cause of a budget deficit, and also be associated with other spending programmes, leaving budget deficit negatively correlated with investment. A third option is that these two effects counterbalance each other, leaving the coefficient small or insignificant. In most developed countries the telecommunication companies are private-owned, thereby not affected by a budget deficit. Still, in many developing countries the companies are state-owned. Even though many are run as independent companies, it might be the case that governments in deficit tap their state-owned companies for resources. For that reason I have chosen to include budget deficit as a variable. Supply is generally affected by demand; the higher the demand, the higher the supply. A large waiting list for main telephone lines would imply a large demand, resulting in a large supply. Thus, a positive and significant relationship between supply and waiting list is expected. The impact of telephone revenue on supply is straightforward. Its inclusion is a matter of course, and the estimate ought to be positive.

The telecommunications infrastructure production function is affected by the annual investment in telecommunications (TTI) and the geographic area. The adding of the former is evident and a positive correlation is anticipated. A large country needs more investment compared to a small country to accomplish a given telecommunications infrastructure, thus giving a negative correlation between area and infrastructure stock. Table 3.3 below contains definitions of all the variables, in which equation they appear, and their expected direction of correlation with the dependent variables.

3.6 EMPIRICAL IMPLEMENTATION

Given the model specified in section 3.4, and the variables discussed in the preceding section, the empirical implementation of the model is given by the following regressions:

Output equation:

$$\log(\mathrm{GDP}_{it}) = a_{0i} + a_1\log(\mathrm{TLF}_{it}) + a_2\log(\mathrm{PEN}_{it}) + a_3 t + e^1_{it} \quad (3.5)$$

Demand equation:

$$\log(\mathrm{PEN}_{it} + \mathrm{WL}_{it}) = b_0 + b_1\log(\mathrm{GDP}_{it}/\mathrm{POP}_{it}) + b_2\log(\mathrm{TELP}_{it}) + e^2_{it} \quad (3.6)$$

Supply equation:

$$\begin{aligned}\log(\mathrm{TTI}_{it}) = {} & c_0 + c_1\log(\mathrm{GA}_{it}) + c_2\mathrm{GD}_{it} + c_3(1-\mathrm{USCAN})\cdot \mathrm{WL}_{it} + \\ & c_4(1-\mathrm{USCAN})\cdot\log(\mathrm{TELP}_{it}) + c_5\mathrm{USCAN}\cdot\log(\mathrm{TELP}_{it}) + e^3_{it}\end{aligned} \quad (3.7)$$

Production equation:

$$\log(\mathrm{PEN}_{it}/\mathrm{PEN}_{i,t-1}) = d_0 + d_1\log(\mathrm{TTI}_{it}) + d_2\log(\mathrm{GA}_{it}) + e^4_{it} \quad (3.8)$$

Table 3.3 Variable definitions and their expected impact on the dependent variables

Variable	Definition	Equation	Expected sign
GDP	GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 1995 U.S. dollars.	Output	Dependent variable
Capital stock*	Non-residential capital stock net of telecommunications capital in billion 1985 US$	Output	+
Total labour force	Total labour force comprises people who meet the International Labour Organization definition of the economically active population: all people who supply labour for the production of goods and services during a specified period. It includes both the employed and the unemployed. While national practices vary in the treatment of such groups as the armed forces and seasonal or part-time workers, in general the labour force includes the armed forces, the unemployed, and first-time jobseekers, but excludes homemakers and other unpaid caregivers and workers in the informal sector.	Output	+
Main telephone lines	Telephone main lines are telephone lines connecting a customer's equipment to the public switched telephone network. Stated per 100 inhabitants, calculated by dividing the number of main lines by the population and multiplying by 100.	Output Demand Production	+ + +
Cellular telephones	Cellular mobile telephone subscribers per 100 inhabitants. Mobile phones refer to users of portable telephones subscribing to an automatic public mobile telephone service using cellular technology that provides access to the public switched telephone network.	Output Demand Production	+ + +
Personal computers	Personal computers are self-contained computers designed to be used by a single individual. The number of personal computers in use in the country. Primarily ITU estimates based on a number of national and international sources. Stated per 100 inhabitants.	Output Demand Production	+ + +
GDP per capita	GDP per capita is gross domestic product divided by midyear population. Data are in constant 1995 U.S. dollars	Demand	+
Waiting list	Un-met applications for connection to the Public Switched Telephone Network, which have had to be held over owing to a lack of technical facilities (equipment, lines, etc.). This indicator refers to registered applications and thus may not be indicative of the total unmet demand.	Demand Supply	+ +
Telephone revenue	Telephone revenue per main line in current US$. Revenue per main line is the revenues received by firms for providing telecommunications services.	Demand Supply	- +
Budget deficit	Overall budget deficit, including grants, in % of GDP. Overall budget deficit is current and capital revenue and official grants received, less total expenditure and lending minus repayments. Data are shown for central government only.	Supply	?
Telecommunications Investment	Annual telecommunications investment in current US $. Refers to the expenditure associated with acquiring the ownership of telecommunications equipment infrastructure (including supporting land and buildings and intellectual and non-tangible property such as computer software). These include expenditure on initial installations and on additions to existing installations.	Supply Production	+ +
Area	Geographic area (in square kilometres) is a country's total area, excluding area under inland water bodies, national claims to continental shelf, and exclusive economic zones. In most cases the definition of inland water bodies includes major rivers and lakes.	Supply Production	+ -

Sources of definitions: The WDI and ITU databases. Except * which is collected from Röller & Waverman (2001)

In equation 3.5, country fixed effects are controlled for by allowing the intercept to depend on the country i. The total labour force (TLF) is used as a proxy for the stock of human capital. School enrolment is another variable frequently used as a proxy for human capital. The advantage is that it measures not only the stock, but also quality. However, the available data on school enrolment is inferior to the data on labour force, hence I have chosen the latter. The penetration rate of main telephone lines (PEN) is used as a proxy for the stock of telecommunications infrastructure. The penetration rate is bounded between 0 and 1. To transform it into a positive unbounded variable it is redefined as PEN = PEN / (a-PEN), where a is chosen to be equal to 0.74 since the maximum penetration rate is 0.736 main lines per capita.[11]

Compared to equation 3.1, there is one modification in the output equation. Data on the stock of capital net of telecommunications capital (K) do not exist for the developing countries. Thus, this variable cannot be included in the regression when the sample of developing countries is estimated. However, estimations on the OECD sample using a fixed effects model show little difference between a regression where the stock is included, and a regression where it is not. The coefficient of the telecommunications stock variable is small and insignificant, and the coefficients of the other variables change only marginally from the estimation with the stock to the estimation without. On the other hand, when a non-fixed effects model is applied the telecom stock variable is significant and the results change from the first estimation to the second. Since such a tendency is not found in the fixed-effects model, it is likely that the stock variable captures the fixed effects instead of the real stock effect. In other words, we are faced with a spurious correlation and an omitted variable bias, indicating that including fixed effects would be a valid approach. Since the coefficient of the telecommunications stock is small and insignificant in the fixed effects estimation for OECD countries, I have made a qualified decision to leave out the telecommunications stock variable from the entire analysis in order to make the comparison between developing and developed countries more accurate.

The effective demand for telecommunications infrastructure in equation 3.6 is measured as the penetration rate (PEN) and the waiting list (WL) for main lines. The latter is included because the number of main lines existing at any time cannot be explained by demand only. At some prices there will be excess demand in some countries, leading to waiting lists. The telephone revenue per main line (TELP) is used as a proxy for the price of telephone service, since no data on the latter variable is available. Even though this is the closest approximation available it should be mentioned that it is not perfect given that it not only comprise the price, but also quantity. It is not easy to find common exogenous variables explaining the supply of telecommunications infrastructure in equation 3.7, since the countries differ in market structure and level of government interference. Variables describing economic, political and geographical features seem plausible. Those included are geographic area (GA), government deficit (GD) and waiting list for main lines, in addition to the telephone price. A dummy variable for United States and Canada (USCAN) that rules them out is added, because a private market of telecommunications supply has dominated these countries. As a result, a different price elasticity of supply can be expected. In recent years, several other countries around the world have privatised the telecommunications sector, either partially or fully. In 1999 the percentage of countries in the Americas that had privatised was 70 percent, while the corresponding rate in Africa was only 28 percent. However, the later privatising will not affect most of this analysis, which runs until 1999. The production of telecommunications infrastructure is measured by the change in the stock of main lines, i.e. PEN divided by its lagged variable. The production is a function of the total annual

[11] Such a formula is also used by Röller and Waverman, 2001.

investment in telecommunications (TTI) and the geographic area. The larger the country, the greater the investment needed to expand the relative penetration rate of main lines.

I shall estimate three models, all in a simultaneous equation system, by using a Seemingly Unrelated Regression estimator. In the first model the intercept in (3.8) is held constant, thus not controlling for fixed effects. In the second it allows for country-specific effects. In the last model the first equation is re specified in order to allow for non-linearity in the growth effects from telecommunications investments. Telecommunications is subject to network externalities. Since network externalities are not directly observable, the penetration rate is used to measure whether there are increasing returns to telecommunications investment.

$$(3.5') \quad \log(GDP_{it}) = a_{0i} + a_1 \log(TLF_{it}) + (a_2 + a_3 MEDIUM_{it} + a_4 HIGH) \cdot \log(PEN_{it}) + a_5 t + e^1_{it}$$

The MEDIUM and HIGH variables are dummies dividing the countries according to their level of telecommunications infrastructure. Countries with a higher penetration rate than 0.5 main lines per capita are classified in the high group. Those with a penetration rate between 0.25 and 0.5 per capita constitute the medium group, while a rate of less than 0.25 per capita classifies as low. 68 percent of the sample falls into the range of a low penetration rate, 18 percent has a medium penetration rate, and 14 percent a high rate, respectively. Incorporating these dummies makes it possible to investigate whether the countries benefit differently from a marginal growth in telecommunications infrastructure, dependent on their initial level.

So far, telecommunications has been implemented by the variable main telephone lines. At this stage, I wish to include additional telecommunications variables. The cell phone and personal computer variables are implemented in the model by defining a new variable for the stock of telecommunications infrastructure, which includes both main telephone lines, cellular telephones and personal computers:

TELESTOCK = PEN + MOB + PC

The PEN variable in the earlier model is then replaced by the TELESTOCK variable, giving us the following revised model:

$$(3.9) \quad \log(GDP_{it}) = a_{0i} + a_1 \log(TLF_{it}) + a_2 \log(TELESTOCK_{it}) + a_3 t + e^1_{it}$$

$$(3.10) \quad \log(TELESTOCK_{it} + WL_{it}) = b_0 + b_1 \log(GDP_{it}/POP_{it}) + b_2 \log(TELP_{it}) + e^2_{it}$$

$$(3.11) \quad \log(TTI_{it}) = c_0 + c_1 \log(GA_{it}) + c_2 GD_{it} + c_3 (1 - USCAN) \cdot WL_{it} + c_4 (1 - USCAN) \cdot \log(TELP_{it}) + c_5 USCAN \cdot \log(TELP_{it}) + e^3_{it}$$

$$(3.12) \quad \log(TELESTOCK_{it}/TELESTOCK_{i,t-1}) = d_0 + d_1 \log(TTI_{it}) + d_2 \log(GA_{it}) + e^4_{it}$$

$$(3.9') \quad \log(GDP_{it}) = a_{0i} + a_1 \log(TLF_{it}) + (a_2 + a_3 MEDIUM_{it} + a_4 HIGH) \cdot \log(TELESTOCK_{it}) + a_5 t + e^1_{it}$$

However, there is a problem when implementing the demand equation. The waiting list only refers to main lines, and data on waiting lists for the two other variables do not exist. The question is whether there will be excess demand for cell phones and personal computers as well. Probably there will. However, the network for cell phones is more easily expanded than a network for main lines. Whereas a main line network requires separate connection spots and cables for each new client, a cellular base will supply several customers. For each new customer, the main line network needs technical adjustment, while a cellular phone client can be connected to the network with great ease. When a base station is established a number of customers can be connected. One would therefore expect that a potential waiting list for cellular phones is small, thus playing a minor role in the effective demand for cellular phones, provided that the demand for subscriptions and devices is met. Until recently, Internet connection was done by linking up to the fixed telephone network. Today, broadband, which requires a separate net, is developing with speed. There are long waiting lists for broadband connection, but my study runs until 1999 when broadband had a marginal part of the market. Also, as I focus on developing countries, where broadband plays an even smaller part in the market than in the industrialised countries, this is not an important focus. In other words, assuming standard ISDN, the waiting list for main lines also covers the waiting list for Internet connections. To sum up, excluding the waiting lists for cellular phones and Internet connections from the demand equation does not seem to be a problem. Also the supply equation possesses a problem. The telephone price does not refer to cellular telephones or personal computers. There is however a lack of data on price or revenue from these two variables. There exists data on the revenue from the total telecommunications service, but this variable includes the revenue for much more than the three variables studied here. The telephone price is therefore kept as the best available approximation of the telephone, mobile and PC price. The variable abbreviations and descriptions are given in table 3.4 below.

Table 3.4 Variable description

Variable	Description
TLF[a]	Total labour force
PEN[b]	Penetration rate, main telephone lines per capita
GDP[a]	GDP in billion 1995 US$
TELP[a]	Price of telephone service, in 1995 US$, measured as telephone service revenue per main line
GA[a]	Geographic area in sq kilometres
GD[a]	Overall government budget deficit (surplus) in % of GDP
WL[b]	Waiting list for main lines per capita
TTI[b]	Annual telecommunications investment in billion 1995 US$
MOB[b]	Cellular mobile telephone subscribers per capita
PC[b]	Personal computers per capita
USCAN	Dummy variable for United States and Canada
T	Time trend
LOW	Dummy variable set to 1 when PEN ″ 25 percent
MEDIUM	Dummy variable set to 1 when 25 < PEN ″ 50 percent
HIGH	Dummy variable set to 1 when PEN > 50 percent

Sources: [a] WDI 2001; [b] ITU 2002

4 DESCRIPTIVE STATISTICS

The purpose of this chapter is to give an overview of development in GDP and telecommunications, and explore the possibility of a connexion between them. I will investigate the sample as a whole, but also examine whether development is dependent on initial income or varies across time.

4.1 SUMMARY STATISTICS

The summary statistics of the variables applied in the analysis are given in table 4.1. The statistics show the number of observations, the mean, standard deviation and the minimum and maximum values throughout the nineties for the 84 countries in the sample. The number of observations is not identical. The reason is that the missing observations are spread throughout both sample and variables, making it difficult to omit all countries with missing observations and still keep a decent sample. I have therefore chosen to keep countries that have an acceptable number of observations.[12] However, one variable stands out as lacking more observations than the others, namely the budget deficit. In section 6.1 I investigate whether leaving this variable out of the analysis has a significant impact. The table shows that there is a large dispersion in the sample. The difference between the lowest and highest observations of GDP is more than 8500 billion dollars. The telecommunications stock ranges from almost none to universal service. This tendency continues for all the variables. However, the statistics cover a range of ten years, and the minimum and maximum values might have been observed 10 years apart, thus not telling us much.

Table 4.1 Summary statistics, 1990-1999

Variable	Obs.	Mean	Std.dev.	Min.	Max.
GDP, billion constant dollars	833	329	1010	0.76	8580
GDP per capita, constant dollars	833	8272	11218	134	45952
Main telephone lines per 100 capita	840	19.21	21.29	0.11	73.57
Cellular phones per 100 capita	840	4.48	9.99	0	64.14
Personal computers per 100 capita	767	6.35	9.96	0	50.68
Waiting list per 100 capita	764	1.37	2.59	0	20.92
Investment telecommunications, million constant dollars	786	1840	4570	0.56	37100
Telephone revenue per main ine, constant dollars	823	907	552	9	4214
Labour force, million	840	27	88.8	0.45	751
Budget deficit, % of GDP	588	-2.66	4.59	-35.56	16.25
Area, sq km	840	1217833	2675514	610	16888500

When deriving the summary statistics for the initial and final year separately (table 4.2 and 4.3 below), we see that there still exists a considerable difference between countries in the lower and higher ranges. The telecommunications variables suggest an increasing discrepancy. The standard deviation has risen both for the penetration rate of main lines and for cellular telephones and personal computers, indicating that the difference between poor and rich countries has grown. The development of cellular telephones and personal computers has exploded in the top range, while the country holding the minimum value has experienced marginal or no expansion. Conclusions about the sample cannot be drawn from a minimum value alone, but the increased mean and standard deviation together with the minimum value indicate that the less developed countries are falling behind.

[12] See section 3.2 for details

Table 4.2 Summary statistics 1990

Variable	Obs.	Mean	Std.dev	Min	Max
GDP, billion dollars	83	274	897	0.76	6530
GDP per capita	83	7524	10490	144	45952
Main telephone lines per 100 capita	84	16.10	19.54	0.12	68.08
Cellular phones per 100 capita	84	0.47	1.09	0	5.37
Personal computers per 100 capita	68	2.79	4.47	0	21.73
Waiting list per 100 capita	79	1.40	2.32	0	12.62
Investment telecommunications, million dollars	79	1520	3830	1.76	23400
Telephone revenue per main line	81	1028	678	173	3287
Labour force, million	84	25	83.3	0.45	672
Budget deficit, % of GDP	62	-2.91	6.45	-35.56	11.32
Area, sq km	84	1217942	2690626	610	16888500

Table 4.3 Summary statistics 1999

Variable	Obs.	Mean	Std.dev	Min	Max
GDP, billion dollars	82	377	1150	0.96	8580
GDP per capita	82	8987	12267	142	45496
Main telephone lines per 100 capita	84	22.74	23.13	0.18	73.57
Cellular phones per 100 capita	84	15.39	19.51	0	64.14
Personal computers per 100 capita	84	10.54	14.60	0	50.68
Waiting list per 100 capita	64	1.16	2.58	0	17.94
Investment telecommunications, million dollars	73	2270	5160	1.19	28900
Telephone revenue per main line	82	854	522	123	3505
Labour force, million	84	29.1	94.9	0.62	751
Budget deficit, % of GDP	36	-2.65	3.46	-13.02	1.98
Area, sq km	83	1217805	2689819	610	16888500

Looking at the GDP figures, we see the same tendency. The standard deviation rose from 1990 to 1999, indicating that the deviation from the mean, and hence the difference between rich and poor countries, has increased. The poorest country even reduced its GDP per capita by 2 million dollars from 1990 to 1999. The maximum value also decreased, but this is due to an exceptional year for Switzerland in 1990. It is the only year where GDP per capita is larger than in 1999. Still, at the same time, the mean of GDP per capita has increased considerably. This may be a result of a general increase in GDP, or it might be a few rich countries that drove up the mean. The earlier findings indicate the latter.

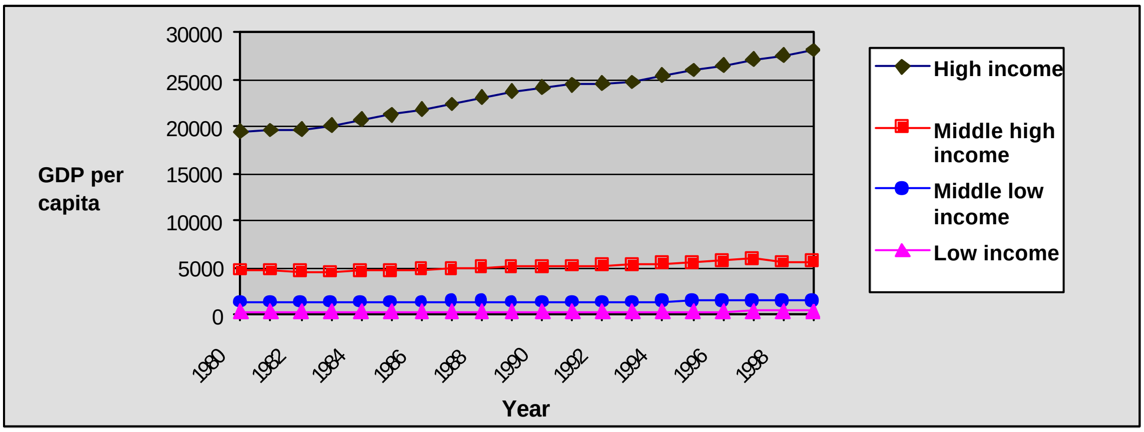
By tabulating the countries with a GDP per capita higher than the mean, it can be shown that it is indeed the rich countries that drive up the mean. Only 25 countries fall into the range above the mean, while 59 countries fall into the range below the mean. This can also be seen by investigating the median, which is 2404 dollars. In order to understand developments over the last 10 years, it is necessary to study the income groups, defined in table 3.1, separately. The summary statistics are given in appendix A, table A.1-A.4.

4.2 SOME DESCRIPTIVE RESULTS

A graphical description of the development in GDP per capita in each income group is given below. I have data of good quality for this variable all the way back to 1980, and consequently look at 20 years in this case in order to get the best idea of the trend.

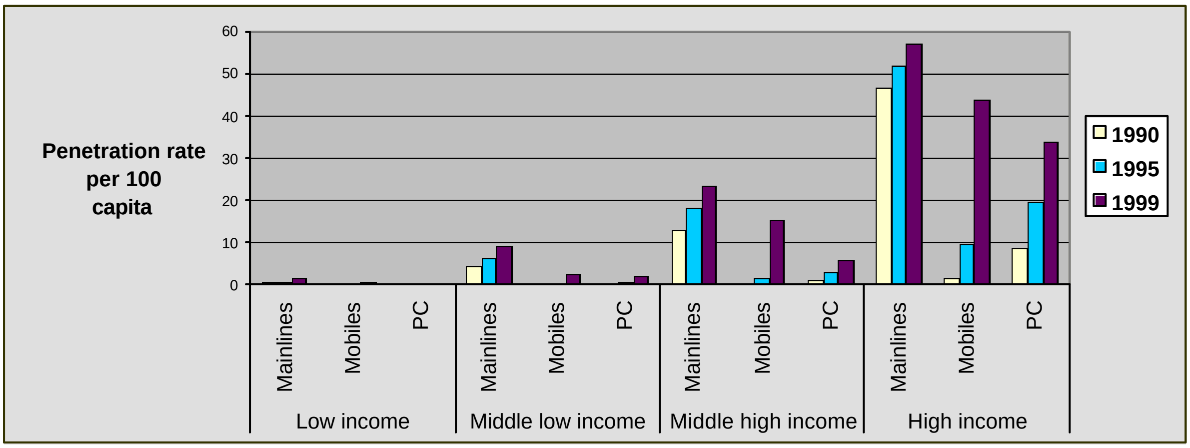
There has been little or no development among the countries in the three lowest income groups. GDP per capita in the lowest income group increased 46 dollars from 1980 to 1999, 131 dollars in the middle low-income group, and rather more, 932 dollars, in the highest. The highest income group, however, made significant progress. The absolute growth from 1980 to 1999 in this group was higher than the absolute value of the GDP per capita in all the three other groups together.[13]

Figure 4.1 GDP per capita development 1980-1999, by income[14]



Some of the same trends are observed for telecommunications development, as shown in figure 4.2. In the period 1990 to 1999 the lowest income group hardly had any increase in infrastructure compared to the other income groups, especially the highest income group. While there was an increase in main lines per 100 inhabitants of 0.9 in the lowest income group, the corresponding growth in the middle low-income group was 4.8, and 10.5 in both the middle high and high-income group. The corresponding figures for cellular telephones were 0.4, 2.3, 15.0 and 41.9, and 0.4, 1.9, 5.0 and 24.8 for personal computers. The developing countries are in other words far behind.

Figure 4.2 Telecommunications development 1990-1999, by income

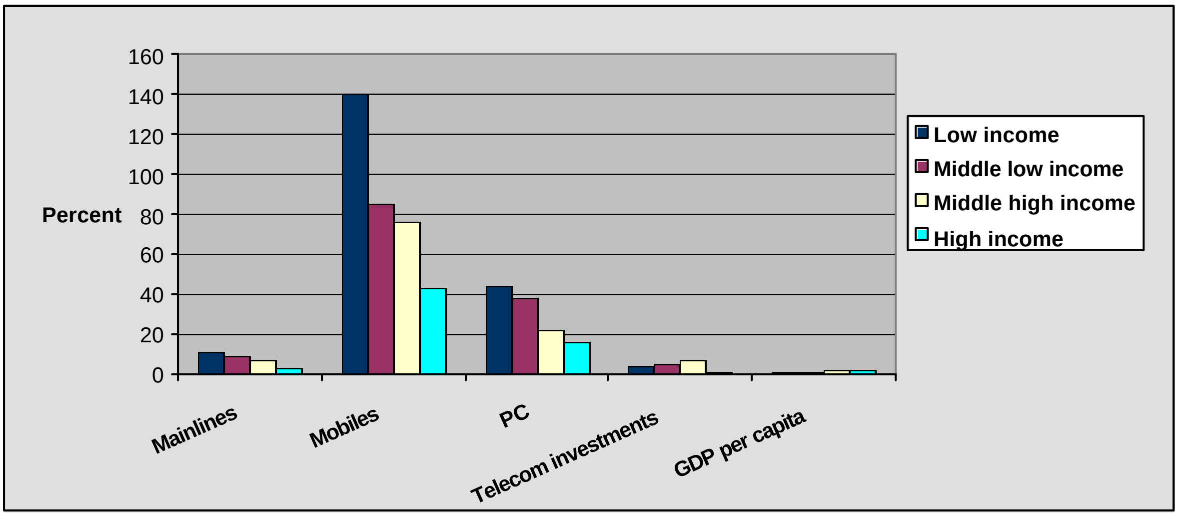


Nevertheless, looking at growth rates in figure 4.3 instead of absolute figures, the picture becomes somewhat different. The largest relative growth has actually taken place in the poorest countries. The lowest income group had the largest growth of both main lines, cellular telephones and personal computers per capita. A possible explanation for the large

[13] The mean of the high-income group increased from 19511 dollars to 28153 from 1980 to 1999, i.e. an augmentation of 8642 dollar. The total mean of the three low-income groups was in 1999 7481 dollars.
[14] Recall from section 3.2 that the dividing of the sample is based on 1990 values of GDP.

growth in cellular telephones is the substitutional role they have had in many developing countries. These countries skipped fixed telephone development all together, possibly due to high fixed costs and credit constraints, and moved on to the development of a cellular network that required lower costs of entry and had the advantage of cash cards that made it accessible to everyone. When it comes to telecommunications investment, the three lowest income groups had a growth of 3.9, 5.1 and 6.8 percent respectively, whereas the highest income group had a much lower growth, i.e. 0.8 percent. Still, the relatively lower growth in the rich countries might be attributed to their already existing stock of telecommunications infrastructure. If the demand is already met, it is not necessary to expand further. This figure indicates that the poor countries are catching up, even if the development is slow. However, for GDP per capita the figures are not that optimistic. The richest countries also had the highest relative growth, with 1.7 percent annual growth. The middle low-income group had the lowest annual growth with 0.9 percent, followed by the lowest group with 1.2 and the middle high group with 1.3 percent.

