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Telecommunications Infrastructure and Economic Development: A Simultaneous Approach

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ABSTRACT

Telecommunications Infrastructure and Economic Development: A Simultaneous Approach*

In this paper we investigate how telecommunications infrastructure affects economic growth. This issue is important and has received considerable attention in the popular press concerning the creation of the "information superhighway" and its potential impacts on the economy. We use evidence from 21 OECD countries over the past twenty years to examine the impacts that telecommunications developments may have had. We estimate a structural model which endogenizes telecommunication investment by specifying a micro-model of supply and demand for telecommunication investments. The micro-model is then jointly estimated with the macro-growth equation. After controlling for country-specific fixed effects, we find evidence of a positive causal link, provided that a critical mass of telecommunication infrastructure is present.

ZUSAMMENFASSUNG

Telekommunikations-Infrastruktur und Wirtschaftsentwicklung: Ein simultanes Modell

In diesem Beitrag wird untersucht, welchen Einfluß die Telekommunikations-Infrastruktur auf die wirtschaftliche Entwicklung ausübt. Diese wichtige Frage hat im Zusammenhang mit der Diskussion um "Informationsautobahnen" Aktualität erlangt. In der vorliegenden Studie wird der Einfluß der Telekommunikations-Infrastruktur für 21 OECD-Länder für die vergangenen 20 Jahre analysiert. Es wird ein Strukturgleichungsmodell geschätzt, in dem Investitionen in die Telekommunikations-Infrastruktur als endogene Variable erfaßt werden und in einem Mikromodell Angebot und Nachfrage nach Telekommunikations-Investitionen spezifiziert werden. Das Mikromodell wird dann zusammen mit der Makro-Wachstumsgleichung geschätzt. Als Ergebnis stellen die Autoren dann eine positive Kausalbeziehung zwischen Telekommunikations-Investitionen und wirtschaftlicher Entwicklung fest, wenn eine kritische Masse an Telekommunikations-Infrastruktur existiert.

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I. Introduction

Explaining the sources of economic growth has ranked amongst the most significant issues that economists have examined. Romer's 1986 work began a set of theoretical and empirical analyses focusing on the endogeneity of the growth process as compared to Solow (1956) type neoclassical growth models which use an aggregate production function approach and exogenous technical changes. Numerous papers since then have attempted to disentangle those elements of a national economy which create growth. Many of these papers have examined empirically whether economic growth is converging relative to the USA and what the forces are that may lead to convergence [see for example Barro and Sala-i-Martin (1992); Mankiw, Romer and Weil (1992); De Long and Summers (1991, 1993)]. Grossman and Helpman (1994) survey the recent literature on the determinants of economic growth and divide these works into three types: one set considers the accumulation of 'broad' capital, including human capital and different types of physical capital. A second set of papers utilize spillovers or external economies, and finally a third set "cast industrial innovation as the engine of growth[1].

This paper investigates how telecommunications infrastructure affects economic growth. This issue is important and has received considerable attention in the popular press concerning the creation of the "information superhighway" and its potential impacts on the economy. We use evidence from 21 OECD countries over the past twenty years to examine the impacts that telecommunications developments may have had.

Telecommunications infrastructure investment can lead to economic growth in several ways. Most obviously, investing in telecommunications infrastructure does itself lead to growth because its products - cable, switches, etc. - lead to increases in the demand for the goods and services used in their production. In addition, the economic returns to telecommunications infrastructure investment are much greater than the returns just on the telecommunication investment itself. Where the state of the telephone system is rudimentary, communications between firms is limited. The transactions costs of ordering, gathering information, searching for services are high. As the telephone system improves, the costs of doing business fall, and output will increase for individual firms in individual sectors of the economy. “If the telephone does have an impact on a nation’s economy, it will be through the improvement of the capabilities of managers to communicate with each other rapidly over increased distances” [Hardy (1980), p. 279]. Thus, telecommunications infrastructure investment and the derived services provide significant benefits; their presence allows productive units to produce better. The ability to communicate at will increases the ability of firms to engage in new productive activities[2]. Moreover, the importance of this effect increases as the information intensity of the

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[1] See also Quah (1993a, 1993b) who criticizes the entire set of empirical studies which examine whether long term growth is converging for a number of countries.

[2] Leff (1984) argues that telecommunications lowers the fixed and variable costs of information acquisition. An expansion of the telecommunications network generates cost savings externalities to other markets. These externalities involve lower costs of search, an increased ability to arbitrage, and increased information on the distribution of prices and services, all leading to lower transactions costs and more

production process increases. Thus, telecommunication investments might lead to benefits in other sectors. In suggesting that a country's telecommunications infrastructure has strong effects on economic growth, it has been argued that telecommunications investments have important spillovers and create externalities[3].

