NETWORK EXTERNALITIES IN TELECOMMUNICATIONS AND ECONOMIC GROWTH

by

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Abstract

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Research on infrastructure has been in the center of economists' attention for at least ten past years. Telecommunications, as a part of infrastructure, has been an especially fascinating area for researchers mainly because of the mechanisms that can translate growth in telecoms sector into economy-wide productivity gains. Due to these mechanisms, named 'network externalities,' social marginal benefits of network expansion are always greater then the private marginal benefits, that are experienced by a new subscriber.

This paper investigates the effects of network externalities in the telecommunications sector in the context of transitional countries. As the empirical part shows, telecommunications has positive but diminishing returns with a threshold level of 40% penetration rate. More specifically, expansion of telecommunications network to penetration rates higher than 40% substantially reduces positive growth effects. Diminishing returns is what characterizes telecoms sector in transitional countries as the impact of network externalities in the developed countries has been found to have positive and increasing returns.

Estimated elasticity of economic growth to telecommunications is about 0.50, which corroborates the results of previous research on infrastructure.

TABLE OF CONTENTS

Table of Contents ... ii
List of Figures ... iii
Acknowledgments ... iv
Glossary ... v
Introduction ... 1
Industry Overview ... 5
2.1 Central Europe ... 8
2.2 Russia and Ukraine ... 10
2.3 Asian Telecoms ... 11
2.4 Recent Trends in the Industry ... 12
Literature Review ... 13
The Data ... 19
Empirical Investigation ... 22
5.1 Estimation Results ... 25
5.2 Sensitivity Analysis ... 29
Conclusions and Policy Implications ... 32
Bibliography ... 34
Appendix ... 36

LIST OF FIGURES

Figure 1. Unsatisfied Demand for Telecommunications (Waiting List, per 100 people) 6
Figure 2. Change in Penetration Rate in Selected CEE Countries 9
Figure 3 Network Externalities 14
Figure 4 Network Externalities and Social Returns.. 15
Figure 5. GDP Per Capita and Penetration Rate 19
Table 1. Average Annual Growth Rates in Selected Countries................................ 20
Table 2. Estimation Results... 26
Table 3. Sensitivity Analysis Results 30
Output 1 Production Function and Hausman Test for Fixed vs. Random Effects 36
Output 2 Production Function with Slope Dummy for Penetration Rate over 40% 37
Output 3 Demand Equation.. 37
Output 4 Supply Equation 38
Output 5 Investment-Capital Relationship 39
Output 6 Sensitivity Analysis with Patents.. 39
Output 7 Sensitivity Analysis with Scientists and Engineers in R&D 40

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GLOSSARY

Fixed Lines. The number of physical connections to the telecommunications network via the land cable.

Mainlines. See Fixed Lines

Penetration Rate. Number of telephone subscriptions per capita. Alternatively, this measure may be expressed in percentage terms, as the number of subscriptions per 100 people.

Soviet Bloc countries. A group of Central and Eastern European countries, whose internal and external policy has been highly influenced by the USSR.

Teledensity. See Penetration Rate

Waiting List. Number of outstanding fixed line subscribers, waiting to be connected to the network, per 1000 people.

Chapter 1

INTRODUCTION

In the last two decades, the information technology and communications industries have seen a tremendous boom fuelled by technological advances. Because of the high returns that these industries offer, they have attracted the attention of the business sector, which resulted in substantial investment. This attention, however, was not confined to the business world alone, as economists have also been interested in learning more about information technology and telecommunications and their effect on economic productivity and growth.

Unlike their business potential, the potential for economic research of the two industries has been barely tapped, and numerous phenomena related to these sectors have been studied very little or not studied at all. Foremost among such little-researched phenomena are network externalities generated by telecommunications and information technology, which are reputed to bring substantial productivity gains and economic improvements.

This paper will focus on the study of telecommunications industry, including the effects of network externalities. In transitional countries, the lack of research effort in the telecommunications sector has been conditioned by two main factors. First, bad quality of data which characterizes many of the former USSR republics renders the results of any study unreliable. Also, the issue of intransparency of state-owned enterprises in many transitional countries aggravates the problem of conducting research in the sector since telecommunications industry has been mostly publicly-owned. The problem of data quality has been partially solved only in the last several years, when international organizations such as World Bank have been able to collect and provide researchers with accurate and systematized data.

Second, it is only in recent years that the telecoms sector has witnessed a considerable inflow of investment in many transitional economies. Previously, due to low investment activity in telecommunications industry and stagnant economies, the sector had generated little interest from researchers. The shortness of time series (5-6 years at most) still presents a problem to empirical research in many topics about transitional economies. However, at this moment the problem can be partially relieved by utilizing longitudinal (panel data) analysis.

Since the telecommunications sector is considered to be a part of the infrastructure capital, it is very instructive to look at the relevant studies which examine the relationship between the public infrastructure and economic development. This will be done in detail in the Literature Review section. Some of the studies have shown that public infrastructure possesses important externalities (see Gramlich (1994), Canning and Bennathan (1999)) which facilitate productivity growth at the country level.

This consideration also applies to the telecommunications sector. Capello and Nijkamp (1996) provide a theoretical justification for the positive impact of telecommunications on economic growth. They show that the industry produces 'network externalities' which render social benefits of telecommunications investment greater then private returns. More specifically, when a firm joins a telecommunications network, the existing users may enjoy wider 'connectivity,' i.e. the number of businesses they can reach increases. This produces positive side-benefits apart from the private benefit to the joining firm. As a result, we can see that the total social return (private plus the side-benefits) is greater than the private return. Eventually, this may lead to productivity increases of the businesses that participate in the network, with the overall cost of doing business falling as a result.

One of the most recent papers in this area by Roller and Waverman (2001) supports this argument and even finds that telecommunications stock exhibits non-linear returns. In other words, additional accumulation of telecommunications stock after some critical mass (threshold point) results in higher growth effects. They also find that a medium level of penetration (20%-30%) in a sample of OECD countries does not cause considerable productivity gains. An interesting extension of this result, as pointed out by the authors, is that some developing countries may achieve growth effects through investment in telecommunications only if their telecom stock is substantially improved.

This paper will supplement the previous literature by looking into the effects of telecommunications on growth for the countries in transition. Mechanisms of growth in the transitional economies which are dissimilar to many of the developed countries may produce interesting results that support (or reject) the previous findings.

The main purpose of the empirical part of the paper will be to test the hypothesis that the telecommunications stock promotes economy-wide productivity growth in the setting of 22 transitional countries. I will look at the dynamics of the series and most interesting correlations in the data set. In addition, I will check for the presence of non-linear returns by including an interaction variable of penetration rate and a dummy variable for the rate of 40% and higher.

The structure of the paper is the following: the Industry Overview sets the background on the developments in the telecommunications industry of the former Soviet countries before and after the collapse of the Soviet Union; the Literature Review section presents the studies that have been made in this field up to date; the Data section provides description of the data and necessary transformations of the series; the Model section presents the methodology of the empirical research and discusses the main results of the econometric analysis as well as sensitivity analysis; and the Conclusion section reiterates the key findings of the paper and suggests possible applications of this study to policy-making.

Chapter 2

INDUSTRY OVERVIEW

This chapter gives a general overview of the telecommunications industry in the countries of the former Soviet Union and the Soviet block. After the collapse of the Soviet Union, the countries had notably different paths of transition and subsequent economic growth. Despite all the differences in the economic transition of these countries, one can easily notice favorable developments in the telecommunications throughout the region. Most remarkably, after the fall of the USSR, the telecommunications sector had attracted the interest of many foreign manufacturers of telecom equipment, which in some countries translated into a fresh inflow of investment.

First of all, the Soviet era was characterized by significant investment into heavy industries, which were seen as the major driving force of Soviet economic development. Highly oriented towards military needs, the economy of the Soviet countries put the lowest priority on consumption goods and services resulting in the underinvestment in these sectors of the economy. Taking into account that the economic objectives were set by the ruling Communist Party, it is understandable that prime resources were directed to the achievement of the highest possible level of growth, therefore leaving the consumption goods as a residual category (Lehmann, 2003).

As a result, the telecommunications industry in the Soviet Union was a priority insofar as the military complex was involved. On the consumption level, the lack of investment in the telecoms sector had been reflected in long waiting lists, indicating a large unsatisfied demand for telecommunications services. Figure 1 shows the number of those in waiting lists per 100 people. All countries of the Soviet bloc had considerable shortages of telecoms network capacity which resulted in the sizable waiting lists and long waiting time until one could finally subscribe to the network. In 1990, in Bulgaria, Russian Federation, and Ukraine seven people out of every 100 could not be connected to the telephone networks at once.

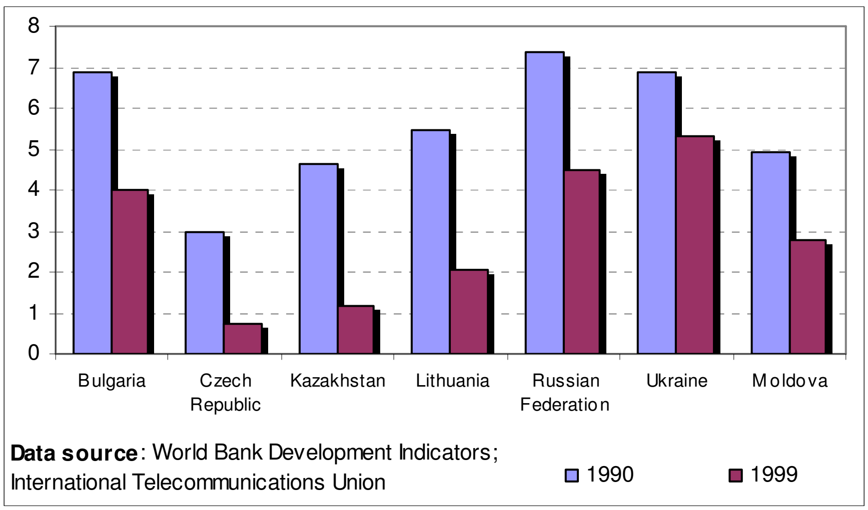

Figure 1. Unsatisfied Demand for Telecommunications (Waiting List, per 100 people)

In addition to the undercapacity of networks, service fees for telecommunications were traditionally kept at unrealistically low levels, which further exacerbated the problem of unsatisfied demand. Such policy made the telecommunications sector extremely dependent on state subsidies. In early 1990s, when the transition policies in most former Soviet republics and CEE countries resulted in high rates of inflation (and even hyperinflation in case of Ukraine), the profits of the telecommunications operators have been significantly eroded. As a result, the potential for investment has decreased significantly.

Thirdly, much of the equipment employed in the Soviet economy (which was not part of the military complex) was either technologically obsolete or physically outdated in comparison to Western standards. During the Cold War, new Western technology was not allowed to penetrate into Soviet countries. Coordinating Committee for Multilateral Export Controls (COCOM) founded in 1949 by Western countries, most of which were NATO members, maintained tight controls on technology dissemination to prevent the results of Western R&D to be used for military purposes in the USSR and Soviet bloc countries. Therefore, telecommunications operators worked with obsolete equipment which did not allow fast expansion of telephone networks and was reflected in the low quality of services. Some researchers estimate that the technological gap in telecoms industry between CEE and their Western counterparts was about 10-15 years (Sadowski, n.d.)

The COCOM restrictions were lifted after the fall of the USSR. The White House press release concerning changes in the policy of COCOM, as of June 17, 1992 says: "The COCOM partners also agreed to an immediate improvement in the availability of advanced telecommunications equipment to the new states of the former Soviet Union effective July 1, 1992. As these states seek to reform and establish closer ties to the economies of the West, better telephone, fax and other data networks are clearly needed." Clearly, this marked the beginning of the new phase for the telecommunications industry in the former Soviet countries. As the Iron Curtain has been removed and COCOM restrictions ceased to apply, new markets opened for foreign telecommunications firms. However, the political and economic factors of any particular Soviet country conditioned the pace of the development of its telecommunications sector. In what follows I will consider telecoms sector in three groups of countries differentiated by geographical location: Central European countries will be represented by Poland, Hungary and the Czech Republic, Russia and Ukraine will represent former Soviet republics (in Europe) and Kazakhstan will stand for Asian Soviet republics.

2.1 Central Europe

The telecommunications industry in Central Europe in the 90s is mostly a success story. The prospects of the accession to the European Union after the fall of the USSR required submission to the prescripts of the European Commission for the creation of the common market for telecommunications services and equipment. The major objective of the Commission initiatives was "to ensure that public contracts [in the telecommunications sector] are awarded without discrimination" (Sadowski, n.d.).

Compliance with the Commission initiatives has subsequently led to privatization and/or reorganization of local telecommunications operators. Privatization has proved to be a very successful measure for attracting fresh investment into telecommunications. In Hungary, international telecoms firms acquired up to 67% of the national public telecommunications operator (PTO). In the Czech Republic, the share of foreign ownership in PTO reached some 33%. In telecoms manufacturing, foreign companies bought significant portions of indigenous telecom firms and, in return, received preferential treatment in tenders of supplies for PTOs.

Due to such healthy inflow of investment into the sector, in early 1990s telecoms industry in CEE enjoyed a major increase in productivity and sales. As an example, consider Hungary, where the sales increase in the telecoms sector (telecoms services and manufacturing) was reported to be as high as 260% by 1996 compared to 1992. In Poland, the entrance of three foreign manufacturers Alcatel, Siemens, and AT&T Lucent brought about an almost 500% increase in the sector sales between 1991 and 1995 (Sadowski, n.d.).

Furthemore, since 1990 governments of most CEE countries initiated investment programs in the telecoms aimed at modernization of equipment and expansion of services (Sadowski, n.d.). Figure 2 shows changes in penetration rates in selected CEE countries from 1990 to 1999.

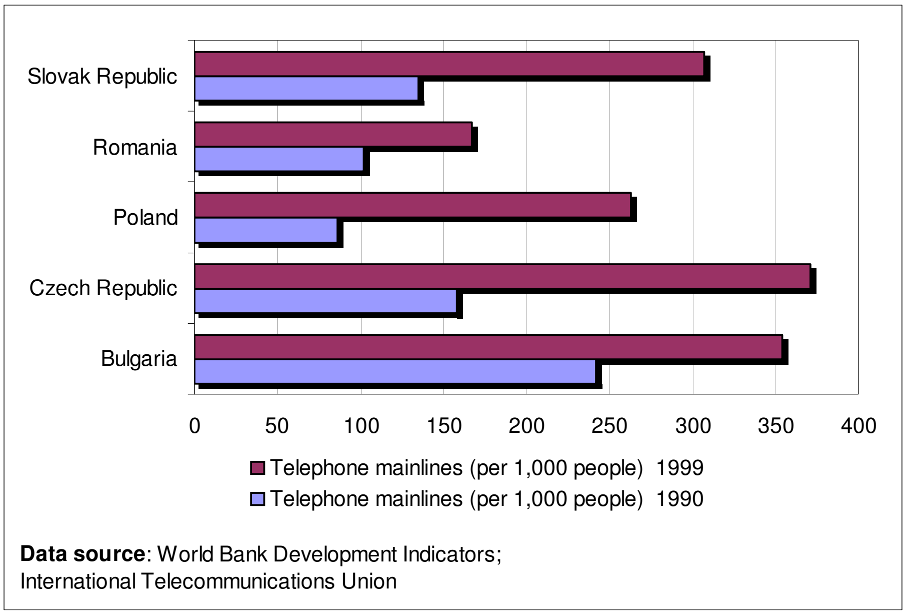

Figure 2. Change in Penetration Rate in Selected CEE Countries

Due to the active reorganization and modernization policy in these countries, their teledensity has improved substantially. Penetration rates in Czech Republic and Bulgaria have approached the world standard of 40%.