Figure 4.3 Annual growth of telecommunications stock per 100 inhabitants, telecommunications investment per capita, and GDP per capita between 1990 and 1999, by income[15]

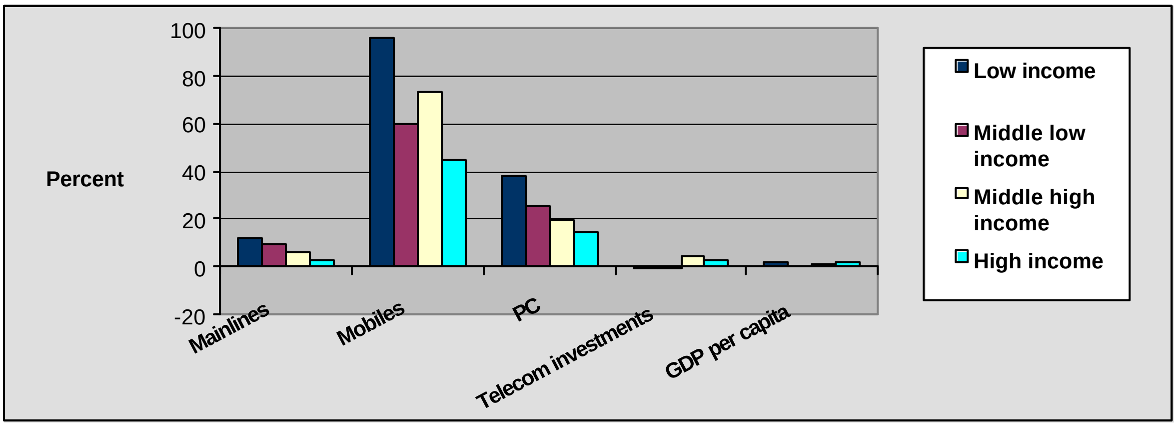


Looking at developments over the last five years in figure 4.4 below, the figures on GDP per capita are somewhat more optimistic in respect of the least developed countries. The lowest income group still had the highest growth in both main lines (12.2 %), cellular telephones (95.7 %) and personal computers (38.2 %). Furthermore, they also had the largest growth in GDP per capita growth with 2.2 percent. However, the investment in telecommunications decreased by 0.3 percent annually for this group during the last five years. The middle low-income group has also experienced a decrease in telecommunications investment. While the least developed countries saw a positive development in the late 90s compared to the 90s as a whole, countries with a middle income did not had the same development. They had a reduction in growth in both main lines, telecommunications investment and GDP the last five years compared to the last ten years, whereas the poorest

[15] The growth rates are calculated by the compounded annual growth formula $r = \left(\frac{x_t}{x_0}\right)^{1/t} - 1$, where x is the income group's mean of main lines, mobiles, personal computers, telecommunications investment and GDP per capita respectively, the subscript 0 is the initial year, here 1990, and the subscript t the last year, here 1999.

countries only had a reduction in investment. Every group had a reduction in the growth in cellular telephones and personal computers, but this is probably due to the explosive growth at the beginning of the 90s. The slowest growth in telecommunications infrastructure over the last five years was seen in the richest countries, in main lines as well as cellular telephones and personal computers. At the same time they had the second largest growth in investment. This is not necessarily contradictory, as a high initial stock implies that a higher investment rate is necessary in order to obtain a relative increase in the stock.

Figure 4.4 Annual growth of telecommunications stock per 100 inhabitants, telecommunications investment per capita and GDP per capita between 1995 and 1999, by income



The observed development can probably be attributed to the fact that the telecommunications "revolution" started earlier in the industrialised countries. While they had their largest growth in the late 80s / early 90s and then experienced a relative slowdown, it was not until the second half of the 90s that the developing countries accelerated their progress. They still grow at an increasing rate. But as mentioned, the industrialised countries far exceed the developing countries regarding absolute growth. A low initial stock makes it easier to achieve a high relative growth rate, and more thorough investigation is necessary to understand the relationship between telecommunications development and economic growth.

4.3 CORRELATIONS

Correlation is a measure of the relationship between two variables that does not depend on the units of measurement, and only indicates a possible relationship between the variables. The correlation between GDP per capita and telecommunications is given in table 4.4.

Table 4.4 Correlation between GDP per capita and telecommunications in logarithmic form[16], total sample

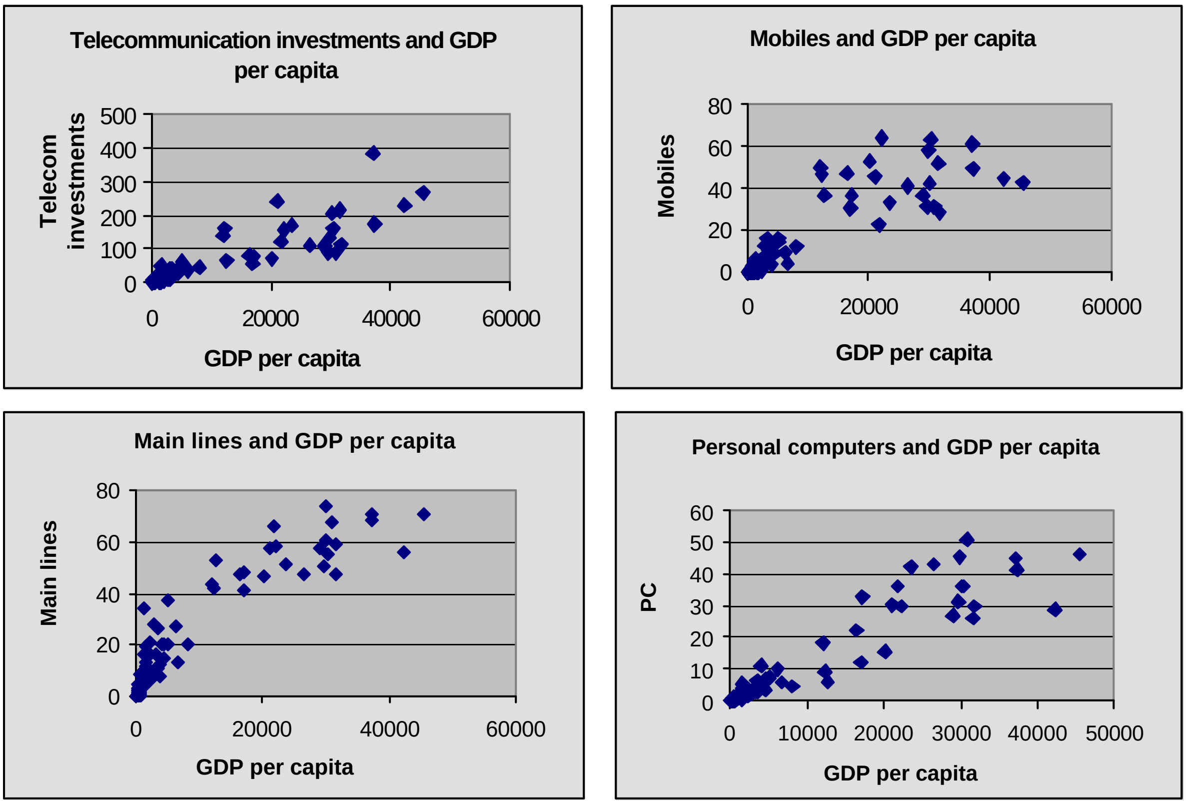
GDP pr cap	Main lines	t-value	Mobiles	t-value	Personal computers	t-value	Telecom investments	t-value
1990-1999	0.9305 [833]	73.22	0.7600 [657]	29.93	0.9069 [637]	54.24	0.9059 [783]	59.78
1990	0.9478 [83]	26.74	0.8577 [43]	10.68	0.9391 [46]	18.13	0.9247 [78]	21.17
1995	0.9341 [84]	23.68	0.9001 [72]	17.28	0.9505 [67]	24.65	0.9231 [83]	21.61
1999	0.9173 [82]	20.60	0.9086 [81]	19.34	0.9577 [80]	29.38	0.9074 [73]	18.20

Number of observations in brackets

[16] The log transformation has reduced the number of observations for mobiles and personal computers since they both have several observations with zero as value.

In the period 1990 to 1999, GDP is strongly correlated with main telephone lines. The association between GDP and PC and between GDP and telecommunications investment is also large, while cellular telephones seem to have somewhat lesser correspondence with GDP. However, cellular telephones were almost non-existent in most countries until the mid-90s. Looking at 1990, 1995 and 1999 separately, the picture changes. While main lines have experienced a declining association with GDP per capita, cellular telephones and PC have had an increasing association. In 1999, the correlation between GDP and PC even exceeded the correlation between GDP and main lines. Still, cellular telephones have had the largest growth in the correlation with GDP. The correlation between GDP and telecommunications investment has diminished, especially in the last five years. Overall, telecommunications has developed towards a high correlation with GDP. All the correlations are statistically significant on a strong level.[17] The correlations between the variables in absolute form in 1999 are charted in figure 4.5.

Figure 4.5 Correlation between GDP per capita and telecommunications in 1999



Until now, I have looked at the correlations for the sample as a whole. It is, however, likely that there are significant differences across countries with various income levels. In table 4.5 below we see that the association between GDP and telecommunications is reduced when looking at the income groups separately. The significance is also reduced considerably. Only the correlations between GDP and main lines or PCs are significant in every income group. These are also the variables with the highest and most stable correlations across income. The annual telecommunications investment is only significant in the two highest income groups, and then on a lower level than was found for the sample as a whole. The lack of association between investment and GDP in the two lowest income groups might be a

[17] The statistical significances are derived from t-values, calculated by running regressions between GDP and each telecommunications variable separately.

result of the low initial stock of telecommunications. As discussed earlier, telecommunications is subject to positive network externalities, implying that the larger the network, the more utility is generated from additional investment. Furthermore, a small network requires a relatively larger investment than a large network to achieve the same expansion, since a large network can partly utilise already existing cables.

Table 4.5 Correlations between GDP per capita and telecommunications in log form in 1999, by income

GDP pr cap	Main lines	t-value	Mobiles	t-value	Personal computers	t-value	Telecom investments	t-value
Low	0.6003 [21]	3.27	0.8122 [20]	5.91	0.5833 [19]	2.96	0.0377 [18]	0.15
Middle low	0.6910 [21]	4.17	0.3269 [21]	1.51	0.6486 [21]	3.71	0.1141 [18]	0.46
Middle high	0.6081 [19]	3.16	0.7049 [19]	4.10	0.6233 [19]	3.29	0.8206 [16]	5.37
High	0.6284 [21]	3.52	0.1999 [21]	0.89	0.5668 [21]	3.00	0.6607 [21]	3.84

Number of observations in brackets

The correlation for cellular telephone subscribers differs to some extent from the other variables. In the lowest income group, cellular telephone is the variable that has the highest correlation with GDP, and the correlation is significant. This is opposed to the highest income group, which has a significantly lower correspondence between number of subscribers and GDP than the other groups. The association is weak or non-existent, since the t-value is low, indicating insignificance. These findings are consistent with the assumption that cellular telephones have become a viable alternative to fixed telephones in the least developed countries, whereas the fixed telephone was widely developed in the industrialised countries before the introduction of cellular telephones. They only serve as a supplement without adding considerable value. However, the correlations for the two middle-income groups do not fall into this pattern. The correlation is relative low and insignificant for the low middle group, while there is a considerable rise in both correlation and significance for the middle high income group.

Overall, there are indications that there exists a relatively strong relationship between GDP and telecommunications stock in the least developed countries, though the results for investment are poor. The cluster with the highest correlations in general is the middle high-income group, while the highest income group follows with a slightly lower correspondence. This indicates that a certain level of telecommunications is needed in order to achieve highest utility, but there is also a degree of saturation where the value of additional development stagnates and finally declines.

However, the correlations only tell us if these variables vary together, not whether there is a causal relationship between them or how large a potential outcome is. It might as well be the GDP level that causes the degree of development of telecommunications. Nevertheless, the lower correlation for low-income countries supports the notion that countries with low GDP per capita invest less and thus have a lower infrastructure. But it does not explain the lower figures for the high-income group. This might indicate a possible one-way causality from telecommunications to economic growth. On the other hand, the correlations might as well be caused by a third unobserved variable. An expansion in the financial sector would presumably require telecommunications investment, and at the same time have a positive effect on economic growth. Correlations can be used to deduce a hypothesis, but more sophisticated tools are necessary to verify them. In the following chapters I will proceed with an econometric analysis that is better suited to examine whether there exists a causal relationship running from telecommunications development to economic growth. Chapter 5 contains a discussion of the methodology underlying the model, while the analysis and the results are elaborated in chapter 6, followed by concluding remarks in chapter 7.

5 ECONOMETRIC METHODOLOGY

As discussed in chapter 2 and 3, the choice of econometric model is based on differing considerations. In order to account for reverse causality, a simultaneous equation approach, endogenising telecommunications development into the aggregated economy, has been chosen. The simultaneous equations are estimated by a seemingly unrelated regression, together with fixed effects to account for country specific effects. In this chapter, I will discuss the methodology underlying these models. First a general panel data model is examined, before I continue elaborating on a fixed effects model and a seemingly unrelated regression model. Finally, I discuss possible problems the sample contains.

5.1 PANEL DATA

My analysis is based on a panel data approach. Panel data combines a cross-sectional dimension *n* with a time-series dimension *T*. Each entity is observed at two or more time periods. The two dimensions allow us to treat more complicated models than in the case of cross-sectional or time-series data separately. A panel includes a wider range of observations. This increases the degrees of freedom, and the collinearity between explanatory variables is recognised, thereby improving the accuracy of the estimates.

The possibility of using information on both time specific-effects and individual features for each entity makes it easier to model unobserved heterogeneity. Unobserved heterogeneity is a frequent problem in econometric studies. By using panel data, it is possible for the estimates of observed and included variables to take into account the factors we cannot observe or for other reasons are left out. The estimates are controlled for these variables, and we are left with the 'pure' effect of the variables included in the regression. Ignoring unobserved heterogeneity could lead to inconsistent or meaningless estimates. A basic linear panel data model for entity i in period t is given by:

$$(5.1) \quad y_{it} = a_i + \mathbf{ß}'\mathbf{x}_{it} + e_{it} \qquad ,i=1,\ldots,n,\ t=1,\ldots,T.$$

where y is the dependent variable for entity i in period t, $\mathbf{ß}'$ is a vector of *K* coefficients, $\mathbf{x}_{it}$ is a vector of *K* explanatory variables, and e_{it} is the error term (Greene, 2000). The constant a_i is assumed to be constant over time, but to diverge between the cross-sectional entities. However, if this constant is the same also across entities, the model can be estimated by the ordinary least square method (OLS), leading to consistent and efficient estimates of a and b. My panel consists of data for different countries, and I expect to find unobservable differences between them that are related to the distinctive characteristics of each country. OLS would therefore be inefficient. The differences between the countries are assumed to be fixed constants, making it appropriate to apply the fixed-effects model.

5.2 FIXED-EFFECTS MODEL

The fixed-effects model looks at the constant a_i in the panel data model (5.1) as a fixed constant, specific for each observation unit. In my sample the observation units are countries. A dichotomous dummy for each country is included in the model, hence the model is also referred to as the least square dummy variable model (LSDV). The simple panel data equation (5.1) can now be written as:

(5.2) $\mathbf{y}_i = \mathbf{d}_i a_i + \mathbf{X}_i \mathbf{ß} + \boldsymbol{e}_i \quad , i = 1,\ldots n$

$\mathbf{y}_i$ and $\mathbf{X}_i$ are the T observations for the *i*th unit, and $\boldsymbol{e}_i$ is the T x 1 vector of disturbance. a_i is the unknown parameter to be estimated, and $\mathbf{d}_i$ is the dummy variable which is 1 for individual i, zero for the others. The underlying assumptions for this model are that the entity-specific effects a_i are constant, and that all $\mathbf{X}_i$ are independent of all $\boldsymbol{e}_i$.