These arguments are in fact reminiscent of the public infrastructure debate of recent years. Public infrastructure refers to more general "traditional infrastructures" such as transportation, sewer systems, water, electricity etc. Early studies show (see for example Aschauer 1989) tremendous returns to public infrastructure investment[4]. As has been pointed out by a growing number of papers, these results are subject to a severe simultaneity bias and spurious correlation. Once these two problems have been econometrically controlled for, returns to infrastructure are much reduced. Clearly, the same problems of reverse causality and spurious correlation do potentially exist for telecommunication infrastructure.

Reverse causality implies that one needs to distinguish two effects: (i) the increase in economic growth which is attributable to increases in telecommunications infrastructure and services development and (ii) the increase in the demand for telecommunication services which is attributable to increases in economic growth (i.e. the income elasticity of telecommunication demand). The causation is clearly two-way and unless telecommunications infrastructure investment is modeled, the measured effect on telecommunications infrastructure on growth will be biased. In this paper we attempt to estimate a simultaneous model for telecommunication investments and economic growth. We specify a structural model which endogenizes telecommunication investment by specifying a micro-model of supply and demand for telecommunication investments. The micro-model is then jointly estimated with the macro-growth equation. In this way, we endogenize telecommunication investment controlling for the simultaneity discussed above. The second problem of spurious correlation may arise because regional specific infrastructure investments might be correlated with other growth promoting measures like R&D investments, investment in human capital, taxes, etc. In order to control for these correlations we will allow for country-specific fixed effects.

This paper concentrates on telecommunication infrastructure. The reason for this is that we believe that telecommunication infrastructure is intrinsically different from other types of infrastructure: information highways are different from transportation highways. One

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efficient operation of the telecommunications - using markets. Leff shows that firms can have more physically dispersed activities as telecommunications increases, and adds that X-inefficiency will be lower.

3 It is a common conception that a modern communications system is essential to development. Studies by the United Nations Economic Commission for Europe, 1987, *The Telecommunication Industry: Growth and Structural Change;* by the International Telecommunications Union, Geneva, 1980, *Information, Telecommunications and Development;* and by R.J. Saunders, J.J. Warford and B. Wellenius, 1983, for the World Bank and the Brundland Commission, *Telecommunications and Economic Development* all attest to the need to have a modern efficient telecommunications sector as part of a nation's basic infrastructure and as a precursor to economic growth.

4 Aschauer found that the return to infrastructure could be as high as 70% per year. This would imply that a $1 million invested over 30 years would result in a return of almost $5 trillion.

seemingly important characteristic of telecommunication technologies, which is not present in other types of infrastructure, are *network externalities:* the more users, the more value is derived by those users. Given that these network externalities are not equally present in public infrastructure in general, one might expect that telecommunication infrastructure investments lead to higher growth effects than what has been found for the other types of infrastructures[5]. Given the importance for public policy in this area, it will be interesting to compare the public infrastructure results to those obtained for telecommunication infrastructure.

Another implication of network externalities is that the impact of telecommunication infrastructure on growth might not be linear, as the growth impact might be larger whenever a significant network size is achieved. This would imply that positive growth effects might be subject to having achieved a *critical mass* in a given countries communications infrastructure. A relevant question to ask is then whether such nonlinearities in telecommunications do exist, and if so, what the critical mass is. Our empirical analysis below will attempt to answer such questions.

The paper is organized as follows. Section II briefly summarizes other related studies. The data and some simple correlations are discussed in Section III, Section IV specifies the econometric model with the results and interpretations in Section V. Section VI concludes.

II. Previous Related Studies

In order to address the impact of infrastructure investments on economic performance it is necessary to differentiate between various types of infrastructure. It is clear that the effect of telecommunication and information technology infrastructure on productivity and economic growth are potentially very different from other types of infrastructures. Given the importance for public policy in this area, it will be interesting to compare the public infrastructure results to those obtained for telecommunication infrastructure. In what follows we first discuss the available evidence for general infrastructure investment and then survey several studies that investigate the impact of telecommunication and information technology on economic performance.