Orientation on the EU accession had forced CEE markets to be more open to foreign markets and counterparts. Considerable sales growth in the sector makes CEE countries a desirable market for entry by foreign capital. This market offers a stiff competition to Eastern European countries, such as Russia and Ukraine, in a search for foreign investment.

2.2 Russia and Ukraine

In Russia and Ukraine, changes in telecommunications sector have not been as profound and fast as in the CEE countries. Participation of foreign firms in the privatization process has been low. The governments have set up a system of stringent regulations with regard to general economic activity by non-nationals and their participation in the privatization. In 1995, according to the Ukrainian Law on Communications, a foreign share in the Ukrainian telecommunications service provider could not exceed 49 percent. In addition, Ukrainian legislation stipulated that only local state or private companies were "entitled to apply for operational and frequency licenses" (Ristau, 1996).

First of all, in both countries, privatization of national PTOs had been stalled due to adverse political and economic factors. Consider the example of Russia, where local authorities of Subjects of Federation can have an influential say in establishing of tariff system for local telecommunications services. Such lack of centralized coordination in the sector has resulted in the wireless telephony having no unified, pan-market mobile standard up to 1998. In connection to the national Russian PTO Sviazinvest, such "policy federalism" in telecommunications sector makes it hard to properly estimate the value of the company and adds to the political risks that potential investors face in Russia.

Secondly, Ukraine and Russia still suffer from the legacy of the Soviet Union economic policy in terms of telecoms tariff system. Most tariffs for local calls are extremely low which forces the local PTO to rely heavily on government subsidies (Ilyashenko, 2002). The situation is further worsened by the attitudes of customers who "perceive [telecommunications] service as a right, not as a purchasing decision" (Kazachkov, 1998). Essentially, this means that customers regard the provision of basic telephone services as a government obligation to its citizens. Such attitude creates additional psychological barriers on the way to rationalizing the tariff system.

Despite the lack of coherent policy for restructuring telecommunications sector, both Ukraine and Russia have made significant progress on the way to modernizing obsolete telecoms equipment and introducing new technologies into the sector. However, faster liberalization of telecoms, which includes creation of a more competitive environment and fewer trade barriers, would stimulate more FDI inflows into the sector and subsequently higher returns.

2.3 Asian Telecoms

Historically, Kazakhstan had the highest telephone penetration rates among the countries of Central Asia. However, in comparison to other former Soviet republics, Kazakhstan's teledensity had on average been much lower (1upinfo.com).

As in the case of Ukraine and Russia, Kazakhstan's obsolete telecoms equipment desperately needed updating. At the same time, PTO equipment utilization rates were high at 98%, which indicated the impossibility of expanding the network without improving the transmitting capacity of the lines (1upinfo.com).

In 1996, Kazakhstan's government started an extensive modernization program in the telecommunications sector. The plans included substitution of obsolete systems with fiber-optic telecommunications lines and construction of two new international connections: TransAsian-European line and the line which connects Russia with the Far East (Lavrinenko, 1996).

2.4 Recent Trends in the Industry

Despite high sales increases in the early to middle 90s in the mainlines telecommunications services in CEE, the current leader of the market which can boast network expansion of as much as 100% per annum is the mobile telephones industry. The McKinsey Quarterly Report 2003 says that European mainline telecom providers are losing up to 12% in annual revenues due to a shrinking market share of fixed-voice business.

In many Central European countries, mobile phones provide an equally attractive alternative to the mainline connections, especially in the light of falling tariffs on mobile telephony. Specifically, McKinsey Quarterly says: "The penetration of wireless relative to fixed-phones is already quite high there [in CEE], so many customers may well give up or never adopt fixed-line services."

Even in former Soviet republics, whose fixed line operators have not been doing well due to limited participation of foreign capital, there has been a dramatic increase in the mobile penetration rates. Ukraine had seen a 13-fold increase in the number of mobile subscribers over the period of 2 years, 1999-2001 (Ilyashenko, 2002).

To summarize, telecommunications industry in the former Socialist countries has seen some positive changes since the early 1990. In some states, growth of the sector brought significant revenue increases. The question that the following research will try to answer is whether there exists any connection between the growth in telecommunications sector and the overall productivity of the economy. The next chapter will try to establish this connection by reviewing the existing literature on research in telecommunications.

C h a p t e r 3

LITERATURE REVIEW

Technological advances of the last decades have made many of the telecommunications services less expensive and therefore more available to the general public. This significantly boosted the demand for telecommunications services and as a result increased the share of the latter in the national accounts.

A more interesting question, however, is whether the telecommunications sector possesses any mechanisms that translate increases in the telecom stock into the improvements in productivity, or growth effects. A paper by Capello and Nijkamp (1996) presents a theoretical justification of the positive spillovers of the telecom sector into other sectors of the economy. The main idea is that a firm receives positive net benefits by connecting to a network that expands the number of potential business partners to that firm.

Figure 3 below explains the concept of network externalities graphically. If the economic agent behaves rationally, he will choose the amount of services provided by telecommunications industry so as to maximize his profits. This quantity is found by equalizing the agent's marginal costs to his marginal benefits. In the absence of externalities, the optimizing quantity is at Q which corresponds to the equilibrium price P_1. The total marginal benefit received by the network subscriber, however, is higher than P_1. Every subscriber that joins the network receives additional benefits created by other subscribers (including future subscribers.) *Total Benefit* curve outlines the total benefits received by the agent, and the distance AB represents the value of additional benefits generated by the network externalities.

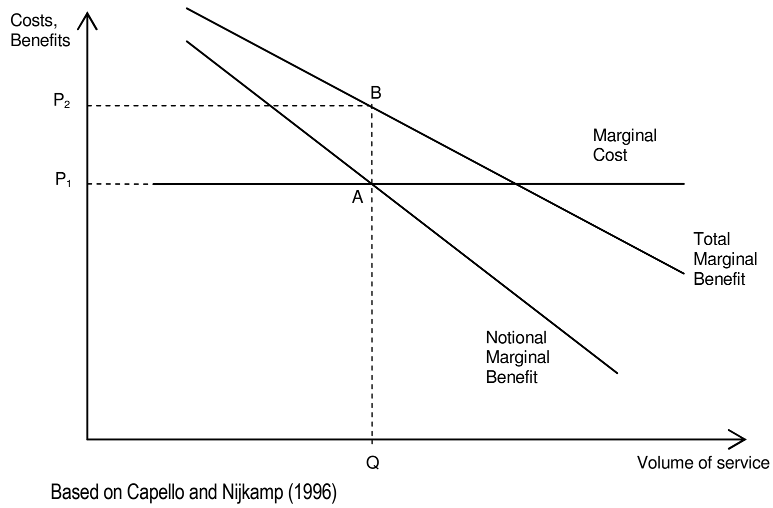

Figure 3 Network Externalities

One may also consider economy-wide effects of network externalities. Again, a graphical representation is very useful to illustrate that social returns are greater than private returns as the telecommunications infrastructure expands. In Figure 4 the horizontal axis now also measures the number of subscribers in the network. The upward sloping externalities curve demonstrates that the size of the network is positively related to the value of externalities. In reality, there exists some threshold level of density (number of subscribers) in the network, after which any additional subscriber will actually generate negative externality. In this case, however, I will consider only the upward-sloping portion of the externalities curve, assuming that the threshold level corresponds to infinitely large volume of services.