The estimator of b, called the fixed-effects (FE) estimator, is computed by subtracting the group averages from each observation, thereby eliminating the constant a_i, and then estimating the transformed model with OLS (Verbeek, 2000). The estimator for b obtained by this transformation is often called the within group estimator (WG) since it uses the variation within the *i*th group of observations. If the underlying assumptions are fulfilled, the fixed-effects estimator of b is the best linear unbiased estimator (BLUE), and it is consistent when n or T approaches infinity[18].

On the other hand, the model loses degrees of freedom compared to a model without individual effects. Estimating (n-1) extra parameters exacerbates the problem of multicollinearity among the regressors. If $a_1 = a_2 = ... = a_{n-1} = 0$ a pooled OLS estimator[19] is more efficient than the fixed-effects estimator. The restriction that the coefficients of the n-1 dummy variables are equal to zero can be tested with a F-test.

5.3 SEEMINGLY UNRELATED REGRESSION MODEL

The empirical model is based on the endogenous growth theories. By estimating an aggregated production function together with a demand, supply and production function for telecommunications, investment in telecommunications is treated as endogenous in the model. The error terms account for everything that the regressors do not explain, for instance omitted variables and economic shock. A negative shock would presumably be followed by a drop in both demand, supply and production. In other words, the shock is common for all the error terms, making them simultaneously correlated. We are faced by a variance-covariance matrix for the error term that is not block diagonal.[20] By estimating the equations in the system the error covariance matrix structure is recognized, and the estimates become more efficient. This can be done by the Seemingly Unrelated Regression model (SUR), which uses GLS on the system since the assumption of $\operatorname{cov}(e_{it}, e_{jt}) = 0$ is violated. A Seemingly Unrelated Regression model is given by the following stacked model (Greene, 2000):

$$(5.3) \quad \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_M \end{bmatrix} = \begin{bmatrix} \mathbf{X_1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{X_2} & \cdots & \mathbf{0} \\ & \vdots & & \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{X_M} \end{bmatrix} \begin{bmatrix} \mathbf{ß}_1 \\ \mathbf{ß}_2 \\ \vdots \\ \mathbf{ß}_M \end{bmatrix} + \begin{bmatrix} \mathbf{e}_1 \\ \mathbf{e}_2 \\ \vdots \\ \mathbf{e}_M \end{bmatrix},$$

$$\mathbf{y} = \mathbf{xß} + \mathbf{e}$$

[18] However, the FE estimator of the individual effects a_i is only consistent if T→ ∞. If T is fixed and n→ ∞ the FE estimator of a_i is inconsistent since the number of this parameter increases as N increases (Baltagi, 1995).

[19] We are in that case faced by a standard linear regression model where the data are pooled and can be estimated efficiently with OLS.

[20] The off-diagonal elements do not consist of zeros.

As the name suggests, the equations are seemingly unrelated, only linked by their disturbance. The estimates of GLS in a system are more efficient than OLS on each equation on the conditions that the equations are not totally unrelated, the explanatory variables are not identical, and the regressors in one block of equations are not a subset of those in another (Greene, 2000).

5.4 METHODOLOGICAL PROBLEMS

Sample selection bias

When carrying out research on developing countries one faces a problem: The lack of data. The countries with insufficient data are also often the poorest countries. By omitting these countries, there is a danger of not obtaining a representative sample. The data in the World Development Indicators database are mostly collected from national statistical agencies, central banks, and customs services. However, many developing countries lack the resources to train and maintain skilled staff, and to obtain the equipment needed to measure trends in an accurate way. By omitting countries with large fluctuations in GDP, I hope to account for the problem of misleading data. Still, it is a counterbalance between keeping a representative sample and leaving out biased data.

By categorising the countries into four groups based on criteria set in the WDI database, it is possible to check whether the chosen sample is representative for the total WDI sample.[21]

Table 5.1 Distribution in income groups compared to the total sample in the WDI database

Income group	Low	Middle low	Middle high	High	Total
1999 GNI per capita	< $755	$755 - $2,995	$2,996 - $9,266	$9,266 <	
Observations	24	21	16	23	84
Percent of selected sample	29 %	25 %	19 %	27 %	100
WDI database	64	55	38	50	207
Percent of total WDI sample	31 %	27 %	18 %	24 %	100

GNI: gross national product or income measures the total domestic and foreign value added claimed by residents. GNI comprises GDP plus net receipts of primary income (compensation of employees and property income) from non-resident sources. The World Bank uses GNI per capita in US dollars to classify countries for analytical purposes.

Looking at the sub-categorising of my sample in table 5.1, one can see that 29 percent of the countries belong in the low-income group, which is only slightly less than for the whole sample, where 31 percent belong to this group. Comparing all the income groups with the WDI sample shows that my distribution is fairly accurate, even if the two highest income groups are slightly over-represented. In absolute figures, however, the two lowest income groups are in all the largest, with 54 percent of the sample. The largest sub-group is the lowest income group. 54 of the countries fall into the category of developing countries, and an additional 9 are transitional or more advanced developing countries, as defined by the Development Assistance Committee of the OECD (2001). 15 of the developing countries are

[21] Recall from section 3.2 that I then categorised the countries by initial income, since this is commonly used to explain subsequent growth. However, I do not have data on GDP for the total population from which the sample is drawn. In order to be able to compare the sample with the total population I have chosen to follow the categories used by the WDI database in this section, which is based on 1999 GNI per capita. It is the division outlined in table 3.1 and 3.2 that will be used in later analysis.

also defined as least developed countries. This group is in other words not as well represented as wanted, but this is partly due to the low population in some of these countries. 14 are excluded on that ground, while the other 20 do not have sufficient data.

Despite the low representation of least developed countries, the high rate of developing countries indicates that the sample is fairly representative after leaving out countries with few and deceptive data. However, this does not exclude the possibility of a selection bias in my sample. I will not elaborate on this subject further, but it should be borne in mind that the generalization of the final results to the whole population should be done with care.

Omitted variable bias

Economic growth is a complex issue. There are infinite numbers of variables that affect growth. Only relevant variables are supposed to be included in an econometric specification. Still, it is often difficult to decide which variables are relevant, and one risks omitting relevant variables. As a result the observed correlation may be spurious, i.e. the product of a third unknown causal variable. In single cross-section regressions the country-specific aspects of the aggregated production function are not accounted for, making the error term, which now subsumes the country-specific effect, correlated with the explanatory variables. This leads to omitted variable bias, resulting in inconsistent estimates of both the coefficients of the explanatory variables and the variance. It is possible that the coefficient estimates are more precise in the model with omitted variables than in the correct specified model, because the variance in the mis-specified model is often smaller. The variance in the model with an omitted variable is given by $\mathrm{Var}[\mathbf{ß}_1] = s^2(\mathbf{X}_1'\mathbf{X}_1)^{-1}$, while the variance in the correct model is equal to $\mathrm{Var}[\mathbf{ß}_{1,2}] = s^2(\mathbf{X}_1'\mathbf{M}_2\mathbf{X}_1)^{-1}$ (Greene, 2000). Whether the variance in the mis-specified model actually is smaller than the variance of the correct model depends on s^2 and $\mathbf{M}_2$, and the relationship between them. However, it is not possible to test hypotheses about the coefficients due to the biased variance. By using fixed-effects regression one can correct for the country-specific part of the bias.

Simultaneous causality bias

The complexity of economic growth also leads to difficulties in distinguishing the different economic effects from another, and there is often a mutual influence between the variables. Simultaneous causality bias is defined as causality that runs both from the explanatory variables, X, to the dependent variable, Y, and from Y to X (Hsiao, 2003). In other words, it is a question of what we have actually measured, the influence of telecommunications development on economic growth, or economic growth on telecommunications development.

Failing to appreciate this reverse causality means overstating the estimates, which might explain the high correlation between public infrastructure investment and economic growth found in early studies[22]. Recall from section 3.4 that the simultaneity causality bias is sought to be recognised by specifying a system of simultaneous equations that endogenise telecommunications development into the aggregated economy.

[22] For an example, see Aschauer, 1989.

6 ECONOMETRIC ANALYSIS

The econometric analysis presented in this chapter is based on a choice of models and specifications. Mutual for every model is that the growth effects from telecommunications development are estimated by a simultaneous equation approach. By using a seemingly unrelated regression (SUR) to estimate the equations in a system, the simultaneous correlation between the error terms is accounted for. The regressions are first run with a simple seemingly unrelated regression method (SUR), before turning to a more sophisticated method where the SUR model is estimated together with a fixed-effects model, allowing for country-specific effects. To begin with, the fixed-effects model is specified with main lines as the only variable measuring telecommunications, given that this is the variable generally used in earlier studies of telecommunications. Then the numbers of cellular telephones and personal computers are added as explanatory variables. Finally, a variable measuring different levels of telecommunications penetration is included in order to test whether a critical level of infrastructure is required before growth effects are found.

The analysis is carried out for 84 countries over the period 1990 to 1999. The regressions in this chapter are based on the specification in equation 3.5 to 3.12. My purpose is to investigate whether the growth effects from telecommunications development are dependent on income, in other words if there are significant differences between developing countries and industrialised countries. Consequently, the regressions are run both for the sample as a whole, and for industrialised and developing countries separately. This is done by including dummies for the two sub-samples. To investigate whether the results are robust regardless of method, an alternative specification is applied in the last section.

6.1 A SEEMINGLY UNRELATED REGRESSION APPROACH

The regressions in this section are estimated in a system using SUR. It turns out that several countries drop out of the analysis, due to the lack of observations of budget deficit as seen in the descriptive statistics. The regressions are run both with the budget deficit variable, reported in the first column (model 1a), and without it, reported in the second column (model 2a) in order to test whether including the variable in the analysis is a necessity.

First I look at model 1a, the regression that includes the budget deficit variable. The results from the output equation show that the number of main telephone lines (PEN) is positively and significantly related to the GDP. The elasticity is 0.672. This means that a one percent increase in the penetration rate increases the output by 0.672 percent, a result quite large. To illustrate the effect of the penetration rate on output we look at Uruguay, which has a penetration rate in 1990 close to the sample average. They increased their penetration rate from 13.43 in 1990 to 27.07 in 1999. This is equal to a compounded annual growth rate of 8.10.[23] The corresponding compounded annual growth for GDP per capita was 2.73. Further calculations show that the compounded annual growth effect from telecommunications to GDP per capita is equal to 7.58 percent[24], implying that telecommunications alone would

[23] The growth rate of the penetration rate and GDP between 1990 and 1999 is given by $\log PEN_{99} - \log PEN_{90}$.

[24] The compounded annual growth effect of main lines on GDP is given by

$$\left[\left(\frac{\dfrac{PEN_{99}}{0.74 - PEN_{99}} - \dfrac{PEN_{90}}{0.74 - PEN_{90}}}{\dfrac{PEN90}{0.74 - PEN_{90}}}\right)a_2 + 1\right]^{1/10}$$

The term in parenthesis is the asymptotic growth rate over ten years, adjusted for the transformation the penetration rate is subject to in the analysis. By multiplying this term by the

Table 6.1 Results from estimating the growth effects of telecommunications using SUR

	1a - SUR with budget deficit		1b – SUR without budget deficit	
Variable	**Coefficient**	**t-value**	**Coefficient**	**t-value**
Output equation – Dependent variable: logGDP				
LogTLF	0.914	69.51	0.901	85.44
LogPEN	0.672	58.52	0.665	77.45
Year	-0.025	-3.29	-0.023	-4.05
Constant	62.024	4.03	57.317	5.07
Demand equation – Dependent variable: log(PEN + WL)				
log(GDP / POP)	1.320	70.31	1.316	90.56
LogTELP	-0.373	-10.93	-0.332	-12.83
Constant	-9.724	-46.05	-9.958	-54.52
Supply equation – Dependent variable: logTTI				
LogGA	0.313	5.55	0.053	1.09
GD	0.009	0.43	-	-
WL* nonUSCAN	-11.065	-3.08	-14.562	-4.40
logTELP * nonUSCAN	0.262	1.74	-0.467	-3.57
logTELP * USCAN	0.557	3.58	0.015	0.11
Constant	14.169	10.33	21.919	18.12
Production equation – Dependent variable: log(PEN / PEN_1)				
LogTTI	0.010	4.21	0.011	5.45
LogGA	-0.002	-0.76	-0.003	-1.11
Constant	-0.073	-1.41	-0.075	-1.71
Observations	469		653	

give an annual aggregated growth of 7.58 percent. Taking into account that the actual growth in GDP per capita was 2.73, this is clearly too large an estimate. The questionably large coefficient for the main line variable indicates that large effects, not spoken for in the model, are intercepted in the variable and that an alternative estimation should be considered. The fixed effects model introduced in the next section takes this problem into account. Looking at the other variables in the output equation we see that the total labour force is positively and significant correlated with output at a 0.914 level, as was expected (recall table 3.3), while the time trend is negative and significantly related. I would have expected a positive correlation, but the coefficient has probably marginal effect on the other results.

In the demand equation, the elasticity between GDP per capita and demand is 1.320. Since the income elasticity of demand is significantly larger than one, it means that the telecommunications demand is elastic to income changes. Telecommunications is in other words a luxury good. This must be understood in the light of the sample investigated. 63 out of 84 countries are classified as developing countries, and it is plausible to look at telecommunications as a luxury good in these countries. In developed countries, however, telecommunications is usually looked upon as a necessary good. In the latter group, there is an average penetration rate of 0.51 main lines per capita, which means more than universal service if each household on average consists of 2.5 people. This implies that increased income would result in less than proportional increased demand. The income effect indicates that there is a two-way causality between output and telecommunications. The demand is negatively and significantly dependent on telephone price, measured by the TELP variable. The elasticity is –0.373, indicating that demand is relative inelastic to price, a somewhat surprising result since telecommunications is often looked upon as a luxury good, as seen

elasticity of the penetration rate on GDP we get the additional effect of telecommunications on GDP through 10 years. The additional effect is added to one, representing the initial growth. Finally, the expression is then raised by 1/10 in order to find the annual effect. a_2 is the coefficient of the PEN variable.

above. Still, until the cellular telephone emerged, fixed telephones had few substitutes, making an inelastic demand more likely. A somewhat surprising result is the negative constant, since negative demand is impossible. It might result from the TELP proxy variable comprising both price and quantity, or it may indicate another misspecification in the model.