There are several studies that address the returns to public infrastructure investments. An influential study by Aschauer (1989), estimates a production function on time series data and finds a very large contribution of infrastructure to output. Aschauer suggested that *the stock of public infrastructure capital is indeed a significant determinant of total factor productivity growth*. He also found a striking relationship between the US productivity growth slowdown and the decline in the rate of growth of the public capital

5 For instance in transportation infrastructures no such (positive) network externality exist. In fact, there might be significant *negative* network externalities present in transportation due to congestion.

stock. These early estimates did have an important impact on the public policy debate in the U.S., as infrastructure is often cited as an answer to the employment problem.

Unfortunately, these early empirical results appear to collapse once more sophisticated econometric procedures are used[6]. The Aschauer model constitutes a classical production function approach and can be criticized as not accounting for the appropriate causalities and correlations. For example the work by Holtz-Eakin (1993, 1994) and Garcia-Mila and McGuire (1992) demonstrates that the introduction of state-level fixed effects reduces the returns dramatically. Similar results are obtained by Kelejian and Robinson (1994) and Pereira and Frutos (1995) which use other econometric corrections. Using a cost function model, Nadiri and Mamuneas (1996) show that the returns to public infrastructure are comparable to those of private investments. Hulten and Schwab [(1984), see also. their (1991) study] estimate a production function for the manufacturing sector on state-level data. They found that most of the cross-state variation in value-added growth was explained by variations in the rate of private and capital accumulation, leading them to suggest that *public infrastructure capital was irrelevant in explaining differences in productivity growth*. Recently, Balmaseda (1994,1996) argues that the results found by Aschauer can be explained by simultaneity and aggregation biases. He shows that the large positive effects of public investment on growth can be reduced to zero, if causality and aggregation biases are accounted for. Hulten (1994) offers several explanations for this empirical finding of zero return on public infrastructure.

Thus, the available evidence regarding the returns from public infrastructure appears to be that the original high returns do not hold up once a number of econometric measures are employed. We now turn to studies that focus directly on the effect of telecommunication infrastructures on economic output (for evidence on the positive growth effects of information technology investments see for example Lichtenberg (1995)).

Despite the obvious policy relevance, there are far fewer studies that concentrate on the specific role of telecommunication investment on economic growth and development. As in the research discussed above even fewer studies address the causality between telecommunication investments and growth. As expected, telecommunications infrastructure investments (or stocks) are correlated with economic growth (see also Röller and Waverman (1996)). This evidence, however, does not imply that there is causal relationship. As a consequence, policy suggestions going in the direction of increased infrastructure investments based on this kind of evidence are without merit.

Hardy (1980) is one of the first studies we are aware of that investigates the potential impact of telecommunication on growth. Using data for over 15 developed and 45 developing nations from 1960 to 1973, Hardy regresses GDP per capita on lagged GDP per capita, lagged telephones per capita and the number of (lagged) radios. He concludes that telephones per capita does have a significant impact on GDP, whereas the spread of radio does not.

[6] For a survey see also Munell (1992).

However, when the regression is attempted for developed and developing economies separately, no significant effects occur. One explanation of this might be that there are important fixed effects. Neither fixed effects nor the problem of reverse causality was addressed by Hardy.

A more complete analysis of the telecommunication economic growth relationship is provided by Norton (1992). Using data from 47 countries for the period of 1957-1977, he estimates the effect of the average stock of telephones between 1957 and 1977 on the mean annual growth rate, controlling for the stock of telephones in 1957 and a number of macroeconomic variables. Norton finds that the telecommunication variable is positive and significant and concludes that the existence of telecommunications infrastructure reduces transactions costs since output rises "when the infrastructure is present." Since the beginning period telephone stock is significantly related to subsequent growth, Norton argues that the relationship "is clearly not due to reverse causality."[7] Norton also estimates the higher growth rates that Burma, Honduras, Sri Lanka and Bolivia would have had given the estimated coefficients and either Mexico's or Canada's telephone penetration rates. He finds extremely high impacts and states it is "implausible that Burma could or would have increased its investment- income rate by 55.5% and its growth rate by roughly the same amount simply by increasing its stock of telephones to a level comparable with Mexico's stock". One explanation is that many growth effects are being captured by the telecommunication variables, including the growth of all the industries that telecommunications encourages. This is similar to the state-level fixed effects in the public infrastructure literature.

Finally, there is a recent study by Greenstein and Spiller (1995) who investigate the impact of telecommunication infrastructure (as measured by the amount of fiber-optic cable employed) on economic growth in the U.S. They find that a positive and significant effect exists (output increases some 10% from doubling the amount of fiber-optic cable) in one industry, whereas in manufacturing sectors less of a telecommunications growth effect exists.