As the Figure 4 demonstrates, private marginal returns for any volume of service are lower than the social marginal returns. When another subscriber joins the network, the social marginal benefit is calculated by adding to the private marginal return all benefits that existing users receive from having one more subscriber (distance B_pB_s.)

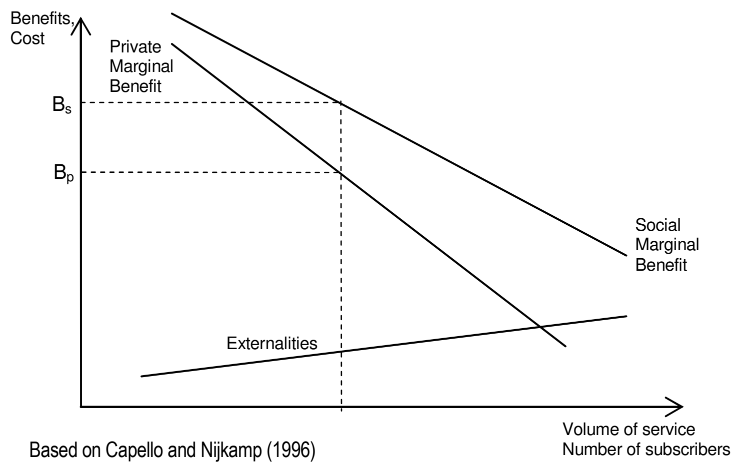

Figure 4 Network Externalities and Social Returns

It is argued that the presence of network externalities in telecommunications sector allows faster exchange of information and, as a result, improvement in productivity rates. Several early works on telecommunications delineate possible effects of network externalities. Hardy (1980) says that telephone networks improve the capability of managers to "communicate with each other rapidly over increased distances" (quoted in Roller and Waverman, 2001). Leff (1984) maintains that telephone network externalities include lower costs of information gathering that lead to lower transactions costs and more efficient production.

A useful starting point for the discussion of estimating network effects is an overview of the more general research on infrastructure. First, infrastructure, and specifically public infrastructure, has lately become a very fashionable area in research which generated a large amount of literature on the topic. The researchers developed a range of models to explain the effects of infrastructure on economic growth and tried a variety of methodologies in response to critique of early research attempts. The study of such literature may give a general guidance in a more specific area of telecommunications infrastructure research.

Secondly, telecommunications sector is often considered to be a part of infrastructure and possesses many features of a public good (Roller and Waverman, 1999). Specifically, telecommunications networks have low marginal cost of use and are almost non-rival in consumption. With respect to the former we can say that as soon as a telecommunications network is in place, the cost of connecting another user to the network is negligible. Also, if we assume an infinite capacity of the telecom system, many subscribers can use the same network without diminishing consumption possibilities of each other. Even though the latter assumption is not realistic, and diminishing returns will set in at some point, telecommunications industry does exhibit the useful qualities of a public good.

Early studies of infrastructure, pioneered by Aschauer (1989), find that the growth effects of the infrastructure are positive and characterized by significant magnitudes. The literature review in this area by Gramlich (1994) lists several works that support this finding. There are also severe criticisms of this result, which argue that the magnitude of the estimated returns on infrastructure is unrealistically high. The estimates of public infrastructure production elasticities (the relationship was estimated in logarithmic form) ranged between 0.38 and 0.56.

The critics have pinpointed several econometric problems which include non-stationarity of the series which was not properly accounted for in the studies; wrong specification forms that miss important variables and produce spurious correlation; and reverse causality issue which deserves a closer scrutiny that follows.

In the study of the link between the public infrastructure and productivity growth, the economic intuition suggests that a reduced growth may also cause a reduction in the infrastructure demand. To tackle the problem of causality, Hulten (1994) turned to the help of a multi-equation model which determined the infrastructure stock endogenously. Surprisingly, the results obtained by using more sophisticated econometric models turned out to be little different from the one of Aschauer (1989). The researchers still obtained very high rates of return on public infrastructure investment.

A recent infrastructure study on transitional economies was done by Kasianenko (2002). He employs a quarterly series data set of eight transitional countries during 1995-2000. The main finding of this work is that there are no unambiguous growth effects of infrastructure at the aggregate level. He also tests the impact of the infrastructure on the micro-level and finds out that "developed infrastructure fosters firms in transition to behave more actively and efficiently."

Research on telecommunications industry followed a story essentially very similar to the one of infrastructure. One of the earliest works that tried to estimate the impact of telecommunications on the economic growth was done by Hardy (1980). He employed a very simple model relating a country's GDP per capita to the lagged telephones per capita, the number of radios, and the lagged GDP per capita. The estimated coefficient of the telephones variable was large. The studies that followed Hardy also used single-equation models.

As in the case of infrastructure research, these studies may fall under severe criticisms. However, with more sophisticated econometric tools that are now available, one can construct a model which would solve the problems of the early infrastructure and telecommunications studies. One of the recent works by Roller and Waverman (2001) accomplishes this task again by endogenising the telecommunications capital. They use a system of four simultaneous equations which separately define the national production, demand and supply of telecommunications capital and an equation which links the telecommunications investment and stock.

The approach of simultaneous equations therefore may be seen as superior because it succeeds in separating the reverse effect of economic growth on telecommunications from the productivity gains of network externalities. However, there is another important consideration that a researcher needs to pay attention to. As Roller and Waverman (2001) have noted, it is important to single out the influence of the telecommunications from other factors that can potentially improve productivity. Human capital, innovations, and research and development are all reputed to impose positive externalities. Capello and Nijkamp (1996) specifically differentiate the network externalities from the technology effects in their theoretical model. Therefore, careful specification is important if one wants to avoid misattributing to telecommunications the impact of other factors. A robustness analysis will follow the estimation of the model to check the results for telecommunications impact.

The empirical section that follows will adopt the econometric model of Roller and Waverman (2001) discussed above as the one which better fits the requirements of proper econometric analysis. Also, following this model will enable me to produce enlightening comparisons between the developed countries, as in the study mentioned above, with transitional countries.

Chapter 4

THE DATA

The sample covers 22 CEE and FSU countries over the period of 5 years (1995-1999.) Most of the series used in the analysis come from the World Bank Development Indicators Database. Telecommunications series have been kindly provided by the International Telecommunication Union. Where applicable, the series have been adjusted to real values with the base year of 1995. Two stock series, both for capital and telecommunications, have been calculated using the perpetual inventory methodology (Hall and Jones (1999) p.89, and Parekh (2002)).

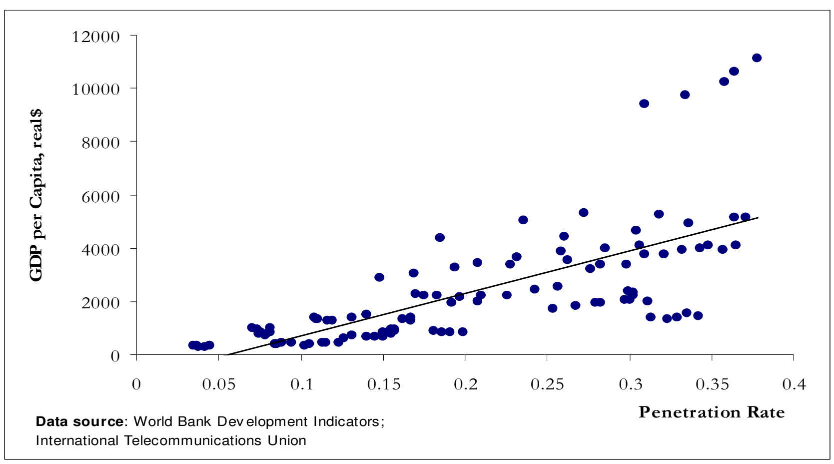

Figure 5. GDP Per Capita and Penetration Rate

A first look at the data reveals that income and total penetration rate (total number of mainlines and mobile telephones per capita) series are positively correlated with the coefficient of correlation 0.7075. In Figure 5 the top five observations correspond to Slovenia which has the highest GDP per capita and one of the highest penetration rates. All other observations seem to fit the linear trend line rather well. However, this graphical representation does not imply any causal relationship between the two variables. The next chapter will venture to establish such a relationship in a formal way.