In the supply equation the geographic area, which is stated in absolute value, is positive, and significantly related to the supply. In other words, large countries invest more in telecommunications than small countries. The budget deficit is positively related to supply. However, the coefficient is not significant and the effect is very small, 0.009. Recall from section 3.5 that the expected effect of a budget deficit on supply was uncertain. The positive and negative effects might have neutralized each other, resulting in the small coefficient seen here. Alternatively, the market structure of the telecommunication industry is one such that the state's budget deficit is unimportant. The waiting list is negatively correlated with supply, whereas a positive correlation was expected. This means that the waiting list is a result of supply constraints rather than excess demand. Finally, the telephone price is positively related to supply. The elasticity is higher for the United States and Canada, as seen in the USCAN variable, than for the rest of the sample, as seen in the nonUSCAN variable. This complies with the theory that the price elasticity of supply in these countries is somewhat different than in the rest of the sample, due to the privately driven market the suppliers in USA and Canada are operating in. A private supplier is more sensitive to price than a public supplier.

From the production equation we learn that the telecommunications production is positively related to annual telecommunications investments, while the geographic area is negatively correlated, yet on a low level. The elasticity is only 0.002 and not significant. To summarize, it was only the waiting list that did not have the expected sign in these equations. All the other variables corresponded to the predictions in table 3.3.

I proceed by looking at the results for Model 1b, where the budget deficit variable is taken out of the analysis. The results in model 1a suggest that is both very low and insignificant. We see that the results in model 1b are quite stable compared to model 1a for the three equations where the budget deficit variable does not enter as a regressor in either of the models. In the supply equation the results show a fairly large change, though. Nevertheless, since the purpose of this analysis is to study the output equation where the results were stable I chose to accept the discrepancies in the supply equation, and exclude the budget deficit variable from the analysis. Note also that if the variable were to be kept, 15 countries would drop out of the analysis, 9 of which belong to the lowest income group. It is of greater value to maintain a representative sample than to keep the budget deficit variable.

Overall, it seems as though telecommunications does have substantial growth effects. However, the magnitude of these effects and some of the other results call for an alternative model, allowing for country-specific effects. Recall from chapter 5 that failing to allow for individual effects when they are in fact present leads to inconsistent estimates. A solution is to use a fixed-effects model, where the individual characteristics are taken into account. the removal of the budget deficit variable is acceptable, since the coefficient

6.2 FIXED EFFECTS MODEL APPROACH

The estimations in this section are based on the fixed-effects model, combined with the SUR model. First I will investigate a simple model with only main telephone lines representing telecommunications infrastructure, making it possible to compare the results with the ones based on the simple SUR model in model 1b. The estimations are reported as model 2a in table 6.2 below.

Table 6.2 Results from estimating the growth effects of telecommunications using SUR and fixed effects [25]

	2a – Standard regression		2b - Additional telecom variables	
Variable	**Coefficient**	**t-value**	**Coefficient**	**t-value**
Output equation – Dependent variable: logGDP				
logTLF	0.824	11.40	0.882	9.54
logPEN	0.101	8.82	0.089	6.89
logPC	-	-	-0.007	-1.02
d_PC	-	-	-0.031	-0.77
logMOB	-	-	0.007	2.31
d_MOB	-	-	0.048	1.72
year	0.006	2.94	0.005	1.40
constant	0.473	0.14	2.758	0.48
Demand equation – Dependent variable: log(PEN + WL)			log(TELESTOCK+ WL)	
log(GDP / POP)	1.294	86.15	1.329	78.19
logTELP	-0.615	-17.44	-0.601	-15.52
constant	-7.919	-32.60	-8.028	-29.92
Supply equation – Dependent variable: logTTI				
logGA	0.099	2.00	0.105	2.06
WL* nonUSCAN	-10.314	-2.99	-111.184	-2.92
logTELP * nonUSCAN	-0.057	-0.43	-0.061	-.043
logTELP * USCAN	0.414	2.83	0.366	2.41
constant	18.570	14.83	18.720	14.22
Production equation – Dependent variable: log(PEN / PEN_1)			log(TELESTOCK / TELESTOCK_1)	
logTTI	0.010	4.92	0.016	4.49
logGA	-0.001	-0.44	-0.006	-1.57
constant	-0.074	-1.70	-0.059	-0.76
Observations	653		581	

We see that the coefficients are considerably smaller than for the estimation without fixed effects in table 6.1, model 1b. The correlation between output and penetration rate is reduced from 0.672 to 0.101. The latter is a much more sober result. Taking the example of Uruguay, the compounded annual growth effect is now 1.51 percent. In other words, the main lines count for 55 % of the GDP per capita annual growth of 2.73 %. This result is more moderate than the estimates in model 1, yet still very large. In table 6.3 below, I have calculated the compounded annual growth rates for GDP per capita, main lines and main lines effect on GDP per capita for the sample together, and for each income group separately. The average main lines contribution to GDP for the total sample is 1.57 percent when PEN is equal to 0.101. At the same time the compounded annual growth of GDP is only 1.31 percent.

Table 6.3 Average compounded annual growth rates, by income

Income group	GDP per capita		CAGR	Main lines per 100 inhabitants		CAGR	Main lines contribution to GDP	
	1990	**1999**	**90-99**	**1990**	**1999**	**90-99**	**PEN = 0.672**	**PEN=0.101**
Low	335	373	0.97	0.61	1.47	7.89	5.52	1.29
Middle low	1323	1437	0.79	4.34	9.11	10.26	7.65	1.62
Middle high	5037	5671	1.78	12.84	23.27	7.80	7.07	1.49
High	24193	28153	1.74	46.63	57.12	2.33	7.74	1.89
Total sample	7524	8987	1.31	16.10	22.74	7.07	6.99	1.57

[25] TELESTOCK = PEN + MOB + PC

The size of this result does not seem plausible, though it indicates that main lines have a significant impact on economic growth. The separate income groups show us that it is the richest countries that have the highest contribution from main lines to GDP, with 1.89 percent. They are followed by the middle low-income group, middle high-income group, and finally the low-income group with 1.29 percent. Relative to GDP growth, the highest contribution is found in the middle low group, followed by the low-income countries, the high-income countries and the middle-high countries. It is only in the latter group that the contribution from main lines is smaller than the compounded annual growth rate of GDP. If we make the assumption that all other factors are constant as the penetration rate increases, 84 percent of the growth can be attributed to main lines contribution in this group. These results are very high, and might be caused by the exclusion of the stock variable. Some of the effects from this variable might be incorporated in the PEN variable. When I tested the significance in the group of OECD countries, the PEN variable did increase somewhat when the stock variable was left out, compared to when it was included. However, since I do not have data on the stock variable for the majority of the countries, this cannot be fully tested. The compounded annual growth rates for each country are reported in appendix B.

The other coefficients do not alter markedly compared to the analysis reported in table 6.1, model 1b. It seems as though some of the effects captured in the coefficients in model 1b were the result of omitted variables. The introduction of country-specific effects has led to an overall reduction in the coefficients, indicating that the fixed-effects specification is more correct. The most significant difference between the non-fixed-effects estimation in model 1b and the fixed-effects estimation in model 2a, except for the reduction in PEN, is the price elasticity (TELP) in the supply equation. While the price elasticity was only significant for the nonUSCAN countries in the first estimation, it is only significant for USA and Canada in the fixed-effects estimation. The latter results are more reasonable. USA and Canada have a private market for supply, usually more price sensitive. Several other countries are dominated by a public market, relative insensitive to price. Also, recall the surprising finding of a significant negative correlation between price and supply in model 1b. In the fixed-effects estimation the negative correlation for nonUSCAN countries is not significant, while the positive correlation found for USA and Canada is significant. The latter elasticity is 0.414, indicating an inelastic relationship. Overall, the fixed-effects estimation in model 2 seems to fit the data better than the non-fixed effects estimation in model 1. In the remaining analysis, I will apply a fixed-effects model. I will only comment on the telecommunications variables in the output equation, unless there are significant changes in some of the other coefficients.

I proceed with model 2b, where additional telecommunications variables are introduced into the analysis. These are personal computers and cellular telephones. The new variables create some problems during the log-transformation. They both have several observations that are zero, thus resulting in missing observations when transforming into natural logarithm. I have attempted to resolve the problem by replacing most of the missing observations by zero. However, the natural logarithm of a number asymptotic to zero is not zero, but a negative number approaching -100. Therefore, I have created dummies that measure the marginal effect of the observations that are not zero. The dummies are named d_PC and d_MOB, and they are equal to one if logPC / logMOB > 0, and equal to zero if logPC / logMOB = 0.

The correlation between cellular telephones and output is small. The elasticity is 0.007, which implies that a one percent increase in the penetration rate of cellular phones increases output by 0.007 percent – not a considerable impact, but the effect is statistically significant. The correlation between the number of personal computers and output is small and insignificant. The influence from main lines to economic growth decreases compared to model 2a. The coefficient is now equal to 0.089, giving a compounded annual growth effect for the sample as a whole of 1.40 percent, compared to 1.57 with the coefficient in model 2a. One might expect the three telecommunications variables to have corresponding properties, thereby risking a possible multicollinearity problem between them. Consequently, I have derived the correlations between the explanatory variables PEN, MOB and PC. The highest correlation is found between main lines and personal computers. The correlation is 0.8468 and significant, indicating high multicollinearity between them. The correlations between main lines and mobiles and between mobiles and personal computers are also significant. They are 0.6332 and 0.7845 respectively. There will always exist multicollinearity to a certain extent in passively generated economic data, and these correlations are at an acceptable level.

6.3 A CRITICAL LEVEL OF TELECOMMUNICATIONS

The theory of network externalities implies that the growth effects from telecommunications might be an increasing function of the telecommunications network. An interesting question in that regard is whether there exists a critical level before the maximum utility of telecommunications infrastructure is achieved. Dummies for the level of penetration rate of main lines, mobiles and cellular telephones are now introduced into the analysis. A medium penetration rate of main lines is defined as a rate between 25 and 50 lines per 100 inhabitants, while a high penetration rate is defined as more than 50 lines per 100 inhabitants. 69 percent of the observations fall into the range of the low penetration rate, 18 percent in the medium range, and 14 percent in the high range. For mobiles, I have only introduced two levels, low and high. A majority of the countries are clustered in the lower range of the scale: 80 percent has a penetration rate below 5 per 100 inhabitants. It does not seem reasonable to divide the sample into more than two. Hence, the low penetration rate is defined as less than 5 mobiles per 100 inhabitants, and the remaining 20 percent with more than 5 per 100 as high penetration. Even if no significant results were found for personal computers, there might exist significant effects within the total range. For the same reason as mobiles, only two levels for this variable are introduced. 77 percent of the countries fall into the range of a penetration rate below 15 mobiles per 100 inhabitants, and 23 percent fall into the range above.

From table 6.4, model 3, we see that it has not been able to detect a critical level of telecommunications. On the contrary, the higher the initial penetration rate of main lines and mobiles, the lower is the impact on output, indicating that it is the countries with lowest initial penetration rate, often the poorest countries, that benefit most from telecommunications development. For personal computers there are indications of a critical level. The high penetration rate group has a positive elasticity of 0.015, which means that countries with a high penetration rate experience an additional growth in output of 0.015 percent when the penetration rate increases by one percent, compared to those countries with a low penetration rate. However, neither the latter result nor the results on mobiles are significant.

I also tested an alternative specification where a scaled version of the penetration rate was introduced: $\log(GDP_{it}) = a_{0i} + a_1\log(TLF_{it}) + a_2\log(PEN_{it}) + a_3\log(PEN_{it}^2) + a_4 t + e_{it}^1$. The alternative specification tested for scale effects independent of the precise level rather than defining exactly what was medium and high penetration rate. However, this specification did not result in any reasonable results, and these are not reported.

Overall, the results do not support the critical level hypothesis. There seem to be no additional growth effects from an increasing penetration rate, which contradicts the notion of positive network externalities. The finding of a decreasing growth effect from main lines if the penetration rate is high indicates that there might be larger growth effects in developing countries than in developed countries, since it is the latter that generally have a high initial penetration rate.

Table 6.4 Testing for the presence of a critical level of telecommunications, using SUR and fixed-effects

	3 – Critical level of telecommunications	
Variable	**Coefficient**	**t-value**
Output equation – Dependent variable: logGDP		
LogTLF	0.809	8.25
LogPEN	0.101	7.22
logPEN * MEDIUM	-0.024	-1.14
logPEN * HIGH	-0.044	-2.68
LogPC	-0.008	-1.23
d_PC	-0.042	-1.00
logPC * HIGH	0.015	1.63
LogMOB	0.007	2.31
d_MOB	0.047	1.67
logMOB * HIGH	-0.002	-0.61
Year	0.006	1.83
Constant	0.880	0.15
Demand equation – Dependent variable: log(TELESTOCK + WL)		
log(GDP / POP)	1.329	78.19
LogTELP	-0.601	-15.51
Constant	-8.020	-29.93
Supply equation – Dependent variable: logTTI		
LogGA	0.105	2.06
WL* nonUSCAN	-11.202	-2.93
LogTELP * nonUSCAN	-0.062	-0.43
LogTELP * USCAN	0.365	2.41
Constant	18.725	14.22
Production equation – Dependent variable: log(TELESTOCK /TELESTOCK_1)		
LogTTI	0.016	4.49
LogGA	-0.006	-0.76
Constant	-0.058	-0.76
Observations	586	

6.4 DEVELOPING VERSUS DEVELOPED COUNTRIES

So far I have studied the sample as a whole, both developing and developed countries. In the following I will look at the two groups separately. I use the classification outlined in table 3.2, where the high-income group is classified as developed countries and the three lowest income groups as developing countries. However, I have made a small adjustment. The income groups in table 3.2 are divided in order to have four quartiles with 21 countries equally distributed in each group. The consequence is that two countries usually looked upon as developed countries, namely Greece and Portugal, are classified as developing countries since there are 21 developed countries with a higher initial income. By excluding all countries that are looked upon as developed countries, the sample is more representative for deducing potential policy decisions for developing countries. Hence, Portugal and Greece are included as developed countries, resulting in a sample of 23 countries in this group. The 61 remaining countries in the low, middle low and middle high-income group are defined as developing countries.

