

International Productivity Differences, Infrastructure, and Comparative Advantage

For Submission to the Review of International Economics

Manuscript 4349

Revised, February 2006

Abstract

This paper provides an empirical analysis of the effect of infrastructure on industry-level productivity and international specialization, as suggested by Clarida and Findlay's (1992) model. Attempting to control for simultaneity with a three-stage least squares estimation strategy, we find that public infrastructure helps to explain patterns of comparative advantage and international specialization.

“Before we can place much faith in the hypothesis of systematic technological differences [between countries], we will need a lot more work to determine the source of these differences. Is it infrastructure? Is it organization forms? Or what?” (Leamer and Levinsohn, 1995, p. 1360)

Introduction

There is a substantial body of evidence that “productivity” differs between countries at the industry level. A number of studies have documented large and persistent sectoral differences in labor productivity between countries (e.g. Van Ark and Pilat, 1993). More recently, several studies have shown that there are also large international disparities in total factor productivity (TFP) (e.g. Bernard and Jones 1996, Hall and Jones 1999, Harrigan 1999). Other studies have shown that sectoral productivity differences across countries in turn affect international specialization in standard Ricardian and neoclassical models of international trade (Harrigan 1997, Golub and Hsieh 2000).

In this paper, we investigate two related questions: 1) the extent to which differences in TFP across countries at the sectoral level can be attributed to differences in the availability of physical infrastructure, and 2) the effects of infrastructure on international specialization of production. While an affirmative answer to the first question implies an affirmative answer to the second one, the latter is also worth investigating because there may be channels of causation from infrastructure to international specialization beyond those operating from relative productivity, as well as problems of measuring relative productivity that could obscure the relationship.

Casual observation in developing countries suggests that poor infrastructure contributes to low productivity. Power outages, weak telecommunications systems, lack of adequate roads are impediments to investment, growth, and poverty alleviation in these countries. (World Bank 2002, Chapter 8) A number of studies have examined the effect of infrastructure on aggregate

output, beginning with Ashauer (1989). Recent studies include Holtz-Eakin (1994), Fernald (1999), Roller and Waverman (2001) and Canning (2001). Gramlich (1994) provides a survey. In addition to the effects on aggregate productivity—absolute advantage—, some recent theoretical literature has suggested that infrastructure is likely to influence sectoral productivity—comparative advantage. Jones (2000) emphasizes the importance of “service links” in lowering transactions costs and thus facilitating international specialization and the location choices of footloose industries. That is, the quality of public services matters for investment decisions in such industries. In a series of papers, Ronald Findlay and his co-authors have modeled the effect of infrastructure on productivity and comparative advantage (Findlay and Wilson 1987, Clarida and Findlay 1992).

The relationships between infrastructure, productivity, and international specialization are of considerable policy relevance. Policy plays a decisive role in the provision of infrastructure due to the public good and natural monopoly dimensions of infrastructure, either directly via public investment or indirectly via the regulatory environment. Government therefore may influence both absolute advantage and comparative advantage through its policies towards infrastructure. Indeed, many countries pledge specific infrastructure improvements as part of a package of targeted investment incentives.¹ Despite the importance of this issue, to our knowledge there have been no previous empirical studies of the effect of infrastructure on comparative advantage.

The endogeneity of infrastructure provision, however, raises difficult problems of identifying the effects of infrastructure on comparative and absolute advantage insofar as governments choose infrastructure conditional on the characteristics of their country. Highly

¹ For example, Costa Rica succeeded in attracting a major investment from Intel in semiconductors in part by committing to funding a new electrical substation (Moran 2002, p. 40).

productive countries can afford higher levels of infrastructure, so the direction of causation runs in both directions. Also, countries with natural comparative advantages in infrastructure-intensive industries may tend to invest more in infrastructure, as Clarida and Findlay's (1992) model suggests.

In our empirical analysis, we control for the endogeneity of infrastructure provision using the insights provided by a model inspired by Clarida and Findlay (1992). We find that after controlling for unobserved heterogeneity across countries and the potential endogeneity of infrastructure, there remains a statistically significant effect of infrastructure on industry-level productivity and comparative advantage.

The remainder of this paper is organized into four sections. Section 1 presents the model and the empirical strategy. Section 2 describes the construction of our TFP and infrastructure data. The results are presented in section 3. Section 4 concludes.

1. Conceptual Framework

Consider a small open economy that produces J goods, indexed by j , using constant returns to scale technologies from M primary factors, indexed by m . Since the country is small, it takes the J -vector of world prices P as given. All product and factor markets are perfectly competitive.

As is well-known, the competitive equilibrium of this economy maximizes the value of final output. A common formulation of this problem (see Dixit and Norman 1980, p. 31) is

$$\begin{aligned} r(P, V) &= \max_x \{P \cdot x \mid (x, V) \text{ feasible}\} \\ &= P \cdot x(P, V) \end{aligned} \tag{1}$$

where $r(P, V)$ is known as the revenue function and $x(P, V)$ is the vector of net output supplies that maximize the value of national income. If factors are continuously substitutable and $M \geq J$, then the vector of net output supplies is given by

$$x_j(P, V) = \frac{\partial r(P, V)}{\partial P_j}, \quad j = 1, \dots, J. \quad (2)$$

In addition to the assumptions implicit in the revenue function, suppose that the production technology for good j can be written as

$$x_j = \theta_j f_j(v_j) = \theta_j \tilde{x}_j, \quad j = 1, \dots, J, \quad (3)$$

where θ_j is a productivity shift parameter defined relative to some base time period or country's output \tilde{x}_j and v_j is an M -vector of factor inputs in good j . An increase in θ_j represents a Hicks' neutral productivity improvement.

Dixit and Norman (1980, p. 138) show that under these circumstance, the revenue function (1) has the particular form $r(\Theta P, V)$, where $\Theta = \text{diag}(\theta_1, \dots, \theta_J)$, such that changes in an industry j 's productivity θ_j affect production in the same way as changes in P_j .

This formulation offers a conceptually straightforward mechanism for introducing productivity differences across countries as a source of comparative advantage, and it has proven useful in Harrigan's (1997) empirical work. We extend this framework by decomposing international productivity differentials into (i) inherent technological differences and (ii) stocks of infrastructure.

We assume that the Hicks' neutral productivity shifter in industry j can be written

$$\theta_j = \omega_j g_j(I), \quad (4)$$

where ω_j is a technological parameter inherent to industry j , I is the stock of infrastructure available in the economy, and $g_j(\bullet)$ is an increasing function that maps the availability of infrastructure into productivity. The $g_j(\bullet)$ function is the same across countries but specific to industry j .² Infrastructure is a source of comparative advantage as its industry-specific productivity effects interact with international differences in factor endowments.

The government is assumed to provide infrastructure using a Leontief technology with a vector of fixed unit input requirements Γ with typical element λ_m indicating the amount of input m required to produce one unit of infrastructure. Since government provision of infrastructure consumes resources, not all of the country's endowments will be available to private firms for the production of final goods. The net vector of factor endowments available for this purpose is given by

$$NV = V - \Gamma \cdot I. \quad (5)$$

² The assumption that the mapping of infrastructure to an "observed" productivity level is the same across countries is necessary to identify the effects of infrastructure on productivity. Infrastructure remains a source of comparative advantage given that observed θ and hence comparative advantage is affected by differences in infrastructure provision. This assumption is analogous to the assumption frequently made in the empirical literature on the Heckscher-Ohlin model that technologies are identical across countries or differ by an equal proportion across industries (e.g., Trefler 1995).

If $G(I) = \text{diag}(g_1(I), \dots, g_j(I))$ and $\Omega = \text{diag}(\omega_1, \dots, \omega_j)$, then the revenue function can be written

$$r(\Omega \cdot G(I) \cdot P, V - \Gamma \cdot I). \quad (6)$$

Given I , the revenue function in (6) has all the standard features. Notably, the gradient of $r(P \cdot \Omega \cdot G(I), V - \Gamma \cdot I)$ with respect to P yields the net supply of each final good produced by the economy:

$$x_j(\Omega \cdot G(I) \cdot P, V - \Gamma \cdot I) = \frac{\partial r(\Omega \cdot G(I) \cdot P, V - \Gamma \cdot I)}{\partial P_j} \quad (7)$$

A welfare maximizing government will choose the level of I that maximizes (6). An increase in I is expected to increase productivity in all sectors, thereby raising absolute advantage, but to an extent that could vary across sectors, therefore influencing comparative advantage. The size of the productivity effect associated with an incremental increase in I depends on other characteristics of the country: its factor endowment V and its technology as summarized by Ω . The cost of an incremental increase in I is the real resources consumed Γ . The optimal level of infrastructure depends on a country's absolute and comparative advantage, and in turn further influences the country's pattern of international specialization. For example, the government of a country with factor endowments and technologies that confer a comparative advantage in industries in which roads are relatively important may provide a larger stock of roads, thereby further reinforcing the comparative advantage in road-intensive industries.

2. Empirical Strategy

Our objective is to estimate the relationships: (1) between unobserved TFP Θ and infrastructure, and (2) between infrastructure and industrial specialization. We will do so using data on observed TFP and industrial specialization across countries, industries, and years. In this section, we specify an econometric model capable of achieving these goals that follows from the conceptual framework presented in the previous section.

First, consider the relationship between infrastructure and observed productivity implied by equation (4). To make equation (4) operational, we assume that the elasticity of productivity with respect to infrastructure provision is constant, so that (4) can be represented in logarithms as

$$\ln \theta_{jt}^c = \beta_j \ln I_t^c + \ln \omega_{jt}^c + e_{jt}^c. \quad (8)$$

According to (8), observed TFP (θ_{jt}^c) in industry j in year t and country c is a function of infrastructure in that country at time t (I_t^c) , unobserved technological ability (ω_{jt}^c) , and a stochastic measurement error (e_{jt}^c) .

To relate infrastructure to observed industrial specialization across countries, we follow Harrigan (1997) in assuming that the revenue function given by (6) can be approximated by a second-order translog:

$$\begin{aligned} \ln r(\Theta P_t, NV) = & a_{00} + \sum_j a_{0j} \ln \theta_j P_j + \frac{1}{2} \sum_j \sum_k a_{jk} \ln \theta_j P_j \ln \theta_k P_k \\ & + \sum_m b_{0m} \ln nv_m + \frac{1}{2} \sum_m \sum_i b_{mi} \ln nv_m \ln nv_i + \sum_j \sum_m c_{jm} \ln \theta_j P_j \ln nv_m, \end{aligned} \quad (9)$$

where the summations over j and k run from 1 to J goods, and the summations over m and i run from 1 to M factors. nv_m is the country's endowment net of the quantity of resources consumed by infrastructure production of factor m . Symmetry of cross effects requires $a_{jk} = a_{kj}$ and $b_{mi} = b_{im}$ for all j, k, i , and m . For expositional convenience, country superscripts and time subscripts have been suppressed. It should be remembered that θ_j is a function of inherent productivity ω_j and the influence of infrastructure as in (8). Linear homogeneity of the revenue function requires

$$\begin{aligned} \sum_j a_{0j} &= 1, & \sum_m b_{0m} &= 1, & \sum_j a_{kj} &= 0, \\ \sum_m b_{mi} &= 0, & \sum_m c_{jm} &= 0. \end{aligned}$$

Differentiating equation (9) with respect to an industry price, P_j , we obtain

$$s_j = a_{0j} + \sum_m c_{jm} \ln nv_m + \sum_k a_{jk} \ln P_k + \sum_j a_{jk} \ln \theta_k, \quad (10)$$

where s_j is the share of the value of output in industry j in total GDP.³ An important feature of (10) is that price changes and changes in productivity in one industry have general-equilibrium effects on other industries (captured by a_{jk}).

³ This equation is identical to Harrigan's (1997) equation (8) except that factor supplies are net of usage in infrastructure.

Substituting (8) into (10) and adding back in country superscripts and time subscripts yields,

$$s_{jt}^c = a_{0j} + \sum_m c_{jm} \ln v_{mt}^c + \sum_k a_{jk} \ln P_{kt} + \left(\sum_k a_{jk} \beta_k \right) \ln I_t^c + \sum_k a_{jk} \ln \omega_{kt}^c + \sum_k a_{jk} e_{kt}^c. \quad (11)$$

Infrastructure influences industry-level productivity as captured by β_j and these changes in productivity in turn have general equilibrium effects through the productivity coefficients, a_{jk} . Equation (11) implies the following empirical specification

$$s_{jt}^c = a_{0j} + \sum_m c_{jm} \ln v_{mt}^c + \alpha_j \ln I_t^c + \nu_{jt}^c \quad (12)$$

where $\alpha_j = \sum_k a_{jk} \beta_k$ is the effect of the level of infrastructure on the share of industry j in total GDP and

$$\nu_{jt}^c = \sum_k a_{jk} \ln P_{kt} + \sum_k a_{jk} \ln \omega_{kt}^c + \sum_k a_{jk} e_{kt}^c + \zeta_{jt}^c \quad (13)$$

is unobserved, consisting of the price vector P , the vector of technological capabilities Ω , and measurement error from both the productivity equation and the specialization equation e_{kt}^c and ζ_{jt}^c , respectively.

In estimating equations (8) and (12), we face an identification problem caused by the fact that technological abilities ω_{jt}^c appears in the unobservables ν_{jt}^c . As our model shows, a country's choice of infrastructure is a function of both its factor endowments and these unobserved technological abilities. Our identification strategy begins by time differencing (5) and (12), which yields

$$\Delta \ln \theta_{jt}^c = \beta_j \Delta \ln I_t^c + \eta_{jt}^c \quad (8')$$

where $\eta_{jt}^c = \Delta \ln \omega_{jt}^c + \Delta e_{jt}^c$ and

$$\Delta s_{jt}^c = \sum_m c_{jm} \Delta \ln v_{mt}^c + \alpha_j \Delta \ln I_t^c + \Delta \nu_{jt}^c. \quad (12')$$

Time differencing eliminates any time-invariant, country-industry specific effects that influence both infrastructure and our two sets of dependent variables, observed TFP and output shares. Note also that only the “innovation” in unobserved technological ability, $\Delta \ln \omega_{jt}^c$, appears in $\Delta \nu_{jt}^c$. Innovations in unobserved technological ability are far less predictable than levels, and thus less likely to affect governments' infrastructure plans. As a result, the degree of endogeneity is lower in a specification estimated in differences than in a specification estimated in levels.

To formalize the idea that infrastructure planning lags advances in technological capabilities, we assume that infrastructure provision takes the form of the partial adjustment model given by

$$\ln I_t^c = \ln I_{t-1}^c + \Psi \left(\ln \tilde{I}_{t-1}^c - \ln I_{t-1}^c \right), \quad (14)$$

where \tilde{I}_{t-1}^c is the optimal level of infrastructure for country c . The conceptual framework presented in the previous section suggests that a country's optimal level of infrastructure is a function of the vector of its factor endowments V^c and its technological capabilities Ω^c . Therefore, we assume

$$\ln \tilde{I}_t^c = \sum_m \phi_m \ln V_{mt}^c + \sum_j \delta_j \ln \omega_{jt}^c, \quad (15)$$

where ϕ_m and δ_j are unknown coefficients. Substituting (15) into (14), time differencing the resulting expression, yields the following first stage equation:

$$\Delta \ln I_t^c = (1 - \Psi) \Delta \ln I_{t-1}^c + \Psi \sum_m \phi_m \Delta \ln V_{mt-1}^c + u_t^c. \quad (16)$$

Note that $u_t^c = \Psi \sum_j \delta_j \ln \omega_{jt}^c + \varepsilon_t^c$, where ε_t^c is an error term associated with measurement of the dependent variable. If inherent technological ability follows a random walk, then lagged growth rates in endowments and infrastructure are appropriate instruments for current changes in infrastructure stocks.

While we rely chiefly on instrumental variables to identify the effect of infrastructure on observed TFP and industrial specialization, the panel data nature of our data allows us to control

for common unobservables. First, to control for technology shocks by industry that are common across countries, we add time-industry fixed effects to (8'). Second, to control for unobserved changes in prices, exogenous TFP levels ω_{jt}^c , and government policies that might also be correlated with both infrastructure provision and industry output shares across countries, we add country-industry-specific intercepts and industry-time time effects to equation (12'). Finally, while we do not observe prices, we can proxy for changes in the relative price of traded goods by including changes in the logarithm of the real exchange rate (*RER*).

Equations (16), (8'), and (12') respectively form an econometric model that specifies a link between (i) factor endowments and the level of infrastructure, (ii) infrastructure and observed productivity, and (iii) infrastructure and the structure of international specialization. Note that the unobserved productivity levels ω_{jt}^c appear in the unobservable terms in all three equations:

$$\text{Productivity Equation (8')}: \quad \eta_{jt}^c = \Delta \ln \omega_{jt}^c + \Delta e_{jt}^c,$$

$$\text{Specialization Equation (12')}: \quad v_{jt}^c = \sum_k a_{jk} \ln P_{kt} + \sum_k a_{jk} \ln \omega_{kt}^c + \sum_k a_{jk} e_{kt}^c + \zeta_{jt}^c,$$

$$\text{Infrastructure Equation (16)}: \quad u_t^c = \Psi \sum_j \delta_j \ln \omega_{jt}^c + \varepsilon_t^c.$$

Given this feature of our system of equations, we estimate our system via three stage least squares. Further, following Harrigan (1997) we impose the linear homogeneity requirements

$$\sum_m c_{jm} = 0 \text{ for the international specialization equation (12').}$$

3. Data and Measurement

We now describe our data. These data fall into two categories, measures of output and total factor productivity, and measures of factor endowments and infrastructure. Further details are provided in Appendix 1.

3.1 *Total Factor Productivity*

We calculate international differences of sectoral TFP for ten industries and eighteen developed and developing countries over the years 1979-97. The data used to construct our measures of TFP are from the United Nations Industrial Development Organization (UNIDO) INSTAT database. From this database we obtain measures of value-added, employment, and capital formation by manufacturing ISIC category. The countries included in our data were selected according to data availability and geographic and economic diversity.⁴ Following much of the literature on productivity comparisons, we use the TFP index proposed by Caves et al (1982), which is defined as

$$\ln \omega_{jt}^c = \left(\ln X_{jt}^c - \overline{\ln X_{jt}} \right) - \sigma_{jt}^c \left(\ln L_{jt}^c - \overline{\ln L_{jt}} \right) - (1 - \sigma_{jt}^c) \left(\ln K_{jt}^c - \overline{\ln K_{jt}} \right), \quad (17)$$

where X is value-added, L is total hours of labor, and K is capital stock. In each of the parentheses, there are individual country variables relative to the mean value of this variable across countries in the sample. Finally, $\sigma_{jt}^c = (q_{jt}^c + \overline{q_{jt}})/2$ is an average of the labor cost share in country c and the cross-country average. This index is widely used because it is superlative in

⁴ The eighteen countries are Austria, Canada, Colombia, Finland, France, Hong Kong, India, Indonesia, Italy, Japan, Korea, Netherlands, Singapore, South Africa, Spain, Turkey, the United Kingdom, and the United States of America. The ten industries are Food Products (ISIC 31, less 312), Textiles (ISIC 32), Wood Products (ISIC 33) Paper Products (ISIC 34), Chemicals (ISIC 35), Metals (ISIC 381), Machinery (ISIC 382), Electronics (ISIC 383), Transport Equipment (ISIC 384), and Instruments (ISIC 385).

the sense that it is exact for a translog functional form, and it is transitive so that the choice of the base country (here a geometric average of sample countries) is unimportant.

In implementing (17), we adjust each country's number of workers by industry and year as reported in UNIDO by the average number of hours per worker by country and year for total manufacturing as reported by the International Labor Organization. Our industry-country-year capital stock data are constructed via the perpetual inventory method using real dollar gross fixed capital formation as reported by UNIDO. The resulting data are then adjusted for year-to-year variations in capacity utilization. Finally, labor cost share data were computed as the ratio of payments to labor in total value-added. Following Harrigan (1997, 1999), we smooth the relatively volatile labor cost coefficients using the fitted values from a regression of labor shares on capital-labor ratios.⁵

3.2 *Output Shares, Infrastructure, and Endowments*

The study also requires data for factor and infrastructure endowments and measures of industrial specialization over time. Output shares were constructed from the UNIDO dataset, which provide data to calculate industry shares of manufacturing, and the World Bank's *World Development Indicators*, which provide output shares of GDP in manufacturing, agriculture and services. Our five factor endowments include physical capital, arable land, and low, medium, and high skilled labor. Aggregate physical capital stocks were constructed using the perpetual inventory method using real gross fixed capital formation data from the *World Development Indicators*. Arable land and total labor force participation are also from this source. Finally, shares of the working population that fall into low, medium, and high education workers come from the Barro-Lee dataset.

⁵ Appendix Table 1 presents summary results for levels and rates of change of TFP for the countries in the sample.

Our three measures of infrastructure are total length of the road network in miles, number of telephone lines in use, and electrical power generating capacity. All three measures are taken from Canning (2001) and extended using data from the *World Development Indicators*. Our choice of infrastructure variables is largely governed by availability over time and countries and are similar to those used in other studies. It can be argued, however, that while roads are pure public goods, telecommunications and electric power are mostly private, albeit subject to increasing returns in some areas. Nonetheless, the natural monopoly character of some telecommunications and electricity services, combined with their importance as shared inputs in all sectors, has entailed a critical role for government policy in determining their supply, both directly and through regulation of private utilities. We have therefore decided to include all three measures of infrastructure. Ideally our measures of all three infrastructure variables would capture some element of quality (failed telephone calls, power outages, etc.). Such data does not exist in the necessary panel format, however, and we are thereby forced to use quantity measures unadjusted for quality. Road network length and number of telephone lines are each normalized by the size of the labor force, while electrical power generating capacity is normalized by the real dollar value of the national capital stock.⁶

Our theory suggests that the relevant measure of endowments is net of the primary factor requirements in the construction, maintenance, and operation of infrastructure. We compute unit factor input requirements for roads, telecommunications, and electrical generating capacity for the United States and assume that these apply to all countries.⁷ We further assume that the factor

⁶ In principle, one would want to normalize roads also by the geographic size of the country. However, since our econometric specifications relate changes in log infrastructure to changes in log TFP, the effect of any time invariant variable is necessarily unidentified.

⁷ The assumption that factor requirements are the same across countries is unlikely to matter much in practice for net factor supplies, given that factor use in infrastructure accounts for a small part of the capital stock. For the United States, for example, infrastructure accounts for about 10-15 percent of the total capital stock and less than 5 percent of employment.

proportions of the construction, telecommunications, and utility sectors of the U.S. economy could be used as proxies for those of roads, telecommunications, and electrical generating capacity, respectively. Unit factor input requirements in U.S. infrastructure were calculated based on data from the Department of Commerce for labor and capital input, and from the Current Population Survey of the Census Department for skill composition corresponding to the Barro-Lee categories.

4. Results

We report estimation results for equations (13)-(15): the growth of infrastructure, and the effects of infrastructure on productivity and comparative advantage as measured by output shares. The results reported in this section all correspond to 3-year time differences, which yield approximately 5 observations for each country-industry pair and a total of 88 country-year observations for each industry. All instruments are lagged four years to avoid any overlap with the dependent variable. The use of differences rather than levels, while aiding in identification, eliminates the information contained in levels and makes it more difficult to obtain easily interpreted and statistically-significant results. Appendix 2 reports results for developed and developing countries separately.

We first estimated (14) for each industry using the instruments suggested by (13) via GMM and conducted Hansen conditional moment tests and Sargan tests to assess our assumption that lagged endowments and infrastructure growth rates are appropriate instruments. In all ten industries considered in our study, we were able to reject the hypothesis that our instruments are invalid at very high levels of confidence.

4.1 Infrastructure Growth

The coefficient estimates of the first-stage equation (13) are shown in Table 1. Each column corresponds to an infrastructure type and each row to an independent variable. The Table reveals that the growth rates of both road length per worker (Roads) and telephone lines per worker (Telecom) are closely related to lagged growth rates of endowments and infrastructure measures, particularly their own lagged growth rate, while the growth rate of electrical generating capacity (Power) is not as closely linked to the corresponding variables. Interestingly, there appear to be significant differences in the types of lagged endowments that matter, with Capital particularly important for Roads, Low and Moderately skilled labor important for Telecoms, and High skilled labor relatively important for Power. The connection between roads and capital is plausible insofar as roads involve much higher capital-labor ratios than telecommunications and electricity. There is insufficient information on the skill-composition of the labor force used in infrastructure provision to assess the relative skill-intensities of telecommunications and electricity provision.

Separating the sample into developed and developing countries has very little effect on the relative magnitude of the effects of the various factor-endowment and lagged-infrastructure variables.⁸

4.2 Growth Rates of TFP

The estimates of equation (14), which relates growth rates in industry TFP to growth rates of infrastructure, are shown in Table 2. The table is organized with each row corresponding to an industry (dependent variable) and each column corresponding to an infrastructure measure

⁸ Results for the stage 1 equation for developed and developing countries separately are available from the authors upon request. Other results for these groups of countries are reported in Appendix 2.

(independent variable). Standard errors for the coefficient estimates are shown in parentheses. Finally, the last two rows show the chi-squared values and their corresponding p-values for two types of tests of cross-equation coefficient restrictions on that column's infrastructure variable. The first is the test of the null hypothesis that the coefficients on changes in infrastructure are jointly zero, while the second is the test of the hypothesis that the coefficients are the same across equations.

We begin with several observations on the general features of the results. The first is that every industry displays a statistically significant, positive relationship between TFP growth and growth in at least one type of infrastructure and in no industry is there a statistically significant, negative relationship between the growth rates of infrastructure and TFP. Second, as indicated by the Chi-squared and corresponding p-values reported in the second row from the bottom in Table 2, the test that all coefficients are equal to zero across industries can be rejected at standard levels for all three types of infrastructure. Third, of the three infrastructure types, Roads appears to have the most pervasive effects across industries. An increase in the length of the road network per worker is associated with a statistically significant increase in TFP in nine of the ten industries, while telephone lines per worker is associated with a statistically significant increase in only Transport Equipment and Scientific Instruments, and electrical generating capacity per dollar of capital is associated with a statistically significant increase in TFP in only Food Products and Chemicals. Taken as a whole, these results are highly suggestive of a positive link between infrastructure provision, particularly with respect to transportation, and industrial productivity.

We now turn to the implications of our results for the hypothesis that infrastructure affects comparative advantage through its differential impact on sectoral TFP. While the

coefficients estimated across industries vary from industry to industry in terms of both magnitude and statistical significance, the standard errors of the coefficients are large relative to their differences across industries. The last row in the table reports the Chi-squared statistic and its corresponding p-value for the test of the hypothesis that the coefficients are the same across industries. The results of these tests indicate that the hypothesis that the effect of Roads is uniform across industries cannot be rejected at standard levels of significance, while the hypothesis that the coefficients on Telecoms and Power are the same can be rejected at reasonable levels. The results suggest that Road provision, while a source of overall productivity differences across countries, i.e., absolute advantage, does not appear to be a clear source of comparative advantage, at least across manufacturing industries. Telecoms and Power affect comparative advantage within manufacturing for some sectors, but the effects are statistically insignificant for about half the industries. It is important to remember, however, that the relatively weak results for Telecoms and Power probably reflect in large part the relatively imprecise estimates of our coefficients, which stems in part from our small sample size and the differencing of the variables. In addition, the effects of unmeasured quality variations in electricity distribution and telecommunications may be more important than the quantity differences used here. More generally, the data for developing countries are likely to be inferior to that of developed countries for both infrastructure and productivity measures. Finally, as noted earlier, roads are the closest to the concept of infrastructure as a pure public good, whereas electricity and telecommunications services are increasingly provided by private suppliers, and therefore fit the model less closely.

Tables 4A and 4B in Appendix 2 report results on the effects of infrastructure on TFP for developed and developing countries separately. The results for developed countries are

considerably stronger than those for developing countries, and for the combined sample, with both Roads and Power having a generally much clearer positive effect on TFP for developed countries than for developing countries, probably reflecting poorer quality of the data for the latter.

4.3 *Industrial Specialization*

We now turn to the relationship between infrastructure and industrial specialization.⁹ Table 3 is organized in the same fashion as Table 2 with each row corresponding to an industry equation and each column corresponding to an independent variable. The first three columns are our three infrastructure measures. The next five columns correspond to factor endowments net of infrastructure provision. The ninth column is the measure of the real exchange rate, where an increase corresponds to a real depreciation. To better understand the effect of infrastructure (and primary factor endowments) on industrial specialization, we included both the agricultural sector (first row) and the service sector (the twelfth row). Finally, the last two rows report Chi-squared and p-values for tests of joint hypotheses across equations. The second row from the bottom corresponds to the Chi-squared and corresponding p-value for the test that all the coefficients for the appropriate input are zero, while the last row corresponds to the Chi-squared and corresponding p-value for test that all the coefficients for the tradeable goods industries (all except services) are the same.

Several general observations are in order regarding the coefficients on primary factor endowments. First, an increase in physical capital is generally associated with increased output in the service sector and lower output in manufacturing. More generally, the endowment

⁹ Recall that all twelve industry output share equations were estimated simultaneously with each other and with the ten industry TFP equations.

variables seem to have opposite effects on manufacturing and services. Second, an increase in least skilled workers is associated with greater agricultural output and an increase in the output of several manufacturing industries while also reducing the output of service industries. Finally, all factor endowment variables are statistically significant in the sense that a joint test that they are collectively zero is resoundingly rejected for each endowment type.¹⁰ The hypothesis that the coefficients on factor endowments for the traded goods sectors are the same is also sharply rejected for each endowment variable.

Next, we briefly discuss the coefficients on changes in the real exchange rate, RER. As expected, an increase in the relative price of traded goods in terms of nontraded goods is associated with an increase in the output of a number of manufacturing industries, such as Textiles, Wood Products, Chemicals, Instruments, and a decrease in the output of nontraded services.

We now turn to the estimated effect of our three infrastructure variables on the structure of industrial production. The output shares of eight industries appear to be influenced by the availability of at least one type of infrastructure. Further, all three infrastructure types are found to be statistically different from zero and to be statistically different from each other as indicated by the Chi-squared values shown in the second-to-last row of Table 3.

Focusing first on Roads, we find that an increase in infrastructure is associated with a shift in output out of manufacturing industries and into services, while the evidence of shifts of output within manufacturing is more subtle. Within manufacturing it appears that an increase in Roads is associated with a decrease in Textiles, Metal Products, and Machinery, relative to Electronics, Chemicals and perhaps Wood Products. As indicated by the Chi-squared and their

¹⁰ Note that the same test (not shown) indicates that the coefficients on only the manufacturing industries are statistically different from zero at standard levels. Further, a test that the coefficients on endowment variables for the manufacturing industries are the same is also resoundingly rejected.

corresponding p-values shown in the last row of Table 3, the hypothesis that the coefficients on Roads across the eleven tradable-goods industries are the same is sharply rejected: growth in the road network appears to be associated with comparative advantage in this specification.

The results for Telecoms per worker are very different from those of Roads. While the coefficient on this variable is statistically significant in three of twelve industries, it is found not to be statistically different from zero in the test of joint significance (see second to last row). Similarly, the coefficients are also found not to be different across industries within the traded goods sector. These results suggest that telecommunications do not appear to be a significant source of comparative advantage. These weak results for telecommunications could reflect the crude nature of the measure of telecommunications used here, notably the omission of the quality of the cost and quality of telecommunications services.

Finally, we turn to Power, shown in the third column of Table 3. The coefficients on Power are statistically different from zero across industries as indicated by the test statistic in the second to last row. Similarly to physical capital, an increase in electrical generating capacity appears to be associated with a shift of production out of manufacturing into services, with the three manufacturing industries with statistically-significant coefficients being negative and the statistically significant coefficient in services positive. Nevertheless, there are very substantial differences in the coefficients within manufacturing, and the Chi-squared value reported in the last row strongly suggests that the coefficients are not identical across traded goods industries. Hence, the availability of electrical generating capacity also appears to be associated with comparative advantage.

Separating the sample into developed and developing countries yields rather divergent results, perhaps reflecting differences in the nature of the products produced as well as greater

measurement problems in developing countries, as noted above. Overall, it appears that infrastructure provision does affect the pattern of specialization but the results are less clear and robust than the effects of infrastructure on TFP.

5. Conclusion

Infrastructure is one of the main candidates for explaining overall international disparities of productivity between countries—absolute advantage. Clarida and Findlay (1992) also proposed that infrastructure could be a source of comparative advantage, i.e., industry-level productivity variations across countries. We calculate total factor productivity for eighteen developed and developing countries and ten manufacturing industries, and study the effects of supplies of roads, telecommunications and electric power on international variations in sectoral TFP. The analysis is complicated by the endogeneity of infrastructure provision: countries with a comparative advantage in a particular sector may invest relatively more in infrastructure that raises productivity in that sector. This paper therefore goes to considerable lengths to address identification and spurious correlation, by focusing on growth rates rather than levels of productivity and infrastructure, and through the use of a three-stage least squares estimation procedure. The use of differences rather than levels, while aiding in identification, eliminates the information contained in levels and makes it more difficult to obtain statistically-significant results. It is therefore encouraging that we still find considerable evidence that increased provision of infrastructure affects total factor productivity.

As expected, increased provision of infrastructure affects absolute advantage insofar as it tends to raise TFP in most sectors, with road networks having a particularly strong effect on TFP. Our results are therefore consistent with the conjecture by Leamer and Levinsohn (1995) that

some of the apparent differences in technology across countries are attributable to infrastructure. We also found that the effect of infrastructure on total factor productivity varied considerably across sectors as suggested by the Clarida-Findlay (1992) model, confirming infrastructure as a source of comparative advantage. This conclusion is reinforced by our finding that changes in the availability of infrastructure alter industrial specialization, although our results here are less robust.

Further research should seek to refine the measures of infrastructure to include quality as well as quantity indicators, such as power outages and failed telephone connections. Improved indicators might help to improve the results for telecommunications and power, which were less successful than for roads. The sources of the different results for developed and developing countries should also be explored further.

References:

- Aschauer, David. 1989. "Is Public Expenditure Productive?" *Journal of Monetary Economics* 23(2). pp. 177-200.
- Barro, Robert and Jong-Wha Lee. 2001. "International Data on Educational Attainment: Updates and Implications." *Oxford Economic Papers* 53(3). pp. 541-563.
- Bernard, Andrew B., and Charles Jones. 1996. "Comparing Apples to Oranges: Productivity Convergence and Measurement across Industries and Countries." *American Economic Review* 86(5). pp. 1216-1238..
- Canning, David. 2001. "The Contribution of Infrastructure to Aggregate Output." Mimeo, World Bank.
- Clarida, Richard, and Ronald Findlay. 1992. "Government, Trade and Comparative Advantage." *American Economic Review* 82(2). pp. 122-127.
- Fernald, John. 1999. "Roads to Prosperity? Assessing the Link between Public Capital and Productivity." *American Economic Review* 89(3). pp. 619-638.
- Findlay, Ronald and John Wilson. 1987. "The Political Economy of the Leviathan." In Economic Policy in Theory and Practice. ed. Assaf Razin and Sadka Efraim. St. Martin's Press. pp. 289-304.
- Golub, Stephen S.. and Hsieh, Chang-Tai. 2000. Classical Ricardian theory of comparative advantage revisited. *Review of International Economics*, 8(2), 221-234.
- Gramlich, Edward, 1994. "Infrastructure Investment: A Review Essay," *Journal of Economic Literature* 32(3). pp. 1176-1196.
- Hall, Robert, and Charles Jones. 1999. "Why do Some Countries Produce so much More Output than Others." *Quarterly Journal of Economics* 114(1). pp. 83-116.

- Harrigan, James. 1997. "Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model." *American Economic Review* 87(4). Pp. 475-494.
- Harrigan, James. 1999. Estimation of Cross-Country Differences in Industry Production Functions." *Journal of International Economics* 47(2).pp. 267-293.
- Holtz-Eakin, Douglas. 1994. "Public-Sector Capital and the Productivity Puzzle." *Review of Economics and Statistics* 76(1). pp. 12-21.
- Jones, Ronald. 2000. Globalization and the Theory of Input Trade. MIT Press.
- Leamer, Edward, and James Levinsohn. 1995. "Testing Trade Theories and Predicting Trade Flows." In Handbook of International Economics vol. 3. ed. By Gene Grossman, and Kenneth Rogoff. North Holland.
- Moran, Theodore H. 2002. Beyond Sweatshops; Foreign Direct Investment and Globalization in Developing Countries. Brookings.
- Roller, Lars-Hendrik and Leonard Waverman. 2001. "Telecommunications Infrastructure and Economic Development: A Simultaneous Approach." *American Economic Review*, 95(4). pp. 1029-46.
- Trefler, Daniel. 1995. "The Case of the Missing Trade and Other HOV Mysteries." *American Economic Review* 85(5). pp. 1029-1046.
- Van Ark, Bart, and Dirk Pilat. 1993. "Productivity Levels in Germany, Japan, and the United States: Differences and Causes." *Brookings Papers on Economic Activity: Microeconomics*, 2. pp. 1-48.
- World Bank. 2002. *World Development Report: Building Institutions for Markets*.

Table 1: Growth in Infrastructure as a function of Growth in Lagged Infrastructure and Lagged Endowments

	Roads	Telecom	Power
<i>Lagged Infrastructure</i>			
Roads	0.49*** (0.07)	0.23** (0.11)	-0.26** (0.13)
Telecom	0.07** (0.04)	0.52*** (0.06)	0.15** (0.08)
Power	0.05 (0.04)	0.21*** (0.06)	0.06 (0.07)
<i>Lagged Endowments</i>			
Capital	0.17*** (0.06)	0.06 (0.10)	-0.09 (0.12)
Arable Land	0.03 (0.05)	-0.14* (0.09)	0.16* (0.11)
Low Skill Lab.	-0.09** (0.04)	0.16** (0.07)	0.11 (0.08)
Mod. Skill Lab.	-0.03 (0.05)	0.30*** (0.08)	0.14* (0.09)
High Skill Lab.	-0.00 (0.03)	0.03 (0.05)	0.13** (0.05)
R-sq.	0.57	0.68	0.29
Chi-2 (p-value)	131.09 (0.000)	202.09 (0.000)	37.73 (0.003)

Notes: N=88. Std Errors in Pareds. Coefficients on time dummies suppressed.
Superscripts *, **, and *** indicate that coefficient is individually significant at 10, 5, 1 percent level respectively.

Table 2: TFP Growth as a function of Infrastructure Growth

Industry	Roads	Telecoms	Power
Food	0.66 ^{***} (0.21)	-0.08 (0.12)	0.35 ^{**} (0.14)
Textiles	0.70 ^{***} (0.19)	0.11 (0.11)	0.08 (0.13)
Wood	0.78 ^{***} (0.20)	-0.12 (0.11)	0.08 (0.13)
Paper	0.48 ^{**} (0.19)	0.16 (0.11)	0.12 (0.13)
Chemicals	0.61 ^{***} (0.21)	-0.05 (0.11)	0.44 ^{***} (0.13)
Metal Prod.	0.62 ^{***} (0.21)	-0.01 (0.12)	0.07 (0.14)
Machinery	0.89 ^{**} (0.20)	0.15 (0.11)	-0.06 (0.13)
Electronics	0.62 ^{***} (0.22)	0.10 (0.12)	-0.10 (0.15)
Transport	0.72 ^{***} (0.28)	0.32 ^{**} (0.15)	0.17 (0.19)
Instruments	0.19 (0.27)	0.38 ^{**} (0.15)	-0.29 (0.19)
Test-Coeff. Jointly Zero (p-value)	35.98 (0.000)	21.24 (0.020)	35.35 (0.000)
Test-Coeff. Equal (p-value)	12.38 (0.193)	21.23 (0.012)	31.27 (0.000)

Notes: N=88 for all industries. Standard errors in parentheses. Superscripts *, **, and *** indicate that coefficient is individually significant at 10, 5, 1 percent level respectively. Coefficients on time dummies are suppressed.

Table 3: Change in Industrial Specialization as a function of Change in Infrastructure and Factor Endowments

	Road	Telec.	Power	Capital	Land	Low Skill Labor	Mod. Skill Labor	High Skill Labor	RER
Agr.	-1.9 (3.5)	2.6 (1.8)	-1.9 (3.0)	-2.0 (2.3)	0.1 (0.9)	1.7* (1.1)	-0.2 (1.5)	0.4 (1.0)	0.6 (0.6)
Food	-0.9 (1.3)	-1.3** (0.7)	0.4 (1.1)	-1.2 (0.8)	0.6* (0.3)	0.1 (0.4)	-0.1 (0.6)	0.7* (0.4)	-0.1 (0.2)
Textile	-7.7*** (1.7)	1.4* (0.9)	1.2 (1.5)	-1.5 (1.1)	0.4 (0.4)	1.5*** (0.5)	1.1 (0.7)	-1.4*** (0.5)	0.7*** (0.2)
Wood	-0.2 (1.2)	0.9 (0.6)	-4.1*** (1.0)	-2.4*** (0.8)	0.1 (0.3)	0.7* (0.4)	1.0** (0.5)	0.5* (0.3)	0.6*** (0.1)
Paper	-1.1 (1.2)	-0.1 (0.6)	1.4 (1.1)	-0.5 (0.8)	0.2 (0.3)	0.8** (0.4)	-0.4 (0.5)	0.0 (0.3)	-0.2 (0.2)
Chem.	1.6 (1.6)	-0.9 (0.8)	-0.8 (1.4)	-2.9*** (1.0)	1.2*** (0.4)	1.7*** (0.5)	1.3* (0.7)	-1.3*** (0.5)	0.8*** (0.3)
Metal	-1.7** (0.9)	0.5 (0.4)	-1.3* (0.7)	-0.9 (0.6)	0.3 (0.2)	0.7*** (0.3)	0.4 (0.4)	-0.6*** (0.2)	0.2 (0.2)
Mach.	-4.1* (2.4)	1.8** (0.8)	-3.6*** (1.3)	-1.3 (1.0)	-2.2** (0.9)	1.4** (0.6)	1.2 (0.9)	1.0** (0.5)	0.4 (0.3)
Elect.	7.8* (4.8)	-1.6 (1.4)	0.2 (2.4)	-3.9*** (1.8)	4.8*** (1.9)	0.9 (1.1)	1.9 (1.7)	-3.6*** (0.8)	0.2 (0.5)
Trans.	-1.2 (1.2)	0.4 (0.6)	-0.5 (1.0)	-0.9 (0.7)	-0.1 (0.3)	0.9** (0.4)	0.2 (0.5)	-0.1 (0.3)	0.0 (0.2)
Sci. Inst.	-0.9** (0.4)	-0.1 (0.2)	0.2 (0.4)	0.1 (0.3)	0.1 (0.1)	0.0 (0.1)	0.0 (0.2)	-0.2 (0.1)	0.2*** (0.1)
Service	7.2 (3.2)	-1.7 (3.7)	10.8* (6.2)	12.2** (4.8)	-3.2* (2.0)	-6.5*** (2.3)	-3.9 (3.1)	1.4 (2.1)	-4.9*** (1.3)
All Zero?	28.97 (0.00)	14.66 (0.26)	26.31 (0.01)	32.17 (0.00)	28.74 (0.00)	37.28 (0.00)	22.94 (0.03)	73.69 (0.00)	
Traded Equal?	24.44 (0.00)	14.22 (0.16)	23.56 (0.01)	30.04 (0.00)	23.88 (0.01)	34.42 (0.00)	28.20 (0.00)	70.00 (0.00)	

Notes: N=88 for all industries. Standard errors in parentheses. *, **, *** indicate coefficient is individually significant at 10, 5, 1 percent level respectively. Coefficients on country intercepts and country time trends are suppressed.

Appendix 1: Data Sources and Methods¹¹

Productivity. Our primary source of data is the United Nations Industrial Development Organization (UNIDO) Industrial Statistics Database (INSTAT) at the 3-digit SIC level. This database contains information on production, value added, capital formation, labor compensation and employment for a large group of countries. To fill the missing data and to provide a consistency check we also made extensive use of the OECD's Structural Analysis Industