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Calling for Innovations - Infrastructure and Sources of Growth

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Abstract

This paper analyzes the impact of infrastructure capital on different sources of economic growth. Starting with the contribution of Barro (1990), the literature on infrastructure and growth mainly focuses on the relation between private and public capital investments. In contrast, we demonstrate a link between (telecommunication) infrastructure capital and endogenous technological change in the context of an dynamic panel estimation applying aggregate country- as well as U.S. firm-level data. The main empirical finding is that the increase in telecommunication infrastructure during the last 30 years enhanced R&D investments but did not affect the accumulation of physical or human capital in our sample. Moreover, we provide an extended R&D growth model, which emphasizes a cost-reducing feature of infrastructure capital, to demonstrate a potential link between the level of infrastructure capital and endogenous technological change.

1 Introduction

In this paper, we analyze the effect of (telecommunication) infrastructure capital on different sources of economic growth. That is, we investigate whether infrastructure investments influence the accumulation of input factors, such as private and human capital, and/or total factor productivity (TFP) and R&D.

Several recent empirical contributions report a positive causal relation between infrastructure and GDP-growth for different regions and time periods.[1] The main empirical challenge in these studies is the identification of *cause and effects* between infrastructure and growth. Fernald (1999) shows that the rise in road services substantially increased the productivity (TFP) across industry in the U.S. from 1953 to 1973.[2] The author employs an implicit test for endogeneity by showing that productivity growth is above average in vehicle intensive industries. Roeller and Waverman (2001) formulate a structural model for the supply and demand of telecommunication infrastructure to separate cause and effects on aggregate production.[3] They find large positive effects of telecommunication investments on economic growth in a panel of 21 OECD countries from 1970-90. Belaid (2004) confirms the results for a panel of 37 developing countries from 1985-2000. Finally, Calderón and Servén (2005) apply an (internal) instrumental variables approach to estimate a positive causal effect of different infrastructure measures on GDP-growth in a panel of 121 countries from 1960-2000.

These studies highlight the importance of infrastructure investments to foster economic growth and development. However, little is known about the explicit role of infrastructure capital in the production process. Does it represent an additional input factor in the production function or does it influence the technology with which other inputs are combined? In other words, are infrastructure investments a complementary input factor to private and human capital accumulation and/or do they trigger technical change by affecting incentives for R&D? In the first case, infrastructure investments feature temporary growth effects in the presence of diminishing returns to capital while in the second they improve the efficiency of all other input factors and hence long-run productivity growth. The corresponding policy implications differ substantially in both settings. Moreover, in the former scenario, infrastructure capital is expected to reflect a crucial growth determinant in less developed countries, while it appears to be less important in R&D driven advanced economies. In this regard, note that the empirical evidence above refers to advanced as well as developing countries.[4] Against this background, the present paper attempts to specify the mechanism

[1] Gramlich (1994) or Holtz-Eakin and Schwartz (1994) survey the earlier empirical literature on infrastructure and growth.

[2] He measures a rate of return of 100% before 1973 and a negative rate from 1973-89. To put it in the words of Fernandez et al. (2001): "the interstate highway system was very productive, but a second one would not be".

[3] The identification of cause and effects crucially hinges on the specification of demand and supply functions and congruence of price elasticities across the OECD countries.

[4] Roeller and Waverman (2001) and Belaid (2004) quantify substantial elasticities of GDP with respect to telephones per worker for advance (0.45) and developing countries (0.5) for similar time periods using

that links infrastructure capital to economic growth in a sample consisting of advanced countries as well as dynamic regions like China and Eastern Europe by accounting for different sources of economic growth. This approach sharpens the understanding of the link between infrastructure and growth and allows to formulate more specific implications for economic policy.

Most part of the theoretical literature on infrastructure and growth suggests that the provision of infrastructure affects economic growth by interacting simultaneously with private capital investments. This literature is substantially influenced by the work of Barro (1990) who incorporates productive public capital in an extended two sector *AK-growth model*. This approach lumps together private and infrastructure capital with intellectual capital that is accumulated by technological progress. Thus, it is implicitly assumed that (broader) capital accumulation, which is studied by neoclassical theory, and technological knowledge are one and the same. In particular, Barro (1990) assumes a Cobb-Douglas production function that features constant returns to scale for the accumulation of private and infrastructure capital because part of this accumulation is supposed to reflect technological progress needed to counteract diminishing returns. It follows that infrastructure or private capital investments feature not only level but also growth effects in the long-run which are only limited due to a financing by distortionary taxes. Yet, the key assumption underlying the Barro model is the link from infrastructure investments to private capital accumulation.[5]

The empirical part of our contribution is related the work of Fernald (1999), Bougheas et al. (2000) and Hulten et al. (2003) who analyze the impact of infrastructure on productivity and product specialization in the U.S. and India, respectively. Moreover, Ford and Poret (1991) find a positive effect of infrastructure capital on TFP-growth using cross-sectional data of nine OECD countries. In contrast to these studies, we focus on different sources of economic growth and apply cross-country as well as U.S. firms panels. In particular, we employ a dynamic panel analysis for 36 countries as well as over 3000 U.S. firms. The rate of technical change is approximated by investments in R&D or TFP-growth. We rely on internal as well as external instrumental variables to control for an endogeneity infrastructure capital. In addition, we apply U.S. firm-level data to investigate the causal

identical estimation techniques.

[5]This approach has been generalized in several ways since - Turnovsky (1997) accounts for public capital which is subject to congestion, Kosempel (2004) for the case of finitely lived households, Turnovsky (2000) for an elastic labor supply and Ghosh and Mourmouras (2002) for an open-economy framework. An alternative approach is followed by Bougheas et al. (2000) who show that infrastructure investments increase an economy's degree of specialization.

effect of changes in aggregate infrastructure on corporate investment decisions. We detect that infrastructure investments enhance the rate of technical change measured by R&D or TFP-growth in subsequent years in the country panel. Similarly, infrastructure capital is found to boost R&D expenses of U.S. firms. In contrast, we do not find a significant effect on investment rates in private or human capital. Our results refine the outcomes of earlier empirical studies outlined above and qualify the mechanisms and policy implications of existing theories based on factor accumulation.

Moreover, we present a simple theoretical model in order to demonstrate a link between infrastructure and technological progress.[6] The distinction between the impact of infrastructure capital on private factor accumulation and technological progress is important at least for two reasons: (i) it relates long-run productivity/GDP-growth to the stock of infrastructure capital instead of its growth rate (as in the former literature); (ii) it comprises different policy implications than the existing models which are based on neoclassical inference. That is, we identify policies that influence the efficiency of the R&D sector (higher education, industrial and innovation policy, absorptive capacity), instead of neoclassical policies that influence the saving behavior, to foster growth and innovations.

Section 2 briefly illustrates some empirical stylized facts in favor of a positive relation between the provision of infrastructure and subsequent enhancements of TFP. In section 3, we outline a simple model to illustrate a potential link between infrastructure and endogenous technical change (R&D). Section 4 defines the empirical strategy to distinguish between cause and effects and reports the empirical findings. The final section concludes.

2 Infrastructure and TFP - some illustrations

In this section, we provide some illustrative stylized facts on the role of infrastructure investments in the growth take-off of India and China since 1980. The two world's largest countries in population size represent two major success stories in terms of economic growth during the last 30 years.

First, we refer to Rodrik (2005) to exemplify the importance of infrastructure investments for productivity growth in India. The author reveals that the tremendous increase in GDP/TFP-growth in India can not be explained by conventional theories. He shows that

[6]The theoretical part is related to Bougheas et al. (2000). However, in contrast to their contribution, we explicitly endogenize technological change, account for dynamic interactions by modelling infrastructure capital as a stock instead of a flow variable and consider several model extensions.

it was not accompanied by institutional reforms, trade liberalizations or enhancements of property rights. In fact, India featured the second highest tariff rates (50.5%) in the world during the 1980s. Policy reforms in the corresponding legislations did not take place before 1991. Instead, as outlined in *Figure* 1, Rodrik underlines that the increase in TFP- and hence GDP-growth was preceded by substantial investments in infrastructure. In addition, he shows that most of the growth-acceleration took place in the manufacturing sector at that time. Against this background, the author suggests that the increase in the provision of infrastructure services in India before 1980 augmented the subsequent productivity in the manufacturing sector. In fact, the empirical work of Hulten et al. (2003) exactly acknowledges this hypothesis for India.

Figure 2 and 3 plot the GDP- and TFP-growth rates together with major infrastructure indices for India and China. The TFP values are computed as the residual from a human capital augmented production function following the baseline specification in Caselli (2005). The infrastructure variables are the number of telephone lines per worker (*telecom*), the share of paved roads in total roads (*paved*) and the length of the railroad network in km per sqkm of land area (*rail*). We normalize the corresponding infrastructure indices in 1980 to display their performance before and after the growth take-off. The graphs demonstrate that the growth-takeoffs around 1980 were mainly due to improvements in total factor productivity. Moreover, they were preceded by major infrastructure investments in both countries. In particular, *Figure* 2 illustrates that the provision of road and railroad services increased substantially in India during the 1970s compared to the preceding decade. The percentage of paved roads fell by 12% from 1960 to 1970, but increased by 21% during the 1970s. In addition, the relative length of the railroad network was augmented by 74% during the 1970s compared to 46% in the previous decade.

Figure 3 reveals a comparable pattern for China. The fraction of paved roads improved by 62% in the 1970s contrasted to 35% in the 1960s. Similarly, the number of telephone mainlines per worker was relatively constant in China before 1975 (overall increase by 8%) while it increased by 47% in the following 10 years. Finally, Figure 2 and 3 display that not only the growth take-offs were preceded by substantial infrastructure investments but also that the following periods were characterized by high productivity growth and ongoing improvements in infrastructure services in both economies. While the latter feature might as well reflect a reversed causality between the two variables, the former suggest a causal link from infrastructure to growth.

These case studies recommend a close connection between the provision of infrastructure and subsequent productivity improvements in India and China. Our empirical analysis in section 4 will approve this conjecture for a country panel that includes the OECD countries as well as some dynamic transition countries from Eastern Europe and China.

3 The model

The aim of this section is to suggest a simple model that links the provision of infrastructure capital in an economy to endogenous technical change and hence to growth in total factor productivity. In contrast to the previous work, which is based on Barro (1990), we explicitly interrelate the incentives of firms to invest in new technologies to the stock of infrastructure capital. Our framework follows the basic structure of growth models of endogenous technological change *à* la Romer (1990). We extend this approach in two dimensions by assuming that: (i) the use of a sizable variety of specialized intermediate goods in the production of final output is costly - e.g. due to transportation, coordination and search costs; (ii) these costs are negatively related to the stock of infrastructure capital provided in the economy. In this regard, Holtz-Eakin and Schwartz (1994), Nadiri and Mamuneas (1994) and Morrison and Schwartz (1996) find robust empirical evidence for a negative relation between firm-level business costs and the provision of infrastructure capital in the economy. Moreover, Bougheas et al. (2000) detect a positive relation between infrastructure capital and the costs of specialization in the intermediate sector for the U.S. economy. Accordingly, we take this empirical evidence for a negative causation between infrastructure capital and business costs for granted and embed this feature into a growth model of endogenous technological change.[7]

The model setup consists of a competitive final output sector, a monopolistic intermediate goods sector and a law of motion for the stock of technologies.

Final output sector (Y):

Competitive firms employ manufacturing labor (L_y) and a (symmetric) combination of all varieties of specialized intermediate goods (x_j) to produce a final output good (Y). As in the basic model of Romer (1990) growth results from an increasing specialization of the

[7]For example, $\phi(G)$ represents that the appearance of a telecommunication network improves a firm's ability to sell/transmit specialized goods without a need to establish a widespread distribution system (compare (Fernald and Ramnath, 2004)).

intermediate goods sector. That is, each specialized intermediate good corresponds to a new technology, whereas A_t denotes the stock of existing technologies. Hence final output is manufactured according to the production function $Y = L_{y,t}^{\chi} \int_0^{A_t} x_{j,t}^{\alpha} dj$, $\alpha, \beta, \chi > 0$. We assume that the production function features constant returns to scale in all input factors ($\alpha + \chi = 1$) and normalize, for convenience, the price of the final output good to one ($p_y = 1$).[8]

The final producer incurs expenses in paying for wages of manufacturing labor (w_y) and a price $p_{I,j}$ for each intermediate good. In addition, the final producer needs to pay for the transportation and coordination costs which are attached to the use of an extensive variety of specialized intermediate inputs. We label these costs ϕ and assume that they are negatively related to the provision of infrastructure capital in the economy. In particular, we suppose that ϕ is a negative, continuous, monotonic function of the infrastructure capital stock with the following properties: $\phi(G)$, $\phi' < 0$, $\phi'' > 0$, $\lim_{G\to\infty} \to 1$, $\lim_{G\to 0} \to \infty$. Thus, ϕ is convex, approaches a lower bound if G approaches infinity and approaches infinity if G approaches 0. The lower bound represents the constraint that the price premium can not become negative. The latter implies that intermediate specialization is not feasible in the absence of infrastructure capital as costs approach infinity. Moreover, we suppose that the infrastructure capital stock is non-rival. Accordingly, $\phi(G)$ cannot be (fully) internalized by the large number of intermediate producers due to a free-rider problem. Thus, ϕ acts like a costly exogenous distortion of the interactions between intermediate and final producers. It raises the effective price of an intermediate good and hence entails an additional markup on the (monopolistic) prices for these goods. Finally, the transportation and coordination costs ϕ are entirely real in that a low provision of infrastructure services induces inefficiencies in combining a large variety of intermediates in final production.[9]

Accordingly, the representative firm in the competitive final output sector takes prices as given and chooses its inputs to maximize instantaneous profits in t ($\pi_{y,t}$):

$$\pi_{y,t} = L_{y,t}^{\chi} \int_0^{A_t} x_{j,t}^{\alpha} dj - \int_0^{A_t} [1 + \phi(G_t)] p_{I,j,t} x_{j,t} dj - w_{y,t} L_{y,t} \quad (1)$$

The final producer determines its use of $x_{j,t}$ and $L_{y,t}$ to maximize its profit resulting in the

[8]The specific form of Y implies that the elasticity of substitution between different intermediate goods is equal to one. Alternatively, we could have employed a constant elasticity of substitution (CES) production function as in Young (1993). In this case, the equilibrium growth rate depends on an additional parameter measuring the degree of substitutability between input factors. Yet, as long as the substitutability is not perfect, a higher provision of infrastructure capital is still growth-enhancing.

[9]In this regard, its functioning is similar to the one of exogenous iceberg costs in trade models.

first-order conditions:[10]

$$p_{I,j,t} = L_{y,t}^{\chi} \alpha x_{j,t}^{\alpha-1} \frac{1}{1+\phi(G)} \tag{2}$$

$$w_y = \chi L_Y^{\chi-1} A x_j^{\alpha} \tag{3}$$

Intermediate capital goods sector (x):

Each intermediate sector j is monopolized since the innovation of a specialized intermediate good creates market power. The intermediate producer can produce the input j at a constant marginal cost of η units of the intermediate good. Hence, each monopolist chooses x_j to maximize her profits ($\pi_{I,j}$) given the perceived inverse demand function for each intermediate ($p_{I,j,t}$). Because of symmetry the profit function is the same for all intermediate producers ($p_{I,j} = p_I$). Hence, we obtain the profit function:[11] $\pi_I = p_{I,j}x_j - \eta x_j = \frac{1}{1+\phi(G)} L_y^{\chi} \alpha x_{j,t}^{\alpha} - \eta x_{j,t}$. Computing the first-order condition and substituting for η results in:

$$\pi_I = (1-\alpha)px \tag{4}$$

R&D sector (A):

The rate of technological change ($\dot{A}$) is a positive function of research labor (L_R), a productivity parameter (λ) and its stock of knowledge (A):

$$\dot{A}_t = \lambda L_{R,t} A_t \tag{5}$$

Following Romer (1990), we implicitly assume that all researchers have free access to the entire stock of knowledge, so that each new innovation/imitation induces a positive externality on future research. In this framework, an increase in population augments the rate of technological change. There are several ways to eliminate such a scale effect which would not change our qualitative results. However, non-scale endogenous growth models would complicate the model without affecting the functioning of infrastructure capital. Instead, we simply abstract from population growth (set $L = 1$).

Households:

Identical, infinitely lived households maximize their utility from consumption (C) subject to a resource constraint and *No-Ponzi* game conditions. The utility function supposes a

[10] Note that final output firms demand the same amount of each intermediate so that $x_j = x$, $p_j = p$, $\pi_j = \pi$ and $Ax_j^{\alpha} = \int_0^{A_t} x_j^{\alpha} dj$ hold because of symmetry.

[11] In the following, we concentrate on symmetric balanced growth equilibria, so that we can omit time subscripts to simplify the notation.

constant relative risk aversion: $u(c_i) = \frac{c_i^{(1-\sigma)}-1}{1-\sigma}$, where σ is the degree of risk-aversion. We implicitly assume an inelastic labor supply. Thus, the consumption plan satisfies the standard Euler equation:

$$\dot{C}_t = \frac{r_t - \rho}{\sigma} C_t \tag{6}$$

where r_t is the real interest rate, ρ a time-preference rate and σ the degree of risk-aversion.

Solution for a balanced growth equilibrium:
In the following, we solve the model for a balanced growth equilibrium, in which A, G, C and Y all grow at the same constant exponential rate. The key mechanism involving technological progress is a free-entry condition into the research sector which translates expected future profits in the intermediate sectors into investments in R&D.[12] In particular, the free entry condition into R&D ensures that the present discounted value of expected future profits from a new innovation equals the costs for the production of a new design. If we assume that monopoly profits last forever the present discounted value equals $\frac{\pi}{r}$, where r is the real interest rate. The costs of a new design are productivity adjusted wages paid to research labor ($\frac{w_R}{\lambda A}$). Thus, the free entry condition amounts to:

$$\frac{\pi}{r} = \frac{w_R}{\lambda A} \tag{7}$$

In accordance with Romer (1990), we impose that the labor force is free to work in the manufacturing or research sector so that in equilibrium wages in both sectors are equal ($w_y = w_R$).[13] Given the wage in manufacturing (3) and the profit function (4), the free-entry condition can be solved for the equilibrium demand for manufacturing labor:

$$L_Y = \frac{\chi r(1 + \phi(G))}{\lambda \alpha (1 - \alpha)} \tag{8}$$

It follows from (5) that the equilibrium rate of technical change amounts to $\gamma = \frac{\dot{A}}{A} = \lambda L_R = \lambda(1 - L_Y)$. We know from the production function that final output grows with the rate of technical change in a balanced growth equilibrium. Hence, $\frac{\dot{C}}{C}$ also grows at that rate. Substituting for L_Y from (8) and $r = \gamma\sigma + \rho$ from (6) we obtain the growth rate for the

[12] Hellwig and Irmen (2001) show that expected future rents due to imperfect competition are not in general necessary to ensure investments in R&D since intentional actions of entrepreneurs looking for profits can trigger such investments even in perfectly competitive markets.

[13] We abstract from any labor market constraints ($L = L_R + L_Y$).

stock of technologies:

$$\gamma = \frac{\dot{A}}{A} = \frac{\alpha(1-\alpha)\lambda - \chi\rho(1+\phi(G))}{\alpha(1-\alpha) + \chi\sigma(1+\phi(G))} \tag{9}$$

We can infer from (9) that the growth rate of the stock of technologies is an increasing function of the stock of infrastructure capital ($\frac{\partial\gamma}{\partial G} > 0$). Since technological change is the only source of GDP-growth in a balanced growth equilibrium, GDP also grows at that rate.[14]

Proposition I: Given the cost-reducing feature of non-rival infrastructure capital in the intermediate goods sector and the assumptions underlying R&D based growth models *à* la Romer (1990), it follows that the rate of technical change (and hence output growth) is an increasing function of the stock of infrastructure capital ($\frac{\partial\gamma}{\partial G} > 0$).

Intuitively, an increase in infrastructure capital augments the demand for specialized intermediate goods by reducing transportation and coordination costs that are associated with the use of a large variety of intermediates in final production. The increase in the demand for intermediates, on the other hand, improves the incentives to invest in R&D. Consequently, investments in infrastructure capital do not only influence the income level of the economy but also its long-run balanced growth path. In section 3, we reported robust empirical evidence in favor of Proposition I.

Besides, γ is a positive function of the productivity of the R&D sector (λ). This relation is quite crucial since the effectiveness of the domestic R&D measured by λ determines the potential scale of the positive infrastructure externality on the incentive to invest in R&D (formally: $\frac{\partial^2\gamma}{\partial G\partial\lambda} > 0$). Hence, there exists a complementarity between the effect of infrastructure investments and the effectiveness of the R&D sector. Since λ is exogenous it represents all country-specific factors that are neglected in this model and that influence the effectiveness of the R&D sector, e.g. property rights, higher education, the ability do adopt foreign technologies. If we set (9) equal to 0 we can compute the threshold level for the productivity of the R&D sector (λ^*) such that γ is positive:

$$\lambda^* > \frac{\chi\rho}{\alpha(1-\alpha)}(1+\phi(G)) \tag{10}$$

[14]The equilibrium growth rate suggests a minor technical restriction: In order to ensure that consumer's preferences are finite we need to impose that the growth of current utility $(1-\sigma)\gamma$ is less than the discount rate ρ.

Thus, if the effectiveness of the R&D sector is too low, infrastructure investments have no growth effect and the long-run TFP-level (A_t) remains constant. In this zero-growth trap, the quality of the institutional framework, that determines the probability of successful innovations, is not sufficient to ensure that the expected returns from investments in R&D outweigh the costs for the given level of infrastructure capital.[15] It follows that a country requires to some degree a sound corporate R&D sector for being able to gain sustainable from infrastructure investments. Note that an analog result applies to investments in the adoption of foreign (intermediate) technologies instead of R&D if the ability to adopt foreign technologies depends on a country's institutional framework and requires corresponding corporate investments. The result is summarized in the following proposition.

Proposition II: Given the assumptions underlying Proposition I it follows that the growth-effect of infrastructure investments depends on the country-specific efficiency of the R&D sector ($\frac{\partial^2\gamma}{\partial G \partial \lambda} > 0$). If the latter is too low relative to the costs of R&D the economy is in a zero growth trap and the long-run TFP level remains constant.

To illustrate the analogous results for the long-run TFP-level (A) we can solve the linear differential equation (9). Hence, we obtain the following solution for the level of TFP:

$$A_t = A_0 \exp\left[\Omega - \Gamma\right]t \tag{11}$$

where $\Omega = \frac{\alpha(1-\alpha)\lambda}{\alpha(1-\alpha)+\chi\sigma(1+\phi(G))}$ and $\Gamma = \frac{\chi\rho(1+\phi(G))}{\alpha(1-\alpha)+\chi\sigma(1+\phi(G))}$. If we take the limit for $t \rightarrow \infty$ to approximate the TFP-level in the long-run balanced growth path, we get:

$$\lim_{t\rightarrow\infty}(A_t) = \left\{ \begin{array}{ccc} \rightarrow\infty & if & \Omega-\Gamma > 0 \\ A_0 & if & \Omega-\Gamma \leq 0 \end{array} \right\} \tag{12}$$

The condition $\Omega - \Gamma > 0$ is of course equivalent to $\lambda > \lambda^*$.

In this respect, the model involves policy implications primarily applicable to less developed countries: if the productivity of the domestic R&D sector (or analog the ability to adopt foreign technologies) is too low, do not support investments in infrastructure capital (first). Expressing the same issue in a positive way: before investments in infrastructure capital are carried out, supplementary policies or institutional changes to support corporate R&D

[15]Note that the growth rate cannot become negative because the re-allocation of human capital (L) from research to manufacturing is bounded by 0.

activities or the ability to adopt foreign technologies have to be implemented.

Note that we have taken the financing structure of infrastructure capital as given in (9) since we focus on the link from infrastructure to R&D and abstract from negative equilibrium growth-effects due to a financing by e.g. a distortionary income tax. However, the long-run growth effects of infrastructure capital is always positive as long as the inefficiency of the decentralized equilibrium (due to the positive externality of G and A) and the associated underinvestment in infrastructure capital outweighs an inefficiency from income tax distortions. Finally, we note that there exist alternative specifications that can potentially explain the link from infrastructure to R&D (and hence TFP-growth). In this respect, improvements in telecommunication infrastructure, in particular the internet, might feature a direct effect on the effectiveness of research labor (λ) and hence R&D investments. However, this simple model is designed to demonstrate a potential connection between infrastructure and R&D, which is independent of factor accumulation and underpins the empirical results provided in the following section.

4 Empirical evidence

In this section, we provide empirical evidence for a positive relation between investments in telecommunication infrastructure and subsequent R&D intensities at the aggregate and firm-level employing dynamic panel estimations. In addition, we find no evidence for an effect on factor accumulation or human capital.

Data:

The OECD provides data for "Main Science and Technology Indicators" for 36 (developed) countries from 1980 until 2004.[16] We employ the "Gross Domestic Expenditure on R&D as a percentage of GDP" to approximate the R&D intensities per country.[17] To approximate a country's infrastructure capital stock, we use the number of telephone mainlines per 1000 worker (*telewo*). The series stems from the World Development Indicator database. This database provides several different infrastructure measures. However, these measures are

[16]The sample contains the following countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States, Argentina, China, Israel, Romania, Russia, Singapore, Slovenia.

[17]The highest fraction of R&D intensities was achieved in Israel in 2002 (5.08%) and the lowest in Greece in 1982 (0.17%). In the U.S. the fraction was roughly around 2.7% during the 90s, which was apart from Sweden, Israel and Japan the highest in the beginning of the 90s.

highly correlated: the correlation coefficient between a country's telephone mainlines per 1000 worker and power generating capacity or the share of paved roads amount to .81 and .61, respectively. Therefore, we exclusively focus on the role of telephone mainlines to avoid problems of collinearity.

Moreover, we consider several variables to control for institutional differences over time and across countries. In particular, we include real GDP per capita in purchasing power parity ($rgdp$), government (gov) and private investment shares (inv) relative to real GDP, trade openness ($open$), the amount of private credits issued by deposit money banks relative to the level of GDP ($credit$), overall property rights (ppr).[18] The first four variables are obtained from the Penn World Tables. The amount of private credits serves as a proxy for the level of financial development and comes from Levine et al. (2000) while the property right index stems from various editions of the Fraser Institute's Economic Freedom of the World database. Moreover, we use the growth rate of real GDP per capita in purchasing power parity ($gdp - growth$) from the Penn World Tables and the average years of schooling in the total population ($tyr25$) from Barro and Lee (1996) as an additional dependent and control variables. Overall, our unbalanced panel covers 6 time observations for 36 countries. *Figure* 4 and 5 show the scatter-plots for telephone mainlines per 1000 worker and the share of private capital investments and R&D investments, respectively.

At the firm-level, we employ U.S. data from the Compustat database. The data relate to the balance sheets of US nonfinancial firms and cover the time period 1970-2000. Specifically, we include the following firm level data: R&D expenses, the amount of total assets ($assets$), total sales ($sales$), operating income before taxes ($oincome$) and the amount of long-term debt ($debt$). All variables are measured in millions of dollars. Overall, we have an unbalanced panel consisting of over 3000 firms and six time observations. In addition, we use the number of telephone mainlines per 1000 worker in the U.S. to investigate the effect of this macroeconomic infrastructure variable on firm level investment decisions.[19] In order to ensure that this aggregate variable does not capture general trends in GDP, we also incorporate the U.S. real GDP per capita and the private investment share. Finally, note that the mix of macro- and microeconomic data allows for an inspection of causality. In particular, the coefficient of the telephone mainlines reflects the causal impact on

[18] We measure the number of telephone mainlines and real GDP in logs. Are other variables enter in levels since they represent shares relative to GDP.

[19] We stress that our results based on the LSDV and the GMM difference estimator do not suffer from an aggregation bias, as outlined by Moulton (1990), since we employ serial correlation robust standard errors to avoid within-group correlation.

(marginal) R&D expenses of a single firm since the latter has no feedback-effect on the aggregate level of infrastructure.

Estimation Procedure:

We use different dynamic panel techniques to examine the coherence between our infrastructure variable and different sources of economic growth. Accordingly, we control for country (firm) fixed effects to account for unobservable, time-invariant factors that influence infrastructure as well as R&D investments (e.g. institutions, geography). In addition, we incorporate time fixed effects which control for common aggregated shocks over time. We consider 5-year averages to smooth out business cycle effects.[20]

Our strategy to address the problem of a potential endogeneity of infrastructure is threefold. First, we employ lagged numbers of telephone mainlines to exclude a reversed effect from R&D to infrastructure investments. Hence, we rely on internal instrumental variables as suggested by Blundell and Bond (1998). These are appropriate in the absence of autocorrelation which is shown to hold in all conclusive specifications. We stress that one would need to suppose that past levels of infrastructure investments are influenced by expected future changes in R&D investments in order to justify a reversed causality in the absence of autocorrelation. Second, we alternatively include a set of external instruments provided by demographic variables. In particular, we account for the rate of urbanization and the population density. The use of demographic variables as external instruments is motivated by Roeller and Waverman (2001) and Canning (1999), who reveal that much of the observed variations in infrastructure stocks are explained by these variables. Moreover, Calderón and Servén (2005) use these demographic variables as external instruments for the stock of infrastructure capital to estimate the effect of infrastructure on GDP-growth or income inequality in a large panel of over 100 countries. Third, we mix of macro- and microeconomic in order to exclude a reversed effect from firm level investments decisions on aggregate macroeconomic variables. That is, we examine the effect of the aggregate U.S. telecommunication infrastructure stock on firm-level R&D expenses since the investment of a single firm has no contemporaneous feedback effect on aggregate macroeconomic variables.[21]

We employ the Arellano and Bond (1991) GMM difference ($GMM - dif$) as well as the

[20]Specifically, we use the following non-overlapping time averages: 1075-1979, ..., 2000-2004.

[21]In addition, we include several firm-level and aggregate control variables and employ serial correlation robust standard errors to preclude spurious correlations.

Blundell and Bond (1998) GMM system estimator ($GMM-sys$) because of the significance of the lagged dependent variable (e.g. lagged R&D ratio). These estimation procedures are based on the general method of moments (GMM) and are constructed to yield consistent estimates in dynamic panels. In particular, Arellano and Bond (1991) estimate a dynamic panel data model in first differences and apply appropriate lagged levels as instruments for the first differences of the endogenous variables. These are valid instruments if (i) the time-varying disturbance $\epsilon_{i,t}$ is not serially correlated, and (ii) the explanatory variables $X_{i,t}$ are weakly exogenous. In other words, considering the following dynamic panel data model in first differences:

$$y_{i,t} - y_{i,t-1} = \alpha(y_{i,t-1} - y_{i,t-2}) + \beta(X_{i,t} - X_{i,t-1}) + (\epsilon_{i,t} - \epsilon_{i,t-1}), \quad i = 1, 2, ..., N, t = 3, 4, ..., T,$$

the basic assumptions of Arellano and Bond (1991) are:

$$E[y_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0, \qquad \text{for} \qquad s \geq 2; t = 3, ...T$$
$$E[X_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0, \qquad \text{for} \qquad fors \geq 2; t = 3, ...T,$$

where $y_{i,t}$ is the dependent variable, $X_{i,t}$ a vector of endogenous and exogenous explanatory variables, N the number of cross-sections, T the number of time-periods, $\epsilon_{i,t}$ the error term and α and β parameters to be estimated. In addition, Blundell and Bond (1998) apply supplementary moment restrictions on the original model in levels, whereby lagged differences are used as additional instruments for the endogenous and predetermined variables in levels. Given that $E[y_{i,t}, \mu_i]$ is mean stationary, the Blundell and Bond (1998) estimator incorporates the additional moment restrictions:

$$E[(y_{i,t-1} - y_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0,$$
$$E[(X_{i,t-1} - X_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0.$$

Hence, they require the additional assumption of no correlation between the differences of these variables and the country-specific effect. The authors show that this procedure is more efficient if explanatory variables are persistent. In all conclusive estimation specifications, we apply heteroscedasticity-robust standard errors and cluster errors at the country (firm) level to obtain standard errors that are also robust to serial correlation. Furthermore, we consider all variables as potentially endogenous apart from the government share and the overall property rights.

Results - R&D:

Table 1 reports the effects of telephone mainlines and the institutional controls on the gross domestic expenditure on R&D as a percentage of GDP. The first column reports a negative contemporaneous correlation between telephone mainlines and the share of R&D after controlling for the institutional and financial indicators. We include the contemporaneous as well as the first lag of the control variables to preclude spurious correlations. Correspondingly, the negative correlation does not simply capture an economy's degree of financial or institutional development. In the next column, we apply the least square dummy variable estimator to additionally control for country fixed effects. The coefficient of infrastructure is still significant on a 1% level. Yet, the corresponding estimates are biased in the presence of a lagged dependent variable. Therefore, we present the results of the GMM difference estimator, which is based on Arellano and Bond (1991) and yields consistent estimates in dynamic panels, in column three. Accordingly, we find that an increase in telephone mainlines by 1% enhances aggregate R&D investments on average by .29% in the subsequent 5 years. The result is significant even on a 1% significance level and is robust to the exclusion of any (combination of) institutional variables. In contrast, only the level of real GDP and a country's degree of openness influenced aggregate R&D investments significantly. Moreover, we can not reject the validity of our (internal) instruments according to the Hansen test of overidentifying restrictions or the test for second order autocorrelation. For example, the number of telephone mainlines per worker increased in the U.S. from 1975 until 1980 by roughly 2%. According to our estimation result, this rise triggered an increase in the R&D share by .58% in the years between 1980 and 1984, which amounts to 21% of the overall R&D share in that period.

In the following columns, we apply the GMM system estimator, which is based on Blundell and Bond (1998) and is more efficient than the previous one in the presence of persistent variables. In column four, we exclusively include our infrastructure indicator as well as the government share and the index of property rights, which we consider as exogenous to R&D, in order to report the results for a reduced size of the instrumental variable matrix.[22] Column five includes all control variables and column six additionally accounts for time fixed effects. In all specifications, we find that an increase in the number of telephone

[22]Here, we account for all lagged levels and differences of telephone mainlines as internal instruments. In the following, we exclusively use the first two appropriate lags of the endogenous variables to avoid *overfitting* - a large number of instruments relative to the number of cross sections (countries).

mainlines promotes R&D investments in the subsequent years. The corresponding coefficients are significant on a 10%, 5% and 1% level, respectively. Finally, in the last two columns, we use our set of exogenous demographic indicators to instrument for a country's infrastructure capital stock in a given period. That is, we drop the internal instruments for the infrastructure variable and instead impose a country's rate of urbanization and its population density as an exogenous instruments.[23] Column eight, our preferred estimation specification, suggests that a 1% increase in the number of telephone mainlines per worker augments the share of aggregate R&D relative to GDP by .24%. This effect even amounts to .35% if we additionally impose time fixed effects. Both coefficients are significant on a 1% level, respectively. Finally, the Hansen test and the test for second order autocorrelation confirm the validity of our instruments and suggest that our model is well specified. Summing up, we find robust evidence in favor of a positive causal effect running from a country's stock of infrastructure to its aggregate R&D investments.

Results - factor accumulation:

The previous findings suggest that adjustments in R&D link improvements in the provision of infrastructure capital to economic growth in subsequent periods in our sample consisting of China, OECD and Eastern European countries. That, is amendments in aggregate R&D represent an important transmission mechanism in the infrastructure growth nexus. In Table 2, we examine the impact of infrastructure capital on the alternative sources of economic growth, which according to an human capital augmented production function are represented by accumulations in private and human capital. In the first four columns, we report the effect of improvements in the number of telephone mainlines per worker on aggregate private investments. Accordingly, we are not able to detect a positive impact of infrastructure capital on private capital accumulation which is significant at conventional levels. In contrast, we find that an increase in a country's degree of trade openness promote private capital investments. Again, the specification tests can not reject that our dynamic panel data model is well specified. Hence, improvements in telecommunication infrastructure do not affect private capital investments if we correctly control for institutional measures or time fixed effects in our sample. In columns five to six of Table 2, we apply an alternative measure for the private investment share since R&D expenditures amount, by definition, for a fraction of the overall private investments. Therefore, we construct an

[23] All other endogenous variables are still instrumented by their suitable own lags (internal instruments).

adjusted measure of private capital investments, net of R&D expenditures.[24] However, we are still not able to reveal stimulating effects of infrastructure investments on private capital accumulation. Finally, the last two columns of Table 2 show that infrastructure investments have no influence on the growth rate or the level of education, measured by the average number of years of schooling for a given country or time period, in our sample.

The previous findings are striking. First, they challenge the conventional growth theories which link growth-promoting effects of infrastructure investments to a stimulation of private capital investments, compare e.g. Barro (1990). Our results reject this complementarity between public (infrastructure) and private capital investments. Instead, they suggest a direct effect of telecommunication infrastructure on technical change in advanced countries and dynamic regions which is independent from private or human capital accumulation. Second, the impact of infrastructure on R&D features different policy implications. That is, the growth-effect of infrastructure investments depends on factors such as intellectual property rights, the degree of product market competition or tertiary education instead of factors that influence a household's saving decision.

Results - productivity growth:

In the following, we investigate if the interplay between infrastructure and R&D indeed causes productivity growth in our sample. Therefore, we estimate the effect of the lagged values of telephone mainlines on the growth rate of real GDP per capita in purchasing power parities. In line with the empirical growth literature, we include the lagged (initial) level of GDP as a lagged dependent variable in the growth regression.[25] Accordingly, we apply a dynamic panel data model. Moreover, we account for the average years of schooling of citizens above 25, our measure of human capital, as a supplementary control variable. It follows that the infrastructure coefficient in the growth regression measures the impact on GDP-growth net of private or human capital investments. Therefore, variations in the growth rate of GDP, after controlling for movements in factor inputs, represent by definition variations in TFP-growth. Table 3 lists the results for the growth regressions. The first two columns report a positive correlation between the number of telephone mainlines and productivity growth. Column three to five display the results of the GMM difference and

[24]That is, we subtract the share of R&D investments from the share of overall investments to obtain the adjusted values.

[25]The corresponding coefficient is negative and significant on a 1% level in all estimation specifications. Compare e.g. Calderón and Servén (2005) or Barro and Sala-i-Martin (1995).

system estimation following Arellano and Bond (1991) and Blundell and Bond (1998), respectively. We detect a significant positive effect of telephone mainlines on productivity growth, whereby the exogeneity of infrastructure can not be rejected. Moreover, we find evidence that economic growth is positively related to the degree of trade openness, the private investment share and the index of overall property rights. These estimates are based on the use of internal instruments for the endogenous variables such as infrastructure. In contrast, we employ our exogenous demographic instruments for infrastructure in column six of Table 3. Accordingly, an increase in the infrastructure capital stock significantly enhances economic growth, net of amendments in factor inputs.

In columns seven to nine of Table 3, we include the aggregate share of R&D instead of the infrastructure variable. Column seven reveals that an increase the aggregate R&D share augments economic growth. The corresponding coefficient is significant on a 1% level. In column eight, we incorporate lagged levels and differences of the number of telephone mainlines as an exogenous instrument for the aggregate R&D share (instead of lagged levels and differences of the R&D share itself). That is, we test if the growth-effect of telephone mainlines is indeed transmitted via R&D investments. In other word, if Y represents GDP, $R\&D$ the aggregate share of R&D, I the infrastructure measure, X the control variables, ϵ the error term and $\alpha_{0,1,2}$, $\beta_{0,1,2}$ parameters, we estimate the following equation by the GMM-based method of Blundell and Bond (1998):

$$\Delta Y_{i,t} = \beta_0 + \beta_1 Y_{i,t-1} + \beta_2 (R\&D)_{i,t} + X^{'}_{i,t}\beta_3 + \eta_i + \epsilon_{i,t} \qquad (13)$$

whereby we treat $R\&D$ as endogenous and model it respectively as:

$$(R\&D)_{i,t} = \alpha_0 + \alpha_1 I_{i,t} + X^{'}_{i,t}\alpha_2 + \eta_i + \epsilon_{i,t} \qquad (14)$$

In accordance with our previous results, column eight reveals that R&D, which is instrumented by lagged levels and differences of the number of telephone mainlines, promotes productivity growth. The corresponding coefficient is significant on a 1% level. Finally, in column nine, we use lagged levels and differences of our exogenous infrastructure instruments - the rate of urbanization and the population density - as instruments for the R&D share. Again, the results suggest that the effect of the exogenous infrastructure instruments is transmitted via adjustments in aggregate R&D. It follows that a substantial part of the impact of telephone mainlines on TFP-growth can be explained by its effect on private

R&D investments.

In the last column of Table 3, we account for interaction terms between the infrastructure variable and institutional factors. In particular, we interact the lag value of the number of telephone mainlines with the property rights indicator from the Fraser Institute of Economic Freedom. In accordance with the prediction of our theoretical model, we find that the interaction term between the infrastructure and the institutional variable is positive and significant on a 5% level. That is, the effect of an increase in the number of telephone mainlines on R&D is augmented if the index of overall property rights improves. The result confirms that the effect of infrastructure on R&D investments increases in the quality of institutions. Hence, we detect a complementarity in the effectiveness of infrastructure investments that supports our theoretical results summarized in Proposition II.

Results - firm-level R&D investments:

In Table 4, we report the effect of telephones mainlines on firm-level R&D investments in the U.S. In line with the previous estimations, we focus on a growth frequency of 5-year-averages. The application of disaggregated data has the advantage that a corresponding correlation between firm-level decisions and macroeconomic variables can be interpreted as a causal effect running from the latter to the former. The first column displays that an increase in telephone mainlines per worker augments corporate investments in R&D after controlling for changes in corporate sales, assets and operating income or aggregate real GDP and private investments. In the second column, we additionally control for firm-level fixed effects. The results reveal a positive impact of telephone mainlines on firm-level R&D expenses, however, the coefficient is biased due to the presence of the lagged dependent variable. Finally, the last two column report the estimates for the GMM difference procedure. We consider the firm-level variables as endogenous and the macroeconomic variables as exogenous. In column three, we exclusively control for corporate sales and aggregate real GDP. Accordingly, an increase of 10 new telephone mainlines per 1000 worker induces an increase in corporate R&D investments on average by 5.36 MIO$. The corresponding coefficient is significant on a 5% level. In the last column, we account for all corporate and macroeconomic control variables. This enhances the coefficient of the infrastructure variable, but also the estimated standard errors. Yet, the corresponding coefficient is still significant on a 10% level. Overall, the firm-level results support the hypothesis that infrastructure investments improve the terms of firms to invest in R&D.

Summing up, the empirical findings suggest that the relation between infrastructure and growth is not linked to factor accumulation in our sample. This finding contradicts the predictions of the theoretical literature on infrastructure and growth, which was initiated by Barro (1990). Instead, we demonstrate that the provision of (telecommunication) infrastructure boosts productivity growth and investments in new technologies (R&D).

5 Conclusion

This article decomposes the growth effect of infrastructure investments. It suggests that infrastructure affects innovative investments and technological change instead of factor accumulation.

The empirical section provides evidence in favor of the identified mechanism from a dynamic panel estimation. We find that investments in (telecommunication) infrastructure cause an increase in R&D investments in subsequent periods. Therefore, we confirm Proposition I of our theoretical model. We control for a potential endogeneity of infrastructure by (i) including internal as well as exogenous instruments for infrastructure and (ii) analyzing the effect of macroeconomic aggregates on firm-level investment decisions. Moreover, we detect that infrastructure promotes total factor productivity growth via adjustments in aggregate R&D and confirm that the effect of infrastructure on R&D investments increases in the quality of institutions. Hence, our results also confirm Proposition II of the theoretical model. Finally, we are not able to detect a positive relation between the provision of infrastructure and private investments in physical or human capital.

The empirical findings are striking since they challenge conventional growth theories which link growth-promoting effects of infrastructure investments to a stimulation of private capital investments. Our results reject this complementarity between public (infrastructure) and private capital investments. Instead, they suggest a direct effect of telecommunication infrastructure on technical change which is independent from private or human capital accumulation in our set of *knowledge-intensive* regions. The impact of infrastructure on R&D features different policy implications. That is, the growth-effect of infrastructure investments depends on factors such as intellectual property rights, the degree of product market competition or tertiary education instead of factors that influence a household's saving decision.

In addition, we suggest a theoretical mechanism that complies with this empirical finding.

In particular, we illustrate a positive link between the provision of infrastructure capital and the incentives to invest in R&D. This result is based on the assumption that infrastructure capital reduces costly inefficiencies due to transportation and coordination costs that stem from the use of a large variety of intermediate goods in the final production sector. Moreover, the model implies crucial complementarities between infrastructure capital and other factors that influence the effectiveness of the R&D sector.

The connection between infrastructure and technical change refines the link between infrastructure and growth and helps to explore productivity differences across countries. The results suggest that future work on the link between infrastructure and growth should be devoted to its effect on innovative activities and technical change.

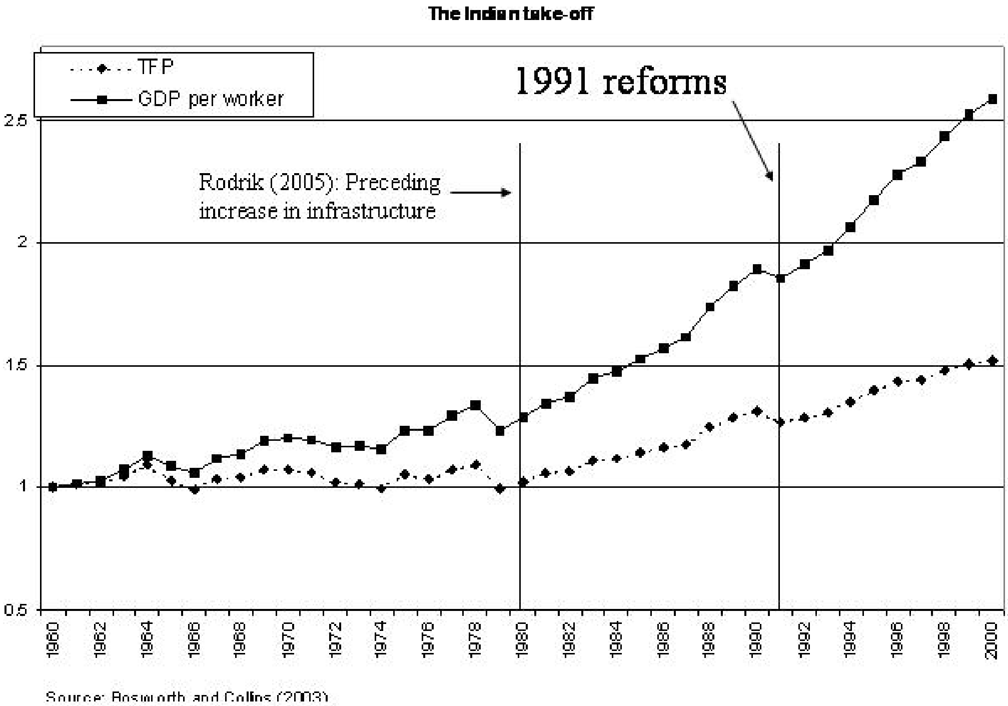
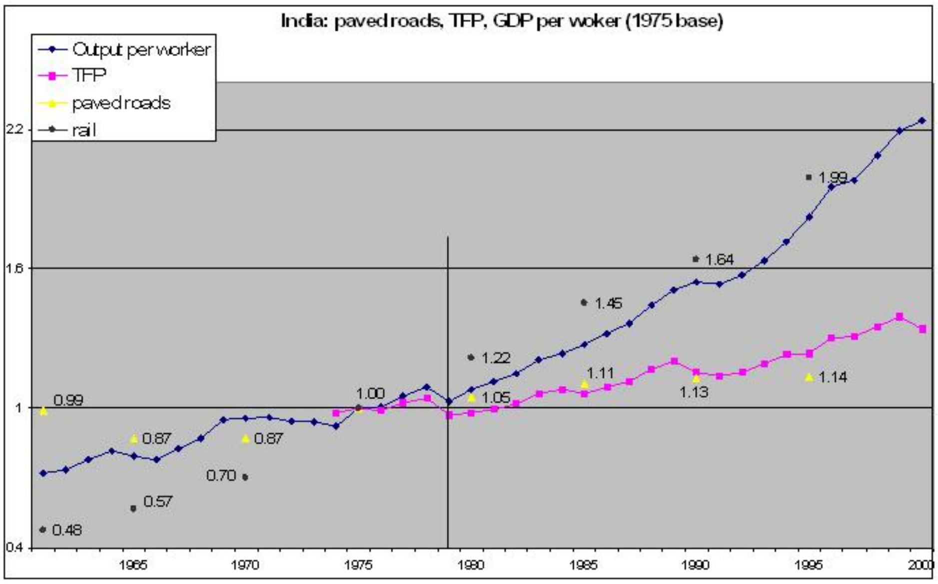


Figure 1: *India - GDP- vs. TFP-growth*



Data: PWT, Barro and Lee (2001), Calderon and Serven (2005)

Figure 2: *India - Transportation infrastructure and TFP-growth*

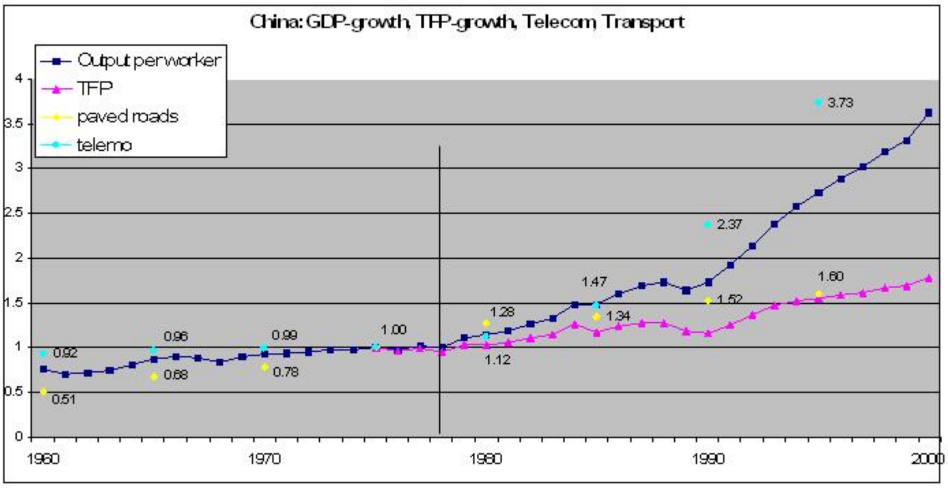


Figure 3: *China - Transportation/telecommunication infrastructure and TFP-growth*

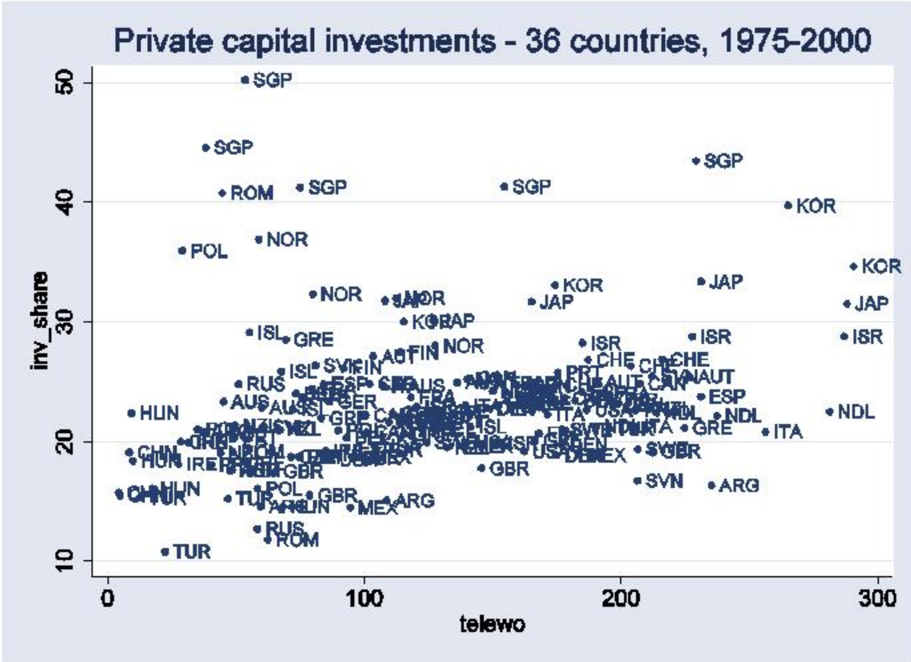


Figure 4: *Scatter-Plot: Private investments share and telephone mainlines*

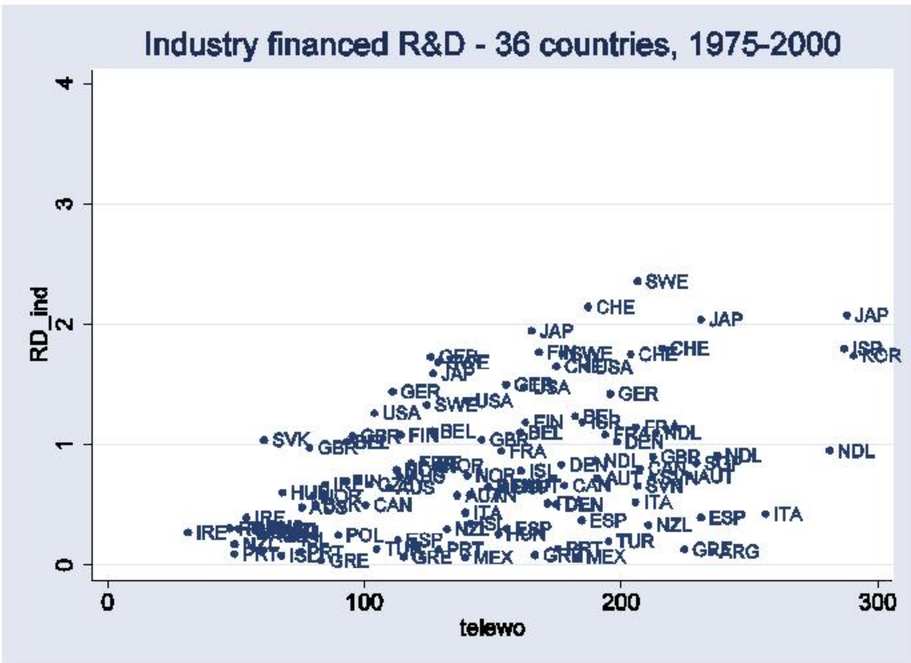


Figure 5: *Scatter-Plot: Share of industry-financed R&D investments and telephone mainlines*

Table 1 - Effect of telephone mainlines on share of R&D investments

	R&D share OLS	LSDV	GMM-diff		GMM-sys[1)]			
l1telewo	.1870***	.4866***	.2915**	.1838*	.2842**	.4506***	.2406**	.3598***
	(2.73)	(3.61)	(2.01)	(1.79)	(2.43)	(3.06)	(2.11)	(2.59)
l1R&D	1.04***	1.08***	.9814***	.9828***	.9477***	.9875***	.9618***	.9929***
	(22.59)	(6.83)	(5.18)	(11.28)	(10.02)	(10.15)	(12.13)	(12.19)
rgdp	.0576	-2.73***	-1.79*		.0698	-.3202	.1341	-.1952
	(.14)	(-3.36)	(-1.91)		(.35)	(-1.22)	(.80)	(-.91)
l1rgdp	-.2385	.1088						
	(-.65)	(.19)						
gov	.0098	-.0014	-.0027	.1838	.0105	.0033	.0130*	.0075
	(1.18)	(-.17)	(-.40)	(1.31)	(1.39)	(.44)	(1.65)	(.95)
l1gov	.0041	-.0014*						
	(.52)	(-1.73)						
ppr	.1183***	.0207	-.0033	.0398	.0577	.1407**	.0493	.1273***
	(3.28)	(.46)	(-.10)	(1.45)	(1.19)	(2.45)	(1.12)	(2.59)
l1ppr	-.0246	.0108						
	(-.77)	(.19)						
credit	.1609	.0208	.0658		-.2054	-.2877*	-.2163	-.2993**
	(.93)	(.20)	(.38)		(-1.38)	(-1.78)	(-1.59)	(-2.10)
l1credit	-.4590**	-.3691						
	(-2.61)	(-1.51)						
open	.0004	.0132**	.0010*		-.0016	-.0004	-.0014	-.0009
	(.08)	(2.64)	(1.91)		(-1.37)	(-.30)	(-1.32)	(-.73)
l1open	-.0012	-.0027						
	(-.20)	(-.69)						
inv	-.0157	.0203	.0077		.0113	.0140	.0110	.0109
	(-.88)	(1.04)	(.61)		(1.22)	(1.54)	(1.43)	(1.50)
l1inv	.0298*	-.0116						
	(1.84)	(-.87)						
Country/Obs.	108	34/108	33/77	36/114	34/111	34/111	34/111	34/111
country FE	no	yes	yes	yes	yes	yes	yes	yes
time FE	no	no	no	no	no	yes	no	yes
Specification tests (p-value):								
2. order serial correlation			.971	.855	.936	.805	.958	.734
Hansen-test			.953	.164	.994	.998	.998	.998

1) in column 7-8 we use internal instruments for R&D determinants except for infrastructure variable. for infrastructure use lagged levels as well as differences of external instruments (urban, pop. density) in columns 5-8 we employ only the first two appropriate lags of the endogenous variables to reduce the number of instruments. 5-year averages 1975-2004 data. all regressions include a constant term, and employ heteroscedasticity robust s.e. in column 2-8 we include s.e. that are robust to within group correlation. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.

Table 2 - Effect of telephone mainlines on factor accumulation

	inv-share				inv-adj		tyr25-growth	tyr25
	OLS	LSDV	GMM-sys		GMM-sys		LSDV	GMM-sys
l1telewo	.6641	1.46	.8675	.4716	.9220	.5507	-.0132	-.0168
	(1.37)	(1.53)	(.52)	(1.01)	(1.04)	(.40)	(-.60)	(-.20)
lag-dep. var.	.6532***	.3360***	.7184***	.7472***	.7039***	.7337***	-	.8910***
	(10.70)	(3.86)	(8.26)	(9.78)	(7.54)	(7.95)	-	(33.87)
rgdp	17.88***	24.23***	-1.10	-.5412	-.5363	-.3915	-.1997***	.1702
	(5.12)	(4.86)	(-.77)	(-.30)	(-.24)	(-.22)	(-4.43)	(1.19)
l1rgdp	-17.72***	-23.03***						
	(-5.87)	(-5.91)						
gov	-.0283	-.0014	-.0302	-.0155	.0629	.0643	.0001	-.0064
	(-.48)	(-1.36)	(-.89)	(-.45)	(1.34)	(1.23)	(.08)	(-1.06)
l1gov	-.0339	-.0411						
	(-.35)	(-.70)						
ppr	-.0404	-.3957	.3845	.2774	.3956	.3829	.0068	.0152
	(-.10)	(-1.00)	(.76)	(.48)	(.71)	(.72)	(.55)	(.30)
l1ppr	-.0363	-.0411						
	(-.20)	(-.70)						
credit	.9118	4.14***	.2816	.2775	-.3940	-.1922	-.0005	-.0600
	(.64)	(3.35)	(.19)	(.19)	(-.34)	(-.17)	(-.02)	(-.27)
l1credit	-.2641	-2.12						
	(-.20)	(-1.31)						
open	-.0081	-.0723	.0172**	.0145**	.0103	.0077	.0014	-.0014***
	(-.18)	(-1.46)	(2.38)	(2.36)	(1.62)	(.77)	(1.33)	(-2.70)
l1open	.0214	.0456						
	(.41)	(1.23)						
Country/Obs.	147	35/147	35/155	35/155	33/106	33/106	35/155	35/155
country FE	no	yes	yes	yes	yes	yes	yes	yes
time FE	no	no	no	yes	no	yes	no	no
Specification tests (p-value):								
2. order serial correlation			.924	.993	.936	.723		.357
Hansen-test			.999	.998	.972	.948		.988

in columns 3-6 and 8 we employ only the first two appropriate lags of the endogenous variables to reduce the number of instruments. 5-year averages 1975-2004 data. all regressions include a constant term, and employ heteroscedasticity robust s.e. in column 2-8 we include s.e. that are robust to within group correlation. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.

Table 3 - Effect of telephone mainlines on productivity growth

	GDP-growth									
	OLS	LSDV	GMM-diff		GMM-sys[1)]			GMM-sys[2)]		
l1telewo	.8749**	.6940	1.56*	2.65***	1.68***	1.89**				1.54**
	(1.98)	(1.39)	(1.89)	(4.50)	(4.83)	(2.42)				(2.17)
l1rgdp	-3.36***	-6.52***	-6.84***	-4.54***	-4.66***	-3.18***	-4.12***	-4.13***	-3.63***	-3.87***
	(-3.78)	(-4.51)	(-2.71)	(-2.77)	(-6.20)	(-3.62)	(-3.40)	(-4.59)	(-3.33)	(-2.91)
gov	-.0065	.0078	-.0350	.1838	-.0213	-.0245	-.0822***	-.0831***	-.0608*	-.0064
	(-.15)	(.20)	(-.73)	(-1.36)	(-.71)	(-.72)	(-2.61)	(-2.78)	(-1.95)	(-.20)
l1gov	.0016	-.0288								
	(.04)	(-.68)								
ppr	.2740	-.0516	.0526	.6186*	.4907**	.3338	.2251	.0162	.2567	.5406
	(1.16)	(-.16)	(1.82)	(1.45)	(1.99)	(1.32)	(.70)	(.07)	(.84)	(1.42)
l1ppr	.3140*	.1386								
	(1.70)	(.79)								
credit	.1663	-1.42	.4152		.5019		.2388	1.35	1.02	
	(.13)	(-1.19)	(.29)		(.19)		(-1.59)	(.93)	(1.01)	
l1credit	-.1605	.1796								
	(-.14)	(.18)								
open	.0118	.1090***	.0437*		.0103		.0200***	.0197***	.0187***	
	(.40)	(4.55)	(1.67)		(1.18)		(2.61)	(2.75)	(2.58)	
l1open	-.0054	-.0260								
	(-.16)	(-1.17)								
inv	.2490***	.2046***	.0725		.1257*	.1614***				
	(3.43)	(2.62)	(.62)		(1.93)	(4.02)				
l1inv	-.1383**	-.2227								
	(2.06)	(-3.60)***								
tyr25	.1975	-.5983	.4118		.2168					-.5056*
	(.56)	(-1.12)	(.75)		(1.05)					(1.65)
l1tyr25	-.1169	.5611								
	(-.32)	(1.22)								
R&D							1.16***	1.26***	.7419*	
							(2.87)	(3.63)	(1.84)	
l1tele*ppr										.1157**
										(2.37)
Country/Obs.	147	35/147	35/118	36/158	35/153	36/158	35/142	35/142	35/142	36/152
country FE	no	yes	yes	yes	yes	yes	yes	yes	yes	yes
time FE	no	no	no	no	no	yes	yes	yes	yes	-
Specification tests (p-value):										
2. order serial correlation			.227	.367	.250	.242	.085	.103	.214	.370
Hansen-test			.702	.050	.999	.841	.932	.916	.984	.511

1) see Table 2. 2) in column 8 and 9 we use first lag of infrastructure variable and demographic variables as exogenous instruments for the R&D share, respectively in columns 5-8 we employ only. the first two appropriate lags of the endogenous variables to reduce the number of instruments. 5-year averages 1975-2004 data. all regressions include a constant term, and employ heteroscedasticity robust s.e. in column 2-8 we include s.e. that are robust to within group correlation. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.

Table 4 - Effect of telephone mainlines on firm-level R&D investments

	R&D investments			
	OLS	LSDV	GMM-diff	GMM-diff
telewo	.6599*	.9840***	.5360**	.6054*
	(1.78)	(2.67)	(2.47)	(1.83)
l1R&D	1.23***	.5415***	.8731***	.4115
	(16.51)	(3.86)	(3.08)	(1.28)
assets	-.0023	-.0074***		-.0039
	(-1.63)	(-3.90)		(-.26)
sales	.0048	.0374***	.0043	.0562
	(1.52)	(3.29)	(.33)	(1.49)
oper. income	.0128	.0261		-.1118
	(.61)	(.72)		(-1.22)
rgdp	-.0085*	-.0122***	-.0045*	-.0076
	(1.80)	(-2.78)	(-1.76)	(-1.56)
inv	-3.91	-.0116		1.35
	(-1.24)	(-2.45)		(.50)
Firms/Obs.	6041	3017/6041	1656/3018	1654/3016
country FE	no	yes	yes	yes
time FE	no	no	no	no
Specification tests (p-value):				
2. order serial correlation			.146	.345
Hansen-test			.220	.224

5-year averages 1970-1999 data. all regressions include a constant term, and employ heteroscedasticity robust s.e. in column 2-4 we include s.e. that are robust to within group correlation. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, and 10%.

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