I will run three estimations for the two groups: A model with main lines as the only telecommunications variable, corresponding to model 2a; a model with mobiles and computers as additional variables, corresponding to model 2b; and finally a model testing for a critical level, equivalent to model 3. For the developing countries the latter model is run for the PEN variable only. Almost all the countries in this group find themselves in the low penetration range of PC and MOB. Hence, there are not enough observations in the higher range to make deductions. I have tested for a critical level within all the three telecommunications variables for the developed countries. The models are all based on fixed-effects estimations.

Developing countries

The results for the 61 developing countries are given in table 6.5. From model 4a we establish that the growth effects from main lines have increased compared to model 2a, where the sample was seen as a whole. A one percent increase in main lines results in an average increase in output of 0.186 percent, compared to 0.101 percent in model 2a. Based on theory and earlier empirical studies outlined in chapter 2, this was unexpected. The theory emphasises that the telecommunications sector is subject to positive network externalities. The higher the penetration rate, the higher the utility should be. The average penetration rate for the developing countries in the sample is 7.35 lines per 100 inhabitants, while the total sample average is 19.21. If the network externalities were dominant, one would expect the elasticity to be higher for the whole sample than for the developing countries separately. The opposite is found. However, these findings correspond with the earlier findings of a lack of additional growth effects from an increasing penetration rate, and hence no critical level. Still, this does not mean that no positive network externalities exist at all. It only suggests that other productivity benefits might exceed the benefits from network externalities. Recall the social benefit analysis by Leff (1984), discussed in section 2.2. He argued that investments in the telecommunications sector leads to welfare effects in developing countries, *inter alia* by improved organisational performance. This might explain the large growth effects found in developing countries.

Table 6.5 Estimations for developing countries, using SUR and fixed-effects

	4a – standard		4b – additional variables		4c – critical level	
Variable	**Coefficient**	**t-value**	**Coefficient**	**t-value**	**Coefficient**	**t-value**
Output equation – Dependent variable: logGDP						
LogTLF	1.021	9.84	1.074	7.93	1.014	9.66
LogPEN	0.186	11.06	0.207	10.47	0.188	11.08
logPEN * MEDIUM	-	-	-	-	0.030	0.87
logPEN * HIGH	-	-	-	-	(dropped)	-
LogPC	-	-	-0.022	-2.83	-	-
d_PC	-	-	-0.119	-2.46	-	-
LogMOB	-	-	0.009	2.54	-	-
d_MOB	-	-	0.085	2.47	-	-
Year	- 0.009	-2.70	-0.014	-2.76	-0.009	-2.68
Constant	28.536	5.05	36.854	4.34	28.491	5.04
Demand equation – Dependent variable: log(PEN + WL)			log(TELESTOCK + WL)			
log(GDP / POP)	1.099	43.40	1.119	39.51	1.099	43.40
LogTELP	-0.724	-19.46	-0.694	-16.63	-0.724	-19.46
Constant	-5.895	-18.24	-6.007	-16.65	-5.895	-18.24
Supply equation – Dependent variable: logTTI						
LogGA	0.472	7.89	0.481	7.52	0.472	7.89
WL* nonUSCAN	1.460	0.47	1.547	-0.44	1.466	0.47
LogTELP	-0.393	-3.28	-0.401	-3.09	-0.393	-3.28
Constant	14.949	11.86	15.032	10.96	14.948	11.86
Production equation – Dependent variable: log(PEN / PEN_1)			log(TELESTOCK / TELESTOCK_1)			
LogTTI	0.018	8.26	0.012	3.43	0.018	8.26
LogGA	-0.010	-3.41	-0.006	-1.42	-0.010	-3.41
Constant	-0.106	-2.45	0.024	0.36	-0.106	-2.45
Observations	456		391		456	

Looking at model 4b in table 6.5, we see that no growth effects are found from the stock of personal computers. On the contrary, there is a negative correlation between computers and output, and the correlation is significant. This might be a result of relatively large fixed costs for computers, compared to wages and profits in developing countries. The evolution is fast, and it has been necessary to renew the computer stock quite often in order to derive advantage from them. The high investment costs might outweigh the growth effects. This must be understood in light of the time span of the analysis. It was not until the mid nineties that the Internet diffused worldwide for the public. In Norway, the first Internet provider for the public was established in 1993 (itavisen.no). The growth effects from the Internet might not be captured properly in the analysis, since it only runs until 1999. Before the launch of the Internet worldwide the growth effects from computers came from efficiency improvements and the like. Benefits from ameliorated communication and information networking, facilitation of trade, etc only emerged in the late nineties. Thus, when data for the latest years are available, an analysis might give a more positive result. For cellular telephones, however, there is a positive relationship with output. The correlation is not large, only 0.009, but it is significant. The same argument can be used here. The growth effects will probably increase when recent years are included. Throughout the nineties the annual growth in the stock of cellular telephones was between 50 and 60 percent. In absolute growth this means a substantial increase in the penetration rate over recent years. Until 1996 the rate was below 1 cellphone per 100 inhabitants. In 1999 the rate had increased to almost 5 per 100 inhabitants. In the early nineties the stock was so low that it is difficult to measure any output effects. If the rate of growth of the stock continues with the same intensity it might find expression in a larger correlation between cellular telephones and economic growth.

In model 4c, depicting the correlations for a critical level, it has not been able to find support for the existence of such a level. A medium level of main lines is slightly correlated with a higher output, but the finding is not significant. There are not enough observations for the high penetration level to deduce any results, thus this coefficient is dropped. Finally, it is worth noticing that the waiting list variable in all these models now has the expected sign, i.e. a positive relationship between waiting list and supply, implying that a large waiting list indicates a high demand and thus an increased supply. However, the coefficients are not significant. The correlation may as well be zero.

Developed countries

The results for the 23 developed countries are given in table 6.6, model 5a-5c. From model 5a, we see that there are lower growth effects from fixed telephones in this group than for developing countries, an anticipated result based on the earlier findings. Since the growth effect was larger in the sub-group of developing countries than for the sample as a whole, I expected to find a reduced effect for developed countries. The result is significant. Based on a coefficient of 0.042, the compounded annual growth effect for the developed countries is found to average 0.94 percent. The corresponding annual compounded growth in GDP is 1.96, which means that 48 percent of the growth can be attributed to telecommunications. This is more sober than the earlier findings, though it still seems large. The total labour force coefficient is extremely significant. This indicates a possible omitting variable problem. The coefficient appears to capture some other factors that are not specified in the model. The variable has been significant throughout the analysis, but never this high. In other words, there might be an omitted variable with particular significance for the rich countries. Recall that the telecommunications stock was left out due to lack of data for several countries. In the developing countries the initial stock is presumably low, thus not that important when explaining growth. In developed countries however, there are significant initial stock levels. If the stock causes the large *t*-value for the labour force, it might signify that the level of telecommunications is important after all, indicating a critical level. I will look further into this in model 5c. The coefficients in the other equations are still fairly stable compared to model 2a, table 6.2. At this point the price elasticities in the supply equation exceed one, indicating an elastic supply in the developed countries. The coefficients are quite similar for nonUSCAN and USCAN countries. This indicates that the market structure is not that different between these countries after all. A private sector driven market structure was introduced in the USA and Canada at an early stage. The coincidence between the two coefficients indicates than the rest of the developed countries have caught up with the USA and Canada when it comes to privatising the telecommunications sector. There were major privatising projects within the sector in the late eighties / nineties in the western world, and it seems like these efforts already show in the statistics.

Table 6.6 Estimations for developed countries, using SUR and fixed-effects

	M5a – standard		M5b – additional variables		M5c – critical level	
Variable	**Coefficient**	**t-value**	**Coefficient**	**t-value**	**Coefficient**	**t-value**
Output equation – Dependent variable: logGDP						
LogTLF	1.122	94.96	1.128	90.38	1.138	92.30
LogPEN	0.042	3.35	0.042	3.15	(dropped)	-
logPEN * MEDIUM	-	-	-	-	0.012	0.55
logPEN * HIGH	-	-	-	-	0.033	2.42
LogPC	-	-	-0.023	-2.37	-0.043	-3.29
logPC * HIGH	-	-	-	-	0.022	2.49
LogMOB	-	-	0.007	1.25	0.006	0.96
d_MOB	-	-	-0.014	-0.31	-0.023	-0.50
logMOB * HIGH	-	-	-	-	0.004	1.10
Year	0.012	7.51	0.015	3.10	0.020	3.67
Constant	-7.180	-4.99	-20.928	-2.19	-31.006	-2.87
Demand equation – Dependent variable: log(PEN + WL)			log(TELESTOCK + WL)			
log(GDP / POP)	1.197	10.82	1.262	10.77	1.201	10.85
LogTELP	-0.375	-2.52	-0.127	-0.81	-0.381	-2.56
Constant	-8.501	-7.98	-10.494	-9.33	-8.495	-7.98
Supply equation – Dependent variable: logTTI						
LogGA	0.331	9.12	0.329	9.07	0.319	8.75
WL* nonUSCAN	-2.764	-0.31	0.676	0.08	-0.807	-0.09
logTELP * nonUSCAN	1.110	3.81	1.251	4.32	1.158	3.96
logTELP * USCAN	1.206	4.17	1.340	4.66	1.262	4.34
Constant	9.692	4.41	8.753	4.00	9.494	4.30
Production equation – Dependent variable: log(PEN / PEN_1)			log(TELESTOCK / TELESTOCK_1)			
LogTTI	0.006	0.73	0.028	2.01	0.005	0.64
LogGA	-0.011	-2.58	-0.029	-3.97	-0.011	-2.48
Constant	0.116	0.76	-0.025	-0.10	0.126	0.83
Observations	197		195		197	

Model 5b includes cellular telephones and computers in the analysis. Cellular telephones have a small positive correlation with output, but the result is not significant. Computers are found to have a negative effect on output. This result coincides with the earlier findings, but it was rather expected that this result would change when looking at the developed countries separately. Experience suggests that there are growth effects from computers in the industrialised world. The negative result is even significant. However, when controlling for level effects in model 5c the result does not survive. The countries with a high penetration have a positive significant correlation between computers and output. About half of the observations fall into the high penetration range. The coefficient is 0.022 and the *t*-value 2.49. If the penetration rate is below 15 computers per 100 inhabitants there are still significant negative growth effects. This indicates that the lack of growth effects in developing countries is not a result of underdeveloped infrastructure, malfunctioning institutions, or other features of the developing society, but rather due to the low penetration rate that does not generate network externalities.

Non-significant level effects for cellphones are found. The estimates are small, positive, but not significant, and support the notion that cellular telephones serve as a substitute for fixed telephones in the developed countries rather than a product with additional value. The level effects for main lines seem significant. There are too few observations in the low penetration rate to derive any results; consequently, the coefficient of PEN is dropped. No significant correlation is found when the penetration rate is below 50 lines per 100 inhabitants, but if the rate exceeds 50, the elasticity is 0.033 and the *t*-value 2.42, thus significant. The theory of a critical level of telecommunications as a result of positive network externalities seems to gain support when we study the developed countries separated from the rest of the sample.

An alternative approach

In order to test whether the results are robust and stable across methods, I have carried out another analysis with a different specification. The alternative method is based on a single-equation specification, and an ordinary least-squares estimation. The model investigates the relationship between long-run economic growth and level of telecommunications, and is specified as follows:[26]

(6.1) $G = a + ßT(i) + ?X + e$,

where G is a growth indicator, T(i) is the *i*th telecommunications variable, and X is other explanatory variables for economic growth. The growth indicator used as dependent variable is the average rate of real per capita GDP growth. I have investigated the same three telecommunications variables as in the preceding analysis. These are averaged over ten years, 1990-1999, and run in separate regressions, each combined with 5 other explanatory variables for economic growth: The logarithms of initial income per capita and initial secondary school enrolment rate, the average ratio of government consumption to real GDP, the average inflation rate, and the average ratio of imports plus exports to GDP. The analysis incorporates the same 84 countries and the same time-period as in the previous study. Despite this, it has not been possible to get significant results corresponding with the results for the simultaneous equation estimation. When looking at the sample as a whole, there were no significant results at all. The sample is probably too heterogeneous to find a common trend. Consequently, I looked at the developing and developed countries separately, but the results were still not equivalent to the simultaneous approach. Since they were somewhat ambiguous between the two studies, I have not reported the results of the alternative approach in detail. It is in any case difficult to compare the results from the two studies, as the method used is different. While the simultaneous equation approach is a panel data analysis, the single equation method is a reduced form analysis that does not take into account the panel data properties since the variables are averaged over the period. The estimates from the simultaneous equation approach are probably the more reliable of the two, as this is a more complex model accounting for a larger range of factors, e.g. fixed effects and spurious correlation.

6.5 SUMMARY AND COMMENTS

There seem to be significant growth effects from main telephone lines. However, it has been more difficult to establish a positive correlation between cellular telephones or

[26] The approach is based on a model developed by King and Levine (1993), and Levine (1997).

personal computers and output. Nor have substantial differences been found that are dependent on the level of penetration rate. Studying all the 84 countries together even showed indications of negative effects as the penetration rate of main lines increased. However, the same results were not found when the sample was divided into developing and developed countries. Then, a high penetration rate of telecommunications led to a higher correlation with GDP, both for developed and developing countries, though the coefficient for developing countries was insignificant. The reason for this difference might be that the sample as a whole is highly influenced by heterogeneity between the countries. I will therefore emphasize the divided sample. There seem to be higher growth effects from telecommunications in the developing countries than in the developed countries. However, these results are somewhat contradicted by the finding of a critical level of telecommunications in the developed countries. Model 5c, table 6.6, showed that a high penetration rate was necessary before substantial growth effects were witnessed.

A disturbing factor in the analysis is the high significance found for the labour force, and also the large coefficient for the constant. This might be a result of an omitting variable bias, making the error term correlated with the explanatory variables. In so doing the effects from the omitted variable are depicted in the coefficients of the included one, thereby raising the impact of the latter to an artificial level. A solution would have been to include possible omitted variables in the model. The problem arises when it is not possible to collect the missing data, as in this case. Instrumental Variable (IV) regression is a possible method to deal with such a problem. It is a general way to obtain a consistent estimator of the unknown coefficients when the regressors are correlated with the error term. The instrumental variables help isolate the part of the regressors that are not correlated with the error term. When the model is non-linear in data or parameters, as is the case here, an extension of the IV method is applied, called the Generalised Methods of Moments (GMM). However, in order to benefit from the IV or GMM method, the instrumental variables must be exogenous, i.e. uncorrelated with the error term, at the same time as they are relevant and correlated with the regressors. If the instruments are weak the estimator may be biased, and if the instruments are not exogenous the estimator is inconsistent. Such instruments are not easy to find. I do not have qualified instruments and have consequently not been able to do a GMM estimation.

When studying time-series, there is always a possibility that earlier periods influence the outcome later on. A dynamic model uses lagged variables to catch up these earlier incidences and include them in the analysis. Specifying a static model when there are dynamic effects makes the error term auto-correlated. However, lagged variables lead to endogenous problems and give biased estimates because of correlation with the fixed effects (Nickell, 1981). On this basis, I have chosen not to test a dynamic model.

In order to test the robustness of the system of equations used I have tried to replicate the study of Röller and Waverman by using the same sample and the same time-span as they did. This has not been successful. Even though I have not used the same database as they have, nor the same econometric method, the results should resemble each other if they were robust. I will not elaborate on this subject, but refer to appendix C for further details.

Despite some concerns, the methodology applied seems to lead to fairly stable estimates. The demand, supply and production equations in the simultaneous equation estimation have the same tendencies throughout the analysis, with only small variations. That is comforting. I also ran the system for the early nineties and late nineties separately, and the trends were the same independent of time. Even though there are differences between the single and simultaneous equation estimations, the tendencies are the same: There are some growth effects from telecommunications, and these effects are highest in developing countries.

7 CONCLUDING REMARKS

The purpose of this paper has been to study whether telecommunications development spurs economic growth in developing countries. Earlier studies have focused on developed countries, and found that there is a positive correlation between telecommunications and economic growth. The increasing difference between rich and poor countries demands new means to reduce the gap and enable developing countries to become self-supporting. Telecommunications has been launched as a potential means, but there is need of more research on the actual effect of such an initiative. This has been my motivation.

The analysis revealed that there are some indications of a relationship between telecommunications and economic growth, but the relationship is not clear-cut. The simultaneous equation model showed that there is a significant growth effect from increasing the penetration rate of main telephone lines. The calculations of the compounded annual growth rate, however, indicated that the coefficients might be too high. These findings correspond with the findings of Röller & Waverman (2001) and Norton (1992). These authors also found a high growth effect from main lines, but concluded that the effect seemed unreasonably high. It indicates that the main lines variable might bring in other growth effects as well. It is difficult to separate the direct effect telecommunications has on economic growth from the growth of the industries that telecommunications encourages. Somewhat surprising was, perhaps, the finding of a larger growth effect from main lines in the developing countries than the developed. This contradicts the hypothesis of positive network externalities, which says that the growth effects increase with the penetration rate. However, when introducing a level variable, the growth effects in the developed countries did increase in proportion to the penetration rate. This appears to be a contradiction, but can perhaps be explained by larger indirect effects in the developing countries. For example, while developed countries already have a well-functioning financial system, and thereby experience marginal effects from increased telecommunications infrastructure, a corresponding amelioration in the infrastructure in the developing countries might have considerable productivity effects in the financial sector. This again diffuses to other sectors, increasing overall productivity. The indirect effect outperforms the network externalities, leading to the seemingly contradictory results.

When extending the analysis to incorporate cellular telephones and computers, I found no growth effects from computers. On the contrary the correlation found was negative, though insignificant. My result corresponds with the findings of Pohjola (2000), who did not observe any significant growth effects from investment in information technology in the 39 countries he studied. However, when he looked at the OECD countries only, he found significant growth effects. The correlations I found remained negative when I divided the sample in developing and developed countries. Still, there were positive significant growth effects from computers in the developed countries when a level variable was introduced. No growth effects were found for the low penetration rate, but they were for countries with a high level of penetration. This corresponds with the findings of Pohjola (2000).

A significant positive correlation was found between growth and cellular telephones, a finding that survived the study of developing countries separately. Earlier studies, like Rodríguez & Wilson (2000), have not been able to establish the same results. Rodríguez & Wilson studied growth and ICT, including cellular telephones, for 110 countries, but did not find any significant link between them. However, their results were attributed to the quality and precision of data rather than the non-existence of a growth effect.

The same data problem is a possible weakness of my analysis. There was a considerable number of lacking observations, which forced me to exclude variables that perhaps were significant. There were also missing observations for the variables that actually were included. In many countries, development in cellular telephones and computers was first observed in the late nineties. It was not until 1995 that the penetration rate of computers in developing countries exceeded 1 per 100 inhabitants, and until 1997 for mobiles respectively. This might lead to insignificant results with respect to these variables in early nineties. However, the results were fairly stable when I ran the analysis for the early 90s and late 90s separately. The lack of observations might also have resulted in a sample selection bias, since countries with few observations had to be left out of the analysis. Still, the comparison between the selected sample and the total population of countries in the WDI database showed that the representation between income groups was fairly accurate.[27] The applied panel is quite large. I have studied 84 countries through ten years, which implies that the results are reasonably strong. This impression is also reinforced by the stability in the results independent of time-span and type of specification. As seen above, my results coincide with earlier findings. Also, the higher growth effects found in developing countries correspond with the hypothesis of convergence.[28] Countries that initially have a small growth tend to grow faster than rich countries.

In other words, there seems to be a significant correlation between telecommunications and GDP growth. Development of main telephone lines has the largest effect, followed by increase in cellular telephones. No significant growth effects are found for computers as long as the penetration rate is low. On the contrary, I have found a significant negative correlation between computers and growth, which probably is due to relative large investment costs in poor countries. However, when the penetration rate exceeds a certain level there are significant growth effects, implying that network externalities are important. Overall, there are larger growth effects from telecommunications expansion in developing countries than in developed countries. This was also verified by the alternative single equation approach, although the individual effects in the two studies had discrepancies.

Most of the earlier studies on telecommunications have concentrated on main telephone lines as the only telecommunications variable. Given the technological development and diffusion, I found it interesting to expand these studies by widening the range to include cellular telephones and computers as explanatory telecommunications variables. The data on these variables are still imperfect, especially for developing countries, and stronger results will presumably be found as new data becomes available and development proceeds. New technology, as the wireless Internet that makes it easier for developing countries to acquire low-cost and fast connection to the Internet, might help reducing the digital divide seen between rich and poor countries today. Still, my results indicate that there already exist significant economic growth effects from telecommunication development in developing countries, making telecommunications an important input in the continuing effort of reducing differences and enhancing development in poor countries.

[27] See table 5.1.

[28] Recall that the model applied in the analysis is an endogenous growth model, and that the finding of convergence contradicts the beliefs of the endogenous growth theoreticians.

‘Information technology is not a magic recipe that will solve all our problems. But it is a powerful force that can and must be used in our global struggle for peace and development.’

Kofi A. Annan
UN Secretary-General

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APPENDIX A
SUMMARY STATISTICS

Table A.1 Summary statistics, low-income countries 1990-1999

Variable	Obs.	Mean	Std.dev.	Min.	Max.
GDP, billion dollars	210	568	1610	0.76	964
GDP per capita	210	345	130	134	769
Main telephone lines per 100 capita	210	0.94	1.18	0.11	8.58
Cellular phones per 100 capita	210	0.08	0.311	0	3.42
Personal computers per 100 capita	185	0.15	0.22	0	1.24
Waiting list per 100 capita	194	0.42	0.54	0.01	2.64
Investment telecommunications, million dollars	196	658	2470	0.56	18200
Telephone revenue per main line	203	1052	743	129	4084
Labour force, million	210	64.1	168	0.69	751
Budget deficit, % of GDP	152	-4.62	4.97	-35.56	5.51
Area, sq km	210	1092238	1961062	25680	9327420

Table A.2 Summary statistics, medium low-income countries 1990-1999

Variable	Obs.	Mean	Std.dev.	Min.	Max.
GDP, billion dollars	210	33.70	38.3	2.57	178
GDP per capita	210	1386	601	523	3017
Main telephone lines per 100 capita	210	6.39	6.59	0.35	34.22
Cellular phones per 100 capita	210	0.59	1.12	0	6.05
Personal computers per 100 capita	178	0.97	1.03	0	5.56
Waiting list per 100 capita	194	2.97	3.89	0.07	20.92
Investment telecommunications, million dollars	197	231	355	2.12	1900
Telephone revenue per main line	203	753	600	65	4214
Labour force, million	210	9.12	8.98	0.56	36.3
Budget deficit, % of GDP	162	-2.30	3.59	-15.42	4.96
Area, sq km	208	549818	595848	10830	2381740

Table A.3 Summary statistics, medium high-income countries 1990-1999

Variable	Obs.	Mean	Std.dev	Min.	Max.
GDP, billion dollars	204	158	175	3.99	752
GDP per capita	204	5453	2960	2134	12652
Main telephone lines per 100 capita	210	17.94	11.74	2.07	52.81
Cellular phones per 100 capita	210	3.51	6.99	0	50.03
Personal computers per 100 capita	190	3.17	2.95	0	18.18
Waiting list per 100 capita	187	2.07	2.36	0	10.74
Investment telecommunications, million dollars	193	1140	1540	14.8	10100
Telephone revenue per main line	203	745	373	9	2556
Labour force, million	210	15.7	21.3	0.45	78.1
Budget deficit, % of GDP	163	-2.20	4.65	-22.66	11.32
Area, sq km	210	1804605	3840404	8870	16888500

Table A.4 Summary statistics, high-income countries 1990-1999

Variable	Obs.	Mean	Std.dev.	Min.	Max.
GDP, billion dollars	209	1070	1820	51	8580
GDP per capita	209	25909	7625	13779	45952
Main telephone lines per 100 capita	210	51.59	9.00	31.60	73.57
Cellular phones per 100 capita	210	13.74	15.13	0.14	64.14
Personal computers per 100 capita	208	19.54	10.67	2.83	50.68
Waiting list per 100 capita	200	0.04	0.09	0	0.68
Investment telecommunications, million dollars	210	5040	7490	235	37100
Telephone revenue per main line	210	1072	275	616	2029
Labour force, million	210	19.1	30.3	1.54	143
Budget deficit, % of GDP	173	-2.25	4.80	-15.45	16.25
Area, sq km	210	1424670	2988909	610	9220970

APPENDIX B

COMPOUNDED ANNUAL GROWTH RATES

Table B.1 Compounded annual growth rates (CAGR) of GDP per capita, main lines, and main lines contribution to GDP per capita growth in percent,[29] by income

	GDP per capita		CAGR	Main lines per 100 inhabitants		CAGR	Main lines contribution to GDP	
	1990	1999	90-99	1990	1999	90-99	PEN = 0.672	PEN=0.101
Low income								
Bangladesh	277	362	2.99	0.20	0.34	6.27	4.08	0.72
Benin	345	402	1.73	0.32	0.74	9.72	6.55	1.26
Burundi	206	143	-3.99	0.15	0.29	7.20	4.73	0.85
China	349	769	9.17	0.59	8.58	34.57	27.37	9.77
Guinea	534	603	1.34	0.20	0.27	3.60	2.28	0.37
India	324	450	3.73	0.60	2.66	17.98	12.99	3.12
Kenya	355	337	-0.59	0.76	1.03	3.42	2.18	0.36
Lesotho	444	513	1.62	0.72	1.02	3.93	2.52	0.42
Madagascar	276	242	-1.46	0.25	0.32	2.96	1.86	0.30
Mauritania	438	483	1.10	0.29	0.64	9.10	6.09	1.15
Mongolia	524	457	-1.52	3.20	4.41	3.61	2.41	0.40
Mozambique	144	198	3.58	0.34	0.40	2.12	1.32	0.21
Nepal	182	222	2.27	0.32	1.13	15.20	10.67	2.37
Nicaragua	460	472	0.29	1.26	3.04	10.29	7.13	1.40
Niger	235	209	-1.27	0.12	0.18	4.72	3.02	0.51
Nigeria	258	250	-0.37	0.30	0.38	2.52	1.58	0.25
Pakistan	448	508	1.41	0.75	2.22	12.81	8.95	1.87
Tanzania	189	188	-0.03	0.29	0.46	5.36	3.46	0.59
Uganda	251	347	3.66	0.17	0.26	5.29	3.41	0.58
Yemen, Rep.	315	286	-1.07	1.10	1.63	4.43	2.87	0.48
Zambia	477	389	-2.26	0.88	0.93	0.55	0.34	0.05
Average	**335**	**373**	**0.97**	**0.61**	**1.47**	**7.89**	**5.52**	**1.29**

[29] See footnote 23 and 24 for details on how the calculations are made

	GDP per capita		CAGR	Main lines per 100 inhabitants		CAGR	Main lines contribution to GDP	
	1990	1999	90-99	1990	1999	90-99	PEN = 0.672	PEN=0.101
Middle low income								
Algeria	1636	1569	-0.46	3.24	5.29	5.61	3.85	0.67
Bulgaria	1716	1414	-2.13	24.20	34.22	3.93	4.26	0.75
Cameroon	764	656	-1.68	0.35	0.64	7.04	4.63	0.83
Colombia	2119	2261	0.72	6.91	16.03	9.81	7.87	1.59
Cote d'Ivoire	779	787	0.12	0.62	1.51	10.36	7.07	1.38
Ecuador	1475	1419	-0.43	4.78	9.10	7.42	5.41	1.00
Egypt, Arab Rep.	971	1191	2.29	3.01	7.51	10.68	7.79	1.56
Honduras	682	689	0.12	1.72	4.42	11.04	7.80	1.57
Iran, Islamic Rep.	1291	1587	2.31	4.04	13.34	14.21	11.20	2.53
Jamaica	1787	1691	-0.61	4.46	19.03	17.49	14.74	3.74
Jordan	1520	1604	0.60	7.16	11.54	5.44	4.04	0.71
Namibia	1901	2097	1.10	3.93	6.38	5.54	3.86	0.67
Peru	1903	2346	2.35	2.61	6.69	11.00	7.96	1.61
Philippines	1097	1138	0.40	1.00	3.88	16.21	11.73	2.70
Romania	1531	1270	-2.06	10.19	16.70	5.64	4.50	0.80
Senegal	566	591	0.47	0.60	1.79	12.79	8.90	1.86
Sri Lanka	580	814	3.84	0.71	3.60	19.70	14.45	3.64
Syria Arab Rep.	956	1238	2.92	4.10	9.93	10.34	7.73	1.55
Thailand	2003	2717	3.45	2.43	8.70	15.23	11.48	2.62
Tunisia	1823	2390	3.05	3.75	8.99	10.19	7.53	1.50
Zimbabwe	686	703	0.27	1.25	2.07	5.79	3.83	0.67
Average	**1323**	**1437**	**0.79**	**4.34**	**9.11**	**10.26**	**7.65**	**1.62**
Middle high income								
Argentina	5782	8100	3.82	9.31	20.11	8.94	7.56	1.50
Botswana	3124	3711	1.93	2.07	7.69	15.71	11.76	2.71
Brazil	4080	4479	1.04	6.50	14.87	9.63	7.61	1.52
Chile	3283	5121	5.07	6.60	20.57	13.47	11.50	2.63
Costa Rica	2992	3994	3.26	10.05	20.41	8.19	6.94	1.35
Greece	10692	12652	1.89	38.86	52.81	3.46	6.30	1.20
Hungary	4857	5151	0.65	9.60	37.09	16.21	17.13	4.68
Korea	7967	12086	4.74	30.97	43.79	3.92	5.33	0.98
Malaysia	3104	4526	4.28	8.93	20.30	9.55	8.10	1.64
Mexico	3187	3613	1.40	6.48	11.22	6.29	4.67	0.84
Oman	5581			5.98	8.96	4.59	3.28	0.56
Panama	2523	3246	2.84	9.27	16.43	6.56	5.24	0.96
Poland	2604	3536	3.46	8.64	26.27	13.15	12.07	2.81
Puerto Rico	10365			27.89	33.29	1.99	2.15	0.35
Portugal	9949	12309	2.39	24.26	42.31	6.38	8.04	1.63
Russian Fed.	3668	2211	-5.47	14.00	21.03	4.63	3.94	0.69
Saudi Arabia	7103	6718	-0.62	7.69	12.95	5.96	4.53	0.81
South Africa	4113	3904	-0.58	9.34	12.76	3.52	2.63	0.44
Turkey	2589	2965	1.52	12.15	28.06	9.75	9.23	1.95
Uruguay	4870	6208	2.73	13.43	27.07	8.10	7.58	1.51
Venezuela	3350	3213	-0.46	7.63	10.76	3.90	2.84	0.47
Average	**5037**	**5671**	**1.78**	**12.84**	**23.27**	**7.80**	**7.07**	**1.49**

	GDP per capita		CAGR	Main lines per 100 inhabitants		CAGR	Main lines contribution to GDP	
	1990	1999	90-99	1990	1999	90-99	PEN = 0.672	PEN=0.101
High income								
Australia	18643	23554	2.63	45.63	51.54	1.36	2.55	0.42
Austria	27660	31550	1.47	41.76	47.24	1.38	2.20	0.36
Belgium	26053	29687	1.46	39.26	50.65	2.87	4.93	0.89
Canada	19129	21754	1.44	56.49	65.76	1.70	7.12	1.39
Denmark	31807	37308	1.79	56.69	68.47	2.12	11.11	2.51
Finland	26821	30355	1.38	53.42	55.18	0.36	0.84	0.13
France	25967	28959	1.22	49.52	57.81	1.73	4.23	0.75
Germany		31721		44.08	58.68	3.23	7.57	1.51
Hong Kong, China	18813	22185	1.85	45.02	58.05	2.86	6.64	1.28
Israel	13779	16438	1.98	34.32	47.13	3.59	5.39	0.99
Italy	18161	20174	1.18	38.76	46.22	1.97	3.00	0.51
Japan	38713	42318	0.99	44.11	55.69	2.62	5.53	1.02
Netherlands	24998	30135	2.10	46.42	60.58	3.00	7.86	1.58
New Zealand	15034	17210	1.51	43.36	48.11	1.16	1.93	0.31
Norway	28840	37142	2.85	50.18	70.92	3.92	22.59	7.18
Singapore	17897	26460	4.44	34.59	47.50	3.59	5.45	1.01
Spain	14075	16989	2.11	31.60	40.99	2.94	3.77	0.65
Switzerland	45952	45496	-0.11	57.36	70.71	2.35	16.28	4.34
Sweden	27272	29866	1.01	68.08	73.57	0.86	26.18	9.09
United Kingdom	18081	21069	1.71	44.07	57.47	2.99	6.71	1.30
United States	26160	30845	1.85	54.46	67.30	2.38	10.65	2.36
Average	**24193**	**28153**	**1.74**	**46.63**	**57.12**	**2.33**	**7.74**	**1.89**
Total sample average	**7524**	**8987**	**1.31**	**16.10**	**22.74**	**7.07**	**6.99**	**1.57**

APPENDIX C
REPLICATION OF THE RÖLLER AND WAVERMAN STUDY

This thesis applies an adapted version of the methodology outlined by Röller and Waverman, (2001). In order to check the robustness in their method I have tried to replicate their analysis with the same countries and the same time-span as they used. However, there are several things that part my analysis and the one they have done. For the first, I don't use the same dataset as they do. They use the Penn World Table 5.6, while I have used the World Development Indicators and the ITU World Telecommunication Indicators. The variables are not depicted in the same denomination. I have been forced to convert several of my variables in order to get the same denomination, but that also give rise to uncertainty and inaccuracy between the two studies. Röller and Waverman have 396 observations for the 21 countries they study, whereas I only have 297 observations available. Finally, we have not used quite the same method. While Röller and Waverman use a General Method of Moments estimation (GMM), I have applied a Seemingly Unrelated Regression (SUR) approach since I did not perceive the instruments to be adequate. The results obtained from my analysis are tabled below in table C2. In model 2a only the SUR model is applied. Then the SUR estimation is combined with fixed effects in model 2b. Finally a dummy for medium and high penetration rate is introduced in order to test for non-linearity, reported in model 2c. The dummy model is also estimated by fixed-effects. The corresponding results from the Röller and Waverman study is reported in table C3, model 3a-3c. The study covers a 20-year period, 1970-1990, and the sample contains the following 21 OECD countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Turkey, United Kingdom and United States.

As seen from table C.2 and C.3 there are significant differences between the two studies, even if the summary statistics are fairly similar (table C.1). The telecommunication stock variable, K, and the GDP[30] are even collected directly from Röller and Waverman, thus identical in the two studies. In spite of this I have not been able to get the same significance from the telecommunication stock variable, nor have I been able to find the same level effects as Röller and Waverman do. Most important, I do not find the same significant coefficients on the PEN variable when using fixed-effects estimation. The differences are probably attributed to the method, where I use SUR while they use GMM. The specification is identical, and the discrepancies in the summary statistics are not large enough to derive such differences in the estimation. Röller and Waverman have used all the explanatory variables but PEN as instrument. However, not all these variables are found to be significant, and thus might not relevant in the study. When I run the fixed-effects estimation without the telecommunication stock variable, I get approximately the same results as with the variable. I don't perceive the instruments available to be good enough, and will thereby not apply GMM. Some of the discrepancies might also result from the use of different databases, even though the summary statistics resemble.

[30] I first estimated the model with a calculated converted GDP. Since the results were so different I decided to try the GDP collected from Röller and Waverman to see if I would get any closer to their results. However, I did not get any closer to reproduce their study.

Table C.1 Comparison of summary statistics

	Replication				The Röller and Waverman study			
Variable	**Mean**	**Std.dev.**	**Min.**	**Max.**	**Mean**	**Std.dev.**	**Min.**	**Max.**
K	413.91	680.40	10.98	3818.58	413.91	680.40	10.98	3818.58
TLF	17.30	24.90	1.10	126	16.70	24.48	1.10	126.42
PEN	0.32	0.14	0.02	0.68	0.30	0.14	0.01	0.68
GDP	424.73	770.76	14.79	4524.97	424.73	770.76	14.79	4524.97
TELP	577	194.30	175	1150	536.66	158.42	244.62	1000.70
GA	1472.16	2966.98	32.82	9220.97	1516.39	3088.25	30.513	9970.61
GD	-15.9	32.70	-217	10.2	-15.48	31.37	-214.57	8.93
WL	0.01	0.02	0	0.11	0.01	0.02	0	0.11
TTI	2.93	4.89	0.05	25.8	2.78	4.73	0.07	25.83
USCAN	0.03	0.18	0	1	0.03	0.18	0	1
T	1980	6.06	1970	1990	11	6.06	1	21
LOW	0.25	0.43	0	1	0.27	0.45	1	0
MEDIUM	0.49	0.50	0	1	0.48	0.50	1	0
HIGH	0.26	0.44	0	1	0.25	0.43	1	0

Table C.2 A replication of Röller and Waverman, using SUR and fixed-effects

	2a – SUR		2b – SUR + Fixed effects		2c - Critical level	
Variable	**Coefficient**	**t-value**	**Coefficient**	**t-value**	**Coefficient**	**t-value**
Output equation – Dependent variable: logGDP						
Constant	5.738	1.19	-21.957	-6.86	-20.654	-6.31
Log	0.223	9.15	-0.016	-1.10	-0.023	-1.54
LogTLF	0.787	30.91	0.275	3.23	0.283	3.34
LogPEN	0.214	15.44	0.011	0.66	0.027	1.54
logPEN * MEDIUM	-	-	-	-	-0.012	-1.12
logPEN * HIGH	-	-	-	-	-0.026	-2.27
Year	0.001	0.40	0.022	12.13	0.022	11.64
Demand equation – Dependent variable: log(PEN + WL)						
Constant	-19.450	-30.19	-17.258	-25.40	-17.249	-25.38
log(GDP / POP)	2.443	31.76	2.373	29.84	2.369	29.79
LogTELP	-0.493	-6.70	-0.738	-8.70	-0.734	-8.64
Supply equation – Dependent variable: logTTI						
Constant	13.784	12.96	14.136	13.30	14.193	13.35
LogGA	0.289	7.96	0.296	8.13	0.297	8.15
LogGD	-2.22e-11	-14.06	-2.21e-11	-13.95	-2.22e-11	-13.98
WL* nonUSCAN	-9.247	-3.38	-9.743	-3.55	-9.838	-3.59
logTELP * nonUSCAN	0.496	3.09	0.428	2.67	0.418	2.60
logTELP * USCAN	0.322	1.96	0.248	1.51	0.236	1.43
Production equation – Dependent variable: log(PEN / PEN_1)						
Constant	0.134	3.06	0.163	3.72	0.163	3.72
LogTTI	-0.004	-1.80	-0.006	-2.40	-0.006	-2.40
LogGA	0.004	2.06	0.005	2.13	0.005	2.13
Observations	297		297		297	

Table C.3 The Röller and Waverman study, using GMM

	3a - OLS		3b - Fixed-effects		3c - Critical level	
Variable	**Coefficient**	**t-value**	**Coefficient**	**t-value**	**Coefficient**	**t-value**
Output equation – Dependent variable: logGDP						
Constant	-8.367	-23.17	-	-	-	-
Log	0.411	11.49	0.556	19.88	0.627	19.01
LogTLF	0.627	16.44	0.614	7.91	0.529	6.52
LogPEN	0.154	7.84	0.045	4.87	0.034	3.55
logPEN * MEDIUM	-	-	-	-	0.010	0.96
logPEN * HIGH	-	-	-	-	0.040	2.40
Year	-0.009	-5.10	-0.005	-2.37	-0.007	-2.80
Demand equation – Dependent variable: log(PEN + WL)						
Constant	2.073	3.90	0.711	2.76	0.718	2.76
log(GDP / POP)	2.382	39.63	2.081	60.42	2.076	59.22
LogTELP	-1.131	-14.55	-1.130	-36.71	-1.127	-36.05
Supply equation – Dependent variable: logTTI						
Constant	-4.267	-1.79	2.257	2.74	2.345	2.80
LogGA	0.396	14.19	0.322	32.49	0.320	31.49
LoggGD	-0.029	-18.97	-0.024	-32.49	-0.024	-31.70
WL* nonUSCAN	3.624	1.09	-6.727	-6.07	-6.739	-6.06
logTELP * nonUSCAN	-0.752	-2.06	-0.050	-0.51	-0.041	-0.41
logTELP * USCAN	-0.535	-1.79	0.150	1.42	0.163	1.53
Production equation – Dependent variable: log(PEN / PEN_1)						
Constant	0.133	7.85	0.141	17.76	0.141	17.60
LogTTI	0.003	2.29	0.002	1.80	0.002	1.58
LogGA	-0.005	-3.22	-0.005	-7.31	-0.005	-7.11
Observations	396		396		396	

Summary

The world economy has experienced an enormous growth the past 50 years. Yet the gap between the richest and the poorest countries has increased. There have been several attempts to explain the increased differences. Proponents of the endogenous growth theory claim that a technological revolution has created a new growth paradigm. Following the information technology revolution seen in the industrialised world in the 90s, information and communication technology has often been launched as a possible remedy for the slow or decelerating growth developing countries have faced.

This paper seeks to explore the relationship between telecommunications development and economic growth by performing an econometrical analysis of 61 developing countries and 23 developed countries between 1990 and 1999. By estimating a simultaneous equation model where telecommunication infrastructure investments are endogenised into the aggregated economy and country specific fixed effects are included, simultaneous causality and spurious correlation are recognised.

The results of the analysis indicate that there is a significant correlation between telecommunication and GDP growth. Overall, there seems to be larger growth effects from telecommunication development in developing countries than in developed countries, a result that contradicts earlier findings and the notion of network externalities. The report suggests that the indirect effects, i.e. the gain in productivity that other sectors experience as a result of development in the telecommunication sector, are more significant in developing countries, and this might explain the large growth effects found in these countries.

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