Table 1. Average Annual Growth Rates in Selected Countries

Country	GDP CAGR*	PEN ** CAGR	MPEN CAGR	TPEN CAGR
Bulgaria	-0.0069	0.0251	0.8208	0.0634
Czech Republic	0.0101	0.0805	1.1127	0.2208
Estonia	0.0407	0.0460	0.6304	0.1664
Hungary	0.0333	0.1033	0.5096	0.1946
Latvia	0.0391	0.0142	0.7418	0.0868
Lithuania	0.0276	0.0405	0.8135	0.1029
Moldova	-0.0207	0.0039	3.6307	0.0403
Poland	0.0426	0.1137	1.1164	0.2039
Romania	-0.0122	0.0486	1.5560	0.1382
Russian Federation	0.0105	0.0436	0.8266	0.0599
Slovak Republic	0.0314	0.0709	1.1158	0.1624
Ukraine	-0.0168	0.0424	0.9775	0.0554
Azerbaijan	0.0585	0.0339	1.0295	0.1089
Belarus	0.0523	0.0580	0.4262	0.0606
Croatia	0.0306	0.0527	0.7741	0.1336
Georgia	0.0483	0.0521	2.2717	0.0911
Kyrgyzstan	0.0465	-0.0043	0.6254	-0.0004
Slovenia	0.0360	0.0415	0.8826	0.2084
Sample Average	**0.0249**	**0.038**	**1.1034**	**0.0954**

* CAGR is compounded annual growth rate
**PEN is mainlines penetration rate, MPEN is mobile telephones penetration rate, and TPEN is aggregate penetration rate of mainlines and mobiles together
Data source: World Bank Development Indicators; International Telecommunications Union

The table above reveals the dynamics of the mainline penetration rates, mobiles, and GDP over the sample period. All countries except for Kyrgyzstan have seen an increase in the mainline penetration rate, with Poland and Hungary on top of the list with more than 10% increase. One can easily notice that CEE countries have managed better improvements in their fixed lines connectivity than the former Soviet republics. By 2000, these countries have reached penetration rates slightly less than 40%, a fairly high indicator by world standards. On average, Central European countries have had over 6% annual increase in mainline subscriptions compared to 4% of the FSU countries. As it was already mentioned in the second chapter of this paper, the orientation toward the accession to the European Union and liberalization of trade have been the major driving forces behind the rapid development of telecommunications in CEE countries.

The mobile telephony sector has been the most dynamic during the last 6 years. One can notice that the average annual growth rate in mobile sector is more than 100%. In Moldova and Georgia, the sector has grown more than 200%, starting from near-zero mobile penetration in 1995 to 3.5% in 2000. However, in absolute numbers, CEE countries are leaders in terms of mobile penetration. By 2000, Slovenia and Czech Republic have some 40% and 60% of mobile penetration, respectively, which is significantly higher than in the mainlines sector in the same countries. In Ukraine, mobile penetration has almost doubled over the last 6 years.

In terms of changes in real GDP, the countries are more heterogeneous. In the period of 6 years, one can observe both positive and negative average growth rates of real GDP. Most CEE and Baltic countries with exception of Bulgaria and Romania exhibit positive growth rates in the range from 1% to 4.3%, with Poland and Slovenia leading the list. Ukraine has a negative CAGR of -1.6%. Azerbaijan and Belarus are the highest-growing countries with 5.8% and 5.2% of annual increase in GDP. Despite the negative growth rates for some of the countries, the average rate in the sample is rather high at 2.5% annually.

Chapter 5

EMPIRICAL INVESTIGATION

To cope with the econometric problems that presented a major critique to many of the earlier studies on infrastructure and telecommunications, I use a multiple equations model. The basic idea of such a model is to determine the telecommunications stock endogenously, with the help of telecommunications supply and demand equations. As it has already been mentioned earlier, the major advantage of such an approach is that it helps to control for the simultaneity bias. By carefully defining the telecommunications stock I will be able to explicitly account for the effect of GDP growth on the telecommunication sector and therefore estimate the productivity gains from telecoms network externalities more precisely.

The study by Roller and Waverman (2000) follows this line of reasoning and offers a four-equation model, which will serve as the backbone of my econometric model. This model consists of the following four equations:

(1) $GDP_{it} = f(K_{it}, L_{it}, TELECOM_{it}, t)$

(2) $TELECOM_{it} = h(GDP_{it} / POP_{it}, PRICE_{it}, t)$

(3) $TI_{it} = g(PRICE_{it}, WAIT_{it}\ GA_{it})$

(4) $TELECOM_{it} - TELECOM_{i,t-1} = y(TI_{it}, GA_{it})$

where subscript i *corresponds to the country and* t *to the time period*

The first equation is a traditional classical production function with an added telecommunication stock variable. The national production (*GDP*) is determined by the level of physical capital stock net of telecommunications (*K*), labor (*L*), telecommunications capital stock (*TELECOM*), and a time trend. To model the telecommunications stock, I will use aggregate teledensity as a proxy, determined as the sum of mainlines and mobile penetration rates. In other words, aggregate penetration indicates how many people have access to either mobile or fixed line telephone networks. As it has been mentioned in chapter two, mobile phones industry is rapidly expanding in transitional countries, which makes it necessary to include the mobile phones into the models.

Since the TELECOM variable will be used as a dependant variable in the Demand Equation (see below), it is convenient to transform it so as to obtain an unbounded distribution. The transformation formula is:

$TELECOM_i=[APEN_i/(0.7-APEN_i)]$

where APEN is the Aggregate Penetration Rate, as defined above

0.7 is the highest APEN in the sample

subscript i *refers to a country*

This transformation is necessary to avoid the problems associated with estimation of models based on truncated distributions.

The second equation defines the demand for telecommunications and is a function of the level of income in the country (*GDP* divided by the population *POP*) the telecommunications price (*PRICE*), proxied by the revenue per mainline, and time trend. The dependent variable on the left-hand side (TELECOM) is the transformed aggregate penetration rate, as defined above.

The third equation describes the supply of telecommunications as a function of price of telecommunications services (*TELP*) and a number of other variables. It is important to note that the supply of telecommunications is modeled here by using a telecommunications investment *TI* (as opposed to the stock) whilst the demand is defined by the telecom stock. This is because consumers use telecommunications stock, not investment (Roller and Waverman, 2001). Other independent variables include geographic area of the target country (*GA*), real value of the foreign direct investment (*FDI*), and waiting list per capita (*WAIT*). Geographic area and waiting list characterize the size of the market, and *FDI* is a proxy for the investment attractiveness of the country. The last equation defines the relationship between the telecommunications investment and stock, where geographical area captures the size effect of any particular country.

The econometric model employs a trans-log specification form. All variables appear in logarithmic transformations except the time trend variable in the production equation.

Table 2 contains results of estimation of two models: the first one as presented above and the second one with an additional variable, a slope dummy for penetration rate over 40%. Such differentiation was used to capture possible scale effects; specifically, the accumulation of telecommunications stock to a certain "critical mass" would bring higher or lower productivity effects. A positive coefficient of this variable, for example, would tell us that growth effects of telecommunications are greater the greater is the telecommunications network.

More formal methods of finding a threshold level for telecommunications stock are beyond the scope of this research; therefore, I have limited my study to checking arbitrarily chosen levels of penetration. Specifically, I examined changes in the TELECOM slope as aggregate penetration rate increased from 20% to 40%. Small size of the subsample did not allow me to check for the influence of either too low penetration rate (such as 10%) or very high one, beyond 40%. On the other hand, 40% penetration of the telephone network corresponds to approximately one telephone per household (Roller and Waverman, 2001) and indicates a fairy high level of communication and information exchange.

Both models are estimated using two-stage-least-squares (2SLS) methodology, which essentially amounts to a separate estimation of each of the four equations, with the help of instrumental variables. Therefore, the coefficients of the last three equations do not change with the introduction of a new dummy variable in the production function.

5.1 Estimation Results[1]

Table 2 provides estimation results of the two models. First, consider the *Production Equation* of the *Model 1*. Appropriate Hausman tests for fixed vs. random effects are provided in the Appendix to this paper. The signs of all variables seem to fall in line with what was expected. *Capital* and *Labor* have positive and significant coefficients with labor contributing slightly more to the growth than capital. Interestingly, the magnitudes of the elasticities of *Capital* and *Labor* are not only within the expected limits, but also sum up to unity, indicating the constant returns to scale in the economy. Time trend coefficient is negative but statistically insignificant in both models, which means that no distinguishable long-term trend is present in the series.

The coefficient of telecommunications in production equation is statistically significant and high at 0.464. It is necessary to keep in mind that this coefficient is not the elasticity of telecoms stock because the variable has been transformed (see above). However, with this estimate of penetration coefficient, one gets a very high percent of telecoms' contribution to the average growth, over 10% per

[1] Stata printouts are provided in the Appendix

annum. Evidentially, such an estimate is unrealistically high for any, even the fastest-growing, transitional country. The *Model 2*, on the other hand, differentiates between the influence of low and high penetration rates, and therefore gives a better estimate of the impact of telecommunications.

Table 2. Estimation Results

Variable	Model 1		Model 2		Roller and Waverman, 2001	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Production Function						
Intercept	.367	0.50	.343	1.13	--	--
Capital	.456	2.06	.587	7.86	0.627	19.01
Labor	.584	2.14	.402	4.53	0.529	6.52
Time trend	-.076	-1.48	-.023	-1.50	-0.007	-2.80
Telecom	.464	2.19	.448	4.91	0.034	3.55
Penetration between 20% and 30% (slope dummy)	--	--	--	--	0.010	0.96
Penetration over 40% (slope dummy)			-.400	-4.45	0.040	2.40
Demand Function						
Intercept	-1.671	-2.46	--	--	0.718	2.76
GDP per capita	.954	6.39	--	--	2.076	59.22
Time	.195	6.01				
Telecom Price	-.033	-0.23	--	--	-1.127	-36.05
Supply Function						
Intercept	1.049	0.89	--	--	2.345	-1.79
Geographic area	dropped*		--	--	0.320	14.19
FDI	.060	0.62	--	--	N/A**	N/A**
Waiting list	.027	0.40	--	--	-6.739	-6.06
Telecom price	.562	2.53	--	--	-0.041	-0.41
Telecom Function						
Intercept	-0.042	-0.18	--	--	0.141	17.60
Investment	0.041	2.90	--	--	0.002	1.58
Geographic area	-0.011	-0.56	--	--	-0.005	-7.11

*Note: due to the fact that the supply function was estimated using fixed effects technique, geographic area, which is constant over the sample period, has been dropped from the estimation.
**estimated coefficients are not available because a different specification was used.

The results of the second model are presented in the 4th and 5th columns of Table 2. The additional slope dummy in the second model is insignificant at a 5% critical level at aggregate penetration rates of more than 20%, 30% and 35% (not shown in the table). Table 2 shows that estimated coefficient of the slope dummy for penetration rates higher than 40% is significant at all conventional critical levels. This coefficient is large and has a negative sign, which implies noticeable diseconomies of scale. In other words, expansion of telecommunications networks to penetration rates higher than 40% is able to bring only marginal gains in productivity. The net growth effect of network expansion over 40% is just 0.048 (i.e.0.448-0.440). After accounting for such differences in impact of high and low penetration rates, the average elasticity of telecommunications is about 0.51. This finding corroborates the existing literature on infrastructure research, with elasticity estimates in the range of 0.38 to 0.56 (see Literature Review.)

One of the intuitive explanations for diminishing scale effects in telecommunications might be inadequate development of infrastructure in the economy. As an example, consider an extreme (and unlikely) case when there is a highly developed telecommunications industry but only a handful of producing firms in the economy. In such a case, further expansion of telephone networks would not lead to useful network externalities as the number of participants is constant. Moreover, as the economy's output is constant and the telephone networks expand, productivity of each network decreases.

Krugman (1999) supports the notion of positive and diminishing network effects. Using the example of the U.S. telegraph and an assumption that American cities entered the telegraph network in size order, he shows with simple calculations that the network would have a growing base but the number of communications would reduce with each connection. This simple illustration was used to show that diminishing returns were just as plausible as the increasing ones, especially when the networks concentrate on connecting the most productive users first and only later enlisting less productive ones (biggest cities in his case).

Although the *Demand* and *Supply* equations are used here primarily as auxiliary tools, they also reveal interesting results. Income elasticity of telecoms services is positive and significant, which means that people demand more telecommunications as their income increases. The coefficient is also less than unity (0.95), implying that telecoms services are viewed not as a luxury good, but rather as a necessity. Interestingly, the price is not a major concern here (one can notice that the price of telecoms services is insignificant in the demand equation.) Indeed, in Ukraine, demand for telephone connection has been so high in the recent years that people have been willing to pay a higher fee for the purpose of installing telephone lines faster. This fee sometimes exceeded a standard installation fee by a factor of 8 to10.

On the other hand, telecommunications price is significant and positively related to the supply of telecommunications in the *Supply Equation*. All other variables in this equation are statistically insignificant, implying that price (or potential revenues) is the main consideration for investors in the telecommunications sector in the transitional countries.

One can also make sensible comparisons of these results to the paper by Roller and Waverman (2001). They investigated the impact of telecommunications on economic growth in a set of OECD countries. The coefficients of major variables in the *Production* equation have the same signs as in the models above. On the other hand, the contribution of capital to growth in their article is greater than that of labor. The telecommunications variable (aggregate penetration rate) is significant, although the magnitudes are quite different. The estimate of telecommunications impact in transitional countries is 0.45, which is about ten times more than its impact in the developed countries (0.038). The larger telecommunications estimates in this study are logical, since transitional countries on average grow faster than developed countries, while penetration rates are lower. This may lead to considerably higher returns of telecoms network expansion. An important caveat to comparing the results of both studies is that Roller and Waverman used a different method of estimation, Generalized Method of Moments, which may also account for some of the differences in the magnitudes of the estimates.

Also, contrary to the results of the *Model 2*, Roller and Waverman have found that scale effects are positive for OECD countries, and the penetration rate higher than 40% causes greater growth effects than the penetration rate of 20% or 30%. At the same time, the coefficient of the high penetration rate in the *Model 2* is much closer in magnitude to the one obtained in the article of Roller and Waverman (compare 0.048 to 0.074, respectively), implying that as the market gets saturated, network expansion brings ever lower returns.

5.2 Sensitivity Analysis

As it was mentioned in the third chapter of this research, it is very important to single out the impact of telecommunications from effects that other factors may have on economic growth. Specifically, one should be very careful not to misattribute the impact of R&D and technology change to telecommunications. The previous analysis has shown that telecommunications network effect is positive, although it has negative economies of scale. In what follows, I will try to check how sensitive the telecommunications coefficients are to inclusion of other variables.

Table 3 displays the results of the sensitivity analysis. The first column reports the results of the *Model 2*, for convenience of comparison. The model in the second column contains an additional variable, the number of patent applications filed by residents in a given country. Since technological change is an important factor, which can have significant impact on economic growth, but is hard to measure precisely, I use the number of patent applications as a proxy for technology. The estimated coefficient is positive and statistically significant at 8% critical level. As the table clearly indicates, the signs and magnitudes of other coefficients are not notably affected by inclusion of the control variable. Specifically, the *Telecom* coefficient is positive and close to the original estimate in magnitude, as is the slope dummy for the high penetration rate.

Table 3. Sensitivity Analysis Results

Variable	Model 2		Number of Patent Applications		Scientists and Engineers in R&D, per mln people	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Production Function						
Intercept	.343	1.13	.530	0.095	.372	0.58
Capital	.587	7.86	.636	10.34	.661	4.93
Labor	.402	4.53	.252	2.79	.322	2.03
Time trend	-.023	-1.50	-.007	-0.54	-.029	-1.20
Telecom	.448	4.91	.336	4.42	.349	2.24
Penetration over 40% (slope dummy)	-.400	-4.45	-.297	-3.99	-.296	-2.09
Control Variable	--	--	.066	1.71	-.033	-1.00

Another potential proxy for technology, the number of scientists and engineers in R&D appears in next model presented in the 3rd column of Table 3. Inclusion of this variable does not change the significance and signs of other estimated coefficients. The magnitudes of the telecoms coefficients change slightly with no substantial change in the net impact of telecommunications at the penetration rates higher than 40% (compare initial 0.048 with 0.053). On the other hand, the model using the number of scientists and engineers as a proxy for technology is not as successful as the previous one (with patent applications) because the coefficient of the control variable is insignificant, indicating that this variable may be a wrong proxy for the technology.

To summarize the results of the sensitivity analysis, one can say that the estimated coefficients of the *Model 2* are robust to inclusion of the technology variable. At the same time, the signs and magnitudes of the telecommunications coefficients do not change drastically with introduction of the technology variable which indicates that the model has not mistakenly attributed the influence of technological change to telecommunications.

C h a p t e r 6

CONCLUSIONS AND POLICY IMPLICATIONS

In the last 5 years, telecommunications industry has shown positive changes in the most transitional countries. Specifically, the countries of CEE have witnessed exceptional progress in the industry by allowing foreign investors enter their markets through trade and privatization. For some countries, such as Poland, the outcome was a five-fold increase in sales in 5 years (1991-1995). Waiting lists have significantly shrunk, as the telephone networks expanded. Their success can be in large part explained by their orientation towards the accession to the European Union, which required liberalization of trade and promotion of competition in the sector.

Aside from the direct impact on the demand for telecoms equipment and services, expansion of telecommunications networks has brought about notable productivity gains in other industries through the mechanism known as 'network externalities.' The results of the empirical part of this paper show that growth effects of telecoms in transitional countries are indeed positive. The estimated elasticity of economic growth with regard to telecommunication stock is about 0.50. This estimate is corroborated by the literature in a more general field of infrastructure research, which gives a range for elasticities of 0.38 to 0.56.

Among the most important findings of this research are the diminishing network effects, which one may observe for the penetration rates higher than 40%. In contrast to the results of Roller and Waverman (2001), who found that productivity gains are larger with higher telecommunications stock (over 40%), the model of this paper has discovered that in transitional countries the impact of telecommunications gets smaller once the penetration rate crosses the threshold of 40%.

Krugman (1999) supports that diminishing network effects are as likely to be observed in the economy as the positive ones. A possible explanation of the decreasing economies of scale is that the most productive connections are usually provided first and followed by less productive ones, which leads to decreasing marginal usefulness (productivity) of every next connection.

This feature of telecommunications networks in transitional economies is important to keep in mind while formulating economic policy agenda. Telecommunications is an essential means for information exchange and can bring about positive productivity gains. However, overemphasizing the role of telecommunications may cause a decrease in growth effects. The policy-maker should be careful to tailor the expansion of the telecommunications networks to economic growth.

Diminishing network returns are also a promising avenue for further research. Specifically, the factors that explain diminishing network returns in transitional countries and increasing returns in developed countries (see Roller and Waverman (2001)) have not been thoroughly researched yet.

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APPENDIX

Output 1 Production Function and Hausman Test for Fixed vs. Random Effects

```
. xtivreg  ln_gdp ln_kap_net ln_labor time (ln_newpen= ln_revenue ln_area ln_fd
> i ln_per_cap  ln_invest)

G2SLS Random-effects regression                 Number of obs      =        98
Group variable: country                         Number of groups   =        20

R-sq:  within  = 0.0837                         Obs per group: min =         3
       between = 0.9699                                        avg =       4.9
       overall = 0.9526                                        max =         5

                                                Wald chi2(4)       =    331.20
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
      ln_gdp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   ln_newpen |   .4635952   .2112749     2.19   0.028     .0495039    .8776865
  ln_kap_net |   .4557723   .2208261     2.06   0.039      .022961    .8885835
    ln_labor |   .5836353    .272267     2.14   0.032     .0500018    1.117269
        time |  -.0761056   .0512561    -1.48   0.138    -.1765657    .0243544
       _cons |   .3670495   .7294886     0.50   0.615    -1.062722    1.796821
-------------+----------------------------------------------------------------
     sigma_u |  .19005027
     sigma_e |  .12064167
         rho |  .71278068   (fraction of variance due to u_i)
------------------------------------------------------------------------------
Instrumented:   ln_newpen
Instruments:    ln_kap_net ln_labor time ln_revenue ln_area ln_fdi ln_per_cap
                ln_invest

. hausman

                ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     Prior       Current       Difference          S.E.
-------------+-------------------------------------------------------------
   ln_newpen |   .2686239     .4635952        -.1949713               .
  ln_kap_net |  -.0965972     .4557723        -.5523694        .4169163
    ln_labor |   2.485212     .5836353         1.901576        .9931288
        time |  -.0474068    -.0761056         .0286988               .
---------------------------------------------------------------------------
                b = less efficient estimates obtained previously from xtivreg
                B = fully efficient estimates obtained from xtivreg

    Test:  Ho:  difference in coefficients not systematic

                chi2(  4) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =     3.44
                          Prob>chi2 =     0.4866
```

Output 2 Production Function with Slope Dummy for Penetration Rate over 40%

```
. xtivreg  ln_gdp ln_kap_net ln_labor time newpen40 (ln_newpen= ln_revenue ln_a
> rea ln_fdi ln_per_cap  ln_invest)

G2SLS Random-effects regression                 Number of obs      =        98
Group variable: country                         Number of groups   =        20

R-sq:  within  = 0.1688                         Obs per group: min =         3
       between = 0.9728                                        avg =       4.9
       overall = 0.9692                                        max =         5

                                                Wald chi2(5)       =   2023.15
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
      ln_gdp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   ln_newpen |   .4477085    .091139     4.91   0.000     .2690793    .6263377
  ln_kap_net |   .5866905   .0746805     7.86   0.000     .4403195    .7330615
    ln_labor |   .4024194   .0887596     4.53   0.000     .2284538    .5763851
        time |  -.0234515   .0156224    -1.50   0.133    -.0540709    .0071679
    newpen40 |  -.3996002   .0897278    -4.45   0.000    -.5754634   -.223737
       _cons |   .3429066    .304315     1.13   0.260    -.2535399    .9393531
-------------+----------------------------------------------------------------
     sigma_u |  .17199373
     sigma_e |  .20967527
         rho |  .40222471   (fraction of variance due to u_i)
------------------------------------------------------------------------------
Instrumented:   ln_newpen
Instruments:    ln_kap_net ln_labor time newpen40 ln_revenue ln_area ln_fdi
                ln_per_cap ln_invest

. hausman

                ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     Prior       Current       Difference          S.E.
-------------+-------------------------------------------------------------
   ln_newpen |    1.298161     .4477085        .8504524     1.672614
  ln_kap_net |   -2.251191     .5866905       -2.837882     3.783552
    ln_labor |    3.266573     .4024194        2.864153     2.841089
        time |   -.1594486    -.0234515       -.1359971      .233632
    newpen40 |   -1.175021    -.3996002       -.7754206     1.539543
---------------------------------------------------------------------------
                b = less efficient estimates obtained previously from xtivreg
                B = fully efficient estimates obtained from xtivreg

    Test:  Ho:  difference in coefficients not systematic

                chi2(  5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =     4.90
                          Prob>chi2 =     0.4277
```

Output 3 Demand Equation

```
. xtreg ln_newpen  ln_revenue new_cap time
```

```
Random-effects GLS regression                   Number of obs      =        98
Group variable (i) : country                    Number of groups   =        20

R-sq:  within  = 0.3935                         Obs per group: min =         3
       between = 0.8119                                        avg =       4.9
       overall = 0.7185                                        max =         5

Random effects u_i ~ Gaussian                   Wald chi2(3)       =    121.21
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
   ln_newpen |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  ln_revenue |  -.0334061   .1457339    -0.23   0.819    -.3190394    .2522272
     new_cap |   .9537669   .1491849     6.39   0.000     .6613699    1.246164
        time |   .1954521   .0324973     6.01   0.000     .1317585    .2591457
       _cons |  -1.670925   .6787004    -2.46   0.014    -3.001154    -.340697
-------------+----------------------------------------------------------------
     sigma_u |  .40622956
     sigma_e |  .44507428
         rho |  .45446514   (fraction of variance due to u_i)
------------------------------------------------------------------------------

. hausman

                ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     Prior       Current       Difference          S.E.
-------------+-------------------------------------------------------------
  ln_revenue |  -.0200228    -.0334061         .0133833      .1179108
     new_cap |   1.909362     .9537669         .9555949      .8513753
        time |   .1719732     .1954521        -.0234789      .0242167
---------------------------------------------------------------------------
                b = less efficient estimates obtained previously from xtreg
                B = fully efficient estimates obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                chi2(  3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =     1.30
                          Prob>chi2 =     0.7293
```

Output 4 Supply Equation

```
. xtreg  ln_invest ln_revenue ln_area ln_fdi ln_newait, fe

Fixed-effects (within) regression               Number of obs      =       101
Group variable (i) : country                    Number of groups   =        21

R-sq:  within  = 0.0926                         Obs per group: min =         3
       between = 0.6902                                        avg =       4.8
       overall = 0.6326                                        max =         5

                                                F(3,77)            =      2.62
corr(u_i, Xb)  = 0.6917                         Prob > F           =    0.0569

------------------------------------------------------------------------------
   ln_invest |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  ln_revenue |   .5620828   .2223921     2.53   0.014     .1192437    1.004922
```

```
     ln_area |  (dropped)
      ln_fdi |   .0601788   .0963771     0.62   0.534    -.1317324    .2520901
   ln_newait |    .027014   .0676651     0.40   0.691    -.1077244    .1617523
       _cons |   1.048992   1.178268     0.89   0.376    -1.297239    3.395223
-------------+----------------------------------------------------------------
     sigma_u |  1.6953147
     sigma_e |  .50885334
         rho |  .91735405   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(20, 77) =    16.23              Prob > F = 0.0000
```

Output 5 Investment-Capital Relationship

```
xtreg   ln_lag ln_invest ln_area

Random-effects GLS regression                   Number of obs      =       102
Group variable (i) : country                    Number of groups   =        21

R-sq:  within  = 0.0051                         Obs per group: min =         3
       between = 0.3431                                        avg =       4.9
       overall = 0.0784                                        max =         5

Random effects u_i ~ Gaussian                   Wald chi2(2)       =      8.43
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0148

------------------------------------------------------------------------------
      ln_lag |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   ln_invest |   .0411969   .0141922     2.90   0.004     .0133808    .0690131
     ln_area |  -.0111469   .0198974    -0.56   0.575    -.0501452    .0278513
       _cons |  -.0423416   .2359726    -0.18   0.858    -.5048394    .4201563
-------------+----------------------------------------------------------------
     sigma_u |          0
     sigma_e |  .31461404
         rho |          0   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Output 6 Sensitivity Analysis with Patents

```
. xtivreg  ln_gdp ln_kap_net ln_labor time newpen40  ln_pat_res (ln_newpen= ln_
> revenue ln_area ln_fdi ln_per_cap  ln_invest)

G2SLS Random-effects regression                 Number of obs      =        93
Group variable: country                         Number of groups   =        20

R-sq:  within  = 0.1932                         Obs per group: min =         2
       between = 0.9806                                        avg =       4.7
       overall = 0.9782                                        max =         5

                                                Wald chi2(6)       =   2696.89
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
      ln_gdp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
```

```
   ln_newpen |   .3356885   .0760176     4.42   0.000     .1866968    .4846803
  ln_kap_net |   .6356232   .0614569    10.34   0.000     .5151699    .7560766
    ln_labor |   .2518303   .0904147     2.79   0.005     .0746207    .4290399
        time |  -.0073281   .0135406    -0.54   0.588    -.0338671    .0192109
    newpen40 |  -.2965629   .0742407    -3.99   0.000     -.442072   -.1510538
  ln_pat_res |   .0664908   .0389763     1.71   0.088    -.0099014    .1428829
       _cons |   .5300348   .3177547     1.67   0.095    -.0927528    1.152823
-------------+----------------------------------------------------------------
     sigma_u |  .16521444
     sigma_e |  .19295592
         rho |  .42300856   (fraction of variance due to u_i)
------------------------------------------------------------------------------
Instrumented:   ln_newpen
Instruments:    ln_kap_net ln_labor time newpen40 ln_pat_res ln_revenue ln_area
                ln_fdi ln_per_cap ln_invest
```

Output 7 Sensitivity Analysis with Scientists and Engineers in R&D

```
. xtivreg  ln_gdp ln_kap_net ln_labor time newpen40  ln_sci (ln_newpen= ln_reve
> nue ln_area ln_fdi ln_per_cap  ln_invest)

G2SLS random-effects IV regression              Number of obs      =        72
Group variable: country                         Number of groups   =        20

R-sq:  within  = 0.2311                         Obs per group: min =         1
       between = 0.9811                                        avg =       3.6
       overall = 0.9794                                        max =         5

                                                Wald chi2(6)       =    416.85
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
      ln_gdp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   ln_newpen |   .3485942    .155489     2.24   0.025     .0438414     .653347
  ln_kap_net |   .6605957   .1339293     4.93   0.000     .3980991    .9230922
    ln_labor |   .3219335    .158795     2.03   0.043     .0107011    .6331659
        time |  -.0291956     .02436    -1.20   0.231    -.0769403    .0185492
    newpen40 |  -.2964755   .1415774    -2.09   0.036    -.5739621   -.0189888
      ln_sci |  -.0327663   .0328398    -1.00   0.318     -.097131    .0315985
       _cons |   .3722387   .6445311     0.58   0.564     -.891019    1.635496
-------------+----------------------------------------------------------------
     sigma_u |  .20303133
     sigma_e |  .04651161
         rho |  .95013652   (fraction of variance due to u_i)
------------------------------------------------------------------------------
Instrumented:   ln_newpen
Instruments:    ln_kap_net ln_labor time newpen40 ln_sci ln_revenue ln_area
                ln_fdi ln_per_cap ln_invest
```