In sum, the above studies provide some evidence that telecommunications investment has positive effects on output. However, most of these studies use single equation models. In contrast to the above papers, we estimate a more structural model which endogenizes telecommunication investment by specifying a micro-model of supply and demand for telecommunication investments. The micro-model is then jointly estimated with the macro-growth equation. This is important because infrastructure investment affects many other sectors which makes a macro-level growth analysis necessary. Moreover, as has been demonstrated by the studies around the public infrastructure debate, fixed effects might be important. In light of the public infrastructure experience, it would be important for

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[7] Norton also estimates a simpler equation for 78 countries for the 1970-80 and 1960-80 periods. Only four right-hand-side variables are included - initial year income per capita, the standard deviation of real output, TELPOP and a dummy variable for centrally planned economies. Again the coefficient on TELPOP is positive and significant. "... consistent with the view that the stock of telecommunications lowers transaction costs and stimulates economic growth."

public policy to investigate whether the positive growth effects of telecommunication investments hold up. Our empirical analysis below will attempt to shed some light on this issue.

III. Data and Correlations

In this section we investigate simple correlations between telecommunications infrastructure investment and aggregate output. Similar to other studies, we utilize data for 35 countries over a twenty year period 1970 to 1990. The 35 countries consist of 21 OECD countries and 14 developing or newly industrialized economics.[8] The 35 countries are listed in Table 1. Generally, data were more prevalent for developed OECD economies than for the other economies.

The data gathered consist of data on general economic variables and country characteristics - GDP, GDP deflator, population, CPI, gross domestic investment, gross domestic savings, government deficit (or surplus), geographic area, population density, labor force, unemployment rate, percentage of school age children in primary, and in secondary school. Most of this data is from the Summers and Heston (1991) data base. Also gathered are data on a number of characteristics of telecommunication developments[9] - mainlines, residential mainlines, waiting list for mainlines, national and international trunk traffic, income from telephone services, national and international telex traffic, income from telex services, the number of data terminals, circuit ends connected to automatic switching exchanges, machines equipped for direct dialing and investment in telecommunication. Much of these data (e.g. number of data terminals) are available for only a few years and for only a few countries. Table 2 defines the variables used in this study. Summary statistics are provided in Table 3.

Before turning to our model, we present some broad averages and examine simple correlations. Table 4 provides estimates for OECD countries of the average growth rates of real GDP per capita and main lines per 100 inhabitants, over the 1971–1990 period. The OECD average growth rate for GDP per capita was 1.96% and for mainlines 3.96%. Overall, real GDP is very strongly positively associated with the number of mainlines (correlation is .99).[10] Given the near total correlation (.94) between the number of mainlines and real GDP across the OECD, it is not surprising that regressions of GDP on mainlines finds substantial effects. Figure 1 shows the relationship for the OECD countries for one year, 1990, between mainlines per 100 inhabitants and real GDP per capita.

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[8] Several of the OECD countries are developing or newly industrializing over part or all of the 1970-1990 period - Greece, Portugal, Spain and Turkey.

[9] We are indebted to Paul Wijdicks (OECD) who was able to acquire much of the data needed in our study.

[10] There is, however, less of a relationship between real GDP per capita and the number of mainlines (.42). Thus the correlation between GDP and mainlines may partially be an artifact of country size. Another explanation is the different degree of development across the OECD.

A univariate linear cross-country regression of mainlines explains about 65% of the variance in GDP.

IV. An Econometric Model of Telecommunication Investment and Growth

In this section we employ a more structural model, a hybrid production function framework, which endogenizes telecommunications investment. In order to endogenize the telecommunications sector into the aggregate economy a micro-model of supply and demand is specified and jointly estimated with the macro-growth equation. In this way, we endogenize telecommunications investment and control for the causal effects discussed above. In addition we will allow for fixed effects.

We relate national *aggregate* economic activity to the stock of capital (K), the stock of human capital (HK), the stock of telecommunications infrastructure (TELECOM), and an exogenous time trend (t). The stock of telecommunications infrastructure is needed (rather than telecommunications investment) since consumers demand telecommunications infrastructure not telecommunications investment per se. A measure of telecommunications demand is required in order to model both the demand for and the supply of telecommunications, itself.

Our aggregate growth/production function equation is then as follows:

Growth: $$GDP_{it} = f\left(K_{it}, HK_{it}, TELECOM_{it}, t\right) \tag{1}$$

The coefficient on TELECOM in equation (1) estimates the one-way causal relationship flowing from the stock of telecommunications development to economic growth. In order to differentiate between the two effects, i.e. the income elasticity of telecommunications infrastructure as well as the impact of TELECOM on GDP, we specify three other equations which endogenize the demand and supply of telecommunications infrastructure and its investments.

Demand for Telecommunications Infrastructure:

$$TELECOM_{it} = h\left(GDP_{it}, TELP_{it}\right) \tag{2}$$

Supply of Telecommunications Investment:

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

Telecommunications infrastructure production function:

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

Equation (2) states that the demand for the stock of telecommunications infrastructure is a function of the price of telephone service (TELP) and GDP. Equation (3) represents the supply of telecommunications infrastructure. Since the supply is in the form of investment we specify in (3) that telecommunications infrastructure investment (TTI) is a function of the telephone price and a number of exogeneous variables effecting supply. Equation (4) provides for the relationship between investment in telecommunications infrastructure and the change in the stock of telecommunications infrastructure.

It is important to note that equations (2), (3), and (4) endogenize telecommunications infrastructure, since these three equations involve the demand for and supply of telecommunication infrastructure. The income elasticity of the demand for telecommunications services is provided for in equation (2).

The empirical implementation of the above model corresponding to (1)-(4) involves estimation of the following system of equations.

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

$$PEN_{it} + WL_{it} = b_0 + b_1 \log(GDP_{it}) + b_2 \log(TELP_{it}) + \varepsilon_{it}^2 \tag{2'}$$

$$\begin{aligned} \log(TTI_{it}) = c_0 + c_1 \log\left(GA_{it}\right) + c_2 GD_{it} + c_3 (1 - USCAN) \cdot WL_{it} \\ + c_4 (1 - USCAN) \log(TELP_{it}) + c_5 USCAN \cdot \log(TELP) + \varepsilon_{it}^3 \end{aligned} \tag{3'}$$

$$PEN_{it} - PEN_{i,t-1} = d_0 + d_1 \log(TTI_{i,t-1}) + d_2 \log(GA) \varepsilon_{it}^4 \tag{4'}$$

where GDP is the real gross domestic product, K is a measure of the real capital stock (from Summers and Heston 1991), TLF (total labor force multiplied by the percentage of the population with secondary education) is a proxy for the stock of human capital, PEN (the penetration rate, the number of main lines per capita) is our proxy for the stock of telecommunications infrastructure, t is a linear time trend, WL is the waiting list per capita, TELP is a measure of the telephone service price, TTI is real investment in telecommunications infrastructure, GD is the real government deficit, GA is the geographic area of the country, and USCAN is a dummy variable for the US and Canada (see Table 2 for variable definitions).

Note that in (1) we allow for the intercept to depend on the country. In other words we control for fixed effects, which has been of crucial importance for the public infrastructure estimates discussed above. Equation (2) states that the *effective* demand for main lines per capita (the number of main lines per capita and the waiting list per capita) is a function of the price of telephone service and real GDP. The waiting list per capita is added to the penetration rate since the number of mainlines in existence at any point in time can not be explained by the telephone price. There would be excess demand in some countries at that price. Unfortunately, there is no measure of the price of telephone service e.g. local service, domestic trunk or international calling available across this broad spectrum of countries. Instead, we use telephone revenue per mainline as a proxy. Equation (3) states that investment in telecommunications infrastructure is a function of the government deficit, the waiting list per capita, the telephone price and the geographic area. The US and Canada are dummied out as the private market driven telecommunications suppliers in the USA and Canada would not respond to government deficits or surpluses.

The model was estimated by nonlinear three stage least squares for the OECD countries[11]. Table 5 reports the parameter estimates for various specifications of model (1')-(4').

V. Results and Interpretation

The first specification of model (1')-(4') does not control for fixed effects and corresponds to the first column in Table 5. The parameter estimates of the growth equation indicate that labor and capital are positive and significantly associated with economic growth. The elasticities for labor and capital are statistically identical and roughly equal to one half. Similarly, we find that the coefficient on the penetration rate in the growth equation is positive and significant. This implies that an increase in the penetration rate generates significant aggregate economic growth. The elasticity is similar to that of labor and capital with the point estimate equal to .55, which implies that a one percent increase in the penetration rate increases economic growth by on average .55%. Thus, our results attribute a very large impact to telecommunications infrastructure. This large effect is reminiscent of the early public infrastructure estimates discussed above. Even though there are reasons to believe that telecommunication infrastructure might be rather important for economic growth, an estimate this large seems excessive. One explanation investigated below is that there is spurious correlation, suggesting a fixed effects model. Note that the coefficient on the time trend is negative and statistically significant. This implies that much of the positive growth effects can be explained by telecommunication infrastructure, human and physical capital. This is consistent with spurious correlation, since it appears that telecommunication picks up many other growth promoting factors.

Before turning to the other equations in column (1) let us emphasize that the focus of the empirical analysis is not on the estimation of demand and supply relationships in the telecommunications industry. Nevertheless, we want to control for them as much as possible. For the demand equation, the effective demand is significantly inversely related to telephone price. The elasticity of demand is estimated at -.417 which is rather small. This is not surprising given the definition of our price variable: revenue per mainline. Thus,

[11] Estimating the model for the non-OECD countries does is not possible since the there are only 53 observations available.

what we estimate here is closer to a revenue elasticity. Regarding the income effect, we find the demand for telecommunications infrastructure is indeed significantly positively related to real GDP, even though the income elasticity is rather small. Nevertheless, this confirms our earlier argument that the causal relationship between telecommunications infrastructure and economic growth runs both ways.

For the supply function we find that the geographic area is very significant in explaining telecommunications investments, i.e. larger countries do invest more in telecommunications. The level of government deficit is also significantly related to telecommunications investment across the OECD. One might have felt that telecommunications infrastructure investment would be positively affected by a government surplus in the OECD since the existence of a surplus would loosen the constraints on investment by the PTT. However, we find a negative relationship, indicating that PTT investment is associated with a deficit. One possible explanation for this is that telecommunications infrastructure investment is associated with other spending programs which jointly cause larger government deficits, i.e., the existence of a deficit is not an impediment to investment in telecommunications infrastructure. The waiting list for mainlines per capita is negatively and significantly related to the supply of telecommunications infrastructure. This suggests that those countries with a large waiting list invest less. Finally, the price of telecommunications services does not determine supply. This is not surprising since all OECD countries (accept the U.S. and Canada for some years) are subject to regulation during our sample period and less driven by market forces.

The last equation reported column (1) in Table 5 is the production function relating investment to the penetration rate. As expected, lagged telecommunications investment is positive and significant. The elasticity is about .002, indicating that a 10% increase in the last years investment would result in a .2% increase in the penetration rate. Again we find that the geographic area is a significant determinant of the penetration rate: the larger the country the more investment is needed to accomplish a given telecommunications infrastructure.

As discussed above in the context of public infrastructure, much of the impact on economic growth disappears once one controls for fixed effects. In order to test whether this is so for telecommunications infrastructure we next re-estimate our model, allowing for a country-specific intercept in equation (1'). The results are tabulated in column (2) of Table 5. As can be seen, most of the parameter estimates and the statistical significance change only slightly. Besides the growth equation, most other parameter estimates are fairly robust. Given the reduced degrees of freedom due to the fixed effects, the level of significance in the growth equation is as expected somewhat lower. We also observe that the parameter estimate on capital is now substantially larger than that on labor. Interestingly, the effect of the penetration rate is halved by incorporating country-specific factors. The point estimate of the elasticity is now .26 implying growth effects that are much more reasonable than before: one percent increase in the penetration rate increases economic growth by about a quarter percentage point. Note, also that the impact is statistically not significantly larger than zero.

These results are indeed very similar to the earlier literature on the returns of public infrastructure capital. It appears that little impact is found, once simultaneities and fixed effects are controlled for. However, as we noted above, there is one possibly important difference: network externalities. A priori there is no reason to believe that the growth impact from telecommunications infrastructure should not be substantially larger than other types of infrastructure that are not subject to network externalities. An implication of network externalities is that the impact of telecommunications infrastructure on growth might not be linear, as the growth impact might be larger whenever a significant network size is achieved. This would imply that positive growth effects might be subject to having achieved a *critical mass* in a given countries communications infrastructure.

In order to test whether such nonlinearities in telecommunications do exist, and if so, what the critical mass is we respecify (1') as,

$$\log(GDPD_{it}) = a_{0i} + a_1 \log(K_{it}) + a_2 \log(TLF_{it}) + a_3 PEN_{it} + \alpha_4 PEN_{it}^2 + a_5 t + \varepsilon_{it}^1 \qquad (1''),$$

where we again allow for fixed country effects. If a_4 is positive, and a_3 negative then we have support for a "diminishing returns" hypothesis. If, however, the signs are reversed (i.e. $a_4 > 0$ and $a_3 < 0$), then we have evidence in support of a “critical mass“ theory, as the impact might be insignificant for low penetration rates.

The estimation results of the system (1"), (2')-(4') are given in column (3) of Table 5. Note that the impact of an increase in the penetration rate on economic growth is increasing in the penetration rate, since a_4 is positive and significant. This is consistent with the belief that telecommunications infrastructure creates network externalities which are an increasing function of the number of participants. Using the estimates in Table 5 we can compute the penetration rate elasticity on output as

$\eta(PEN) = \dfrac{\partial \log(GDP)}{\partial PEN} = \hat{a}_3 + 2\hat{a}_4 PEN$. For the average OECD penetration rate of 30% we

obtain an elasticity of .28, indicating a 2.8% growth effect from a 10% increase in the penetration rate. For the average U.S. penetration rate of 40%, the elasticity is as high as .78, whereas for Germany with an average penetration rate of 32% the elasticity is estimated at .37. Moreover, if Germany would have the telecommunication infrastructure of the U.S. (an increase of some 8%), economic output would be increased by 6.36% (some $ 4.4 billion).

Since the first-order effect of the penetration rate is negative, we find that telecommunications infrastructure investments are growth generating only after a certain point. Our results suggest that there might be a ***critical mass*** phenomenon in infrastructure investments. Given our estimates in Table 5 we calculate this critical mass,

defined by $\eta(PEN^*) = 0$, at a penetration rate of approximately 24%. This is important in light of the fact that the non-OECD countries have a mean penetration rate of only 4%, which is well below the critical level, suggesting that marginal improvements might not generate the desired aggregate growth effects. Therefore, for non-OECD countries growth effects can only be realized if a significant improvement in the telecommunications infrastructure is achieved.

In sum, we find evidence of a critical mass phenomenon which is potentially a crucial difference between public infrastructure and telecommunications (or information technology) infrastructures.

VI. Conclusion

In this paper we have attempted to investigate the relationship between telecommunications infrastructure investments and economic performance. We estimate a model which endogenizes telecommunications investment by specifying a micro-model of supply and demand for telecommunications investments. In order to pick-up economy-wide effects, the micro-model is then jointly estimated with the macro-growth equation. After accounting for simultaneity and country-specific fixed effects, we find that the impact between telecommunications infrastructure and aggregate output is much reduced and statistically insignificant. This empirical finding is consistent with the earlier results on the effect of public infrastructure on output.

One important characteristic of IT technologies, which is not present in other types of infrastructures, are *network externalities*. An implication of network externalities is that the impact of telecommunications infrastructure on growth might not be linear. Allowing for non-linear effects we find evidence of a positive and significant link, provided that a *critical mass* in a countries telecommunication infrastructure has been achieved. This suggests that increases in telecommunications infrastructure could create higher growth effects in OECD countries than in the less-developed non-OECD countries.

An important question not addressed in this paper, and one that would naturally build on the existence of growth effects, is: what market structure might be suited best to appropriate these returns? This includes the specific role of government, if any, in providing an efficient infrastructure to foster growth and competitiveness. A related issue of considerable interest is the relationship between telecommunications infrastructure investments and job creation.

TABLE 1 - List of Countries

OECD Countries	Non–OECD Countries
Austria	Algeria
Australia	Argentina
Belgium	Brazil
Canada	Chile
Denmark	Costa Rica
Finland	Egypt
France	India
Germany	Indonesia
Greece	Korea
Ireland	Malaysia
Italy	Mauritius
Japan	Mexico
Netherlands	Morocco
New Zealand	Tunisia
Norway	
Portugal	
Spain	
Sweden	
Turkey	
United Kingdom	
United States	

TABLE 2 - Variable Description

Variable	Data
K[1]	Non-residential Capital Stock in billion 1985 US$
TLF[1]	Total labor force in millions
PEN[2]	Penetration rate, main lines per capita
GDP[1]	GDP in billion 1985 US$
TELP[2]	Price of telephone service, in 1985 US$, measured as total real service revenue per mainline
GA[2]	Geographic area in thousand km^2
GD[3]	Government surplus (deficit) in billion 1985 US$
WL[2]	Waiting list for main lines per capita
TTI[2]	Investment in telecom infrastructure in billion 1985 US$
USCAN	Dummy variable for US and Canada
T	Time trend

Sources: [1] Penn World Table 5.6 (Summers/Heston); [2] ITU Yearbook 1993; [3] IMF Yearbook 1992, World Bank 1993

TABLE 3 - Summary Statistics

Variable	Mean	Std Dev	Minimum	Maximum
K	443.67	739.27	11.52	4270.73
TLF	16.70	24.48	1.10	126.42
PEN	0.30	0.14	0.01	0.68
GDP	424.73	770.76	14.79	4524.97
TELP	536.66	158.42	244.62	1000.70
GA	1516.39	3088.25	30.513	9970.61
GD	-15.48	31.37	-214.57	8.93
WL	0.01	0.02	0	0.11
TTI	2.78	4.73	.07	25.83
USCAN	0.03	0.18	0	1
T	11	6.06	1	21

TABLE 4 - Growth and Penetration

	GDP per Capita (in US$)		CAGR (%)	Mainline per 100 inhabitants		CAGR (%)
	1971	1990	1971-90	1971	1990	1971-90
Australia	9513	12575	1.48	22.08	47.09	4.07
Austria	10230	16991	2.71	14.19	41.76	5.85
Belgium	10739	16013	2.13	14.83	39.26	5.26
Canada	10985	16472	2.16	31.38	57.46	3.24
Denmark	14708	20496	1.76	26.50	56.63	4.08
Finland	10860	20135	3.30	20.49	53.54	5.18
France	11359	17399	2.27	9.02	49.78	9.41
Germany	12850	19799	2.30	15.76	47.41	5.97
Greece	3750	4896	1.41	11.90	38.94	6.44
Iceland	11648	19724	2.81	28.99	51.37	3.06
Ireland	5764	9921	2.90	8.23	28.06	6.67
Italy	7834	14718	3.37	12.90	38.77	5.96
Japan	13383	22443	2.76	15.39	43.47	5.62
Luxembourg	11251	18783	2.73	25.36	48.17	3.43
The Netherlands	11685	16080	1.69	18.24	46.42	5.04
New Zealand	9409	10490	0.57	29.37	43.60	2.10
Norway	12767	19962	2.38	19.75	50.28	5.04
Portugal	2689	4378	2.60	6.68	24.13	6.99
Spain	5390	8713	2.56	9.52	32.35	6.65
Sweden	13676	20001	2.02	45.90	68.33	2.12
Switzerland	20998	27831	1.49	32.59	58.02	3.08
Turkey	723	1201	2.71	1.16	12.38	13.26
United Kingdom	8490	12625	2.11	16.51	44.25	5.32
United States	14719	18656	1.26	34.06	45.34	1.52
OECD Average	11297	16321	1.96	20.38	42.58	3.96

Notes: GDP per capita is expressed in US$ at 1987 exchange rates and prices; CAGR stands for Compound
Annual Growth Rate.
Source: OECD Communications Outlook 1993, ITU.

TABLE 5

Telecommunication and Growth: OECD Countries

(Nonlinear Three-Stage Least Squares Estimates of Equations (1) - (4))[1]

	(1)		(2)		(3)	
Variable	**Estimate**	**T-Ratio**	**Estimate**	**T-Ratio**	**Estimate**	**T-Ratio**
Growth						
Intercept	-9.697	-25.27	-	-	-	-
K	0.518	13.11	0.622	7.94	0.816	7.41
TLF	0.520	12.93	0.373	1.50	0.499	1.82
PEN	0.550	4.09	0.259	1.27	-1.109	-1.81
PEN^2	-	-	-	-	2.302	2.48
T	-0.010	-6.31	-0.007	-0.83	-0.016	-1.77
Demand						
Intercept	-3.562	-15.63	-2.129	-12.90	-2.130	-12.91
GDP	0.059	11.36	0.042	10.27	0.042	10.28
TELP	-0.417	-15.63	-0.254	-13.09	-0.254	-13.10
Supply						
Intercept	1.259	0.66	1.712	1.15	1.697	1.14
GA	0.396	9.06	0.319	8.63	0.319	8.64
GD[2]	-0.294	-12.95	-0.331	-14.27	-0.330	-14.23
(1-USCAN)*WL	-7.558	-2.07	-12.738	-4.85	-12.678	-4.82
(1-USCAN)*TELP	-0.066	-0.29	-0.135	-0.78	-0.136	-0.78
USCAN*TELP	-0.045	-0.19	-0.144	-0.80	-0.145	-0.81
Production						
Intercept	0.024	8.05	0.025	9.64	0.025	9.63
TTI	0.002	4.16	0.003	6.26	0.003	6.22
GA	-0.001	-3.01	-0.00	-3.40	-0.001	-3.39

[1] Column (1) refers to no fixed effects. Column (2) refers to fixed effects, and Column (3) allows for fixed effects and a quadratic effect of the penetration rate.

[2] Evaluated at sample mean

Number of Observations: 242

Figure 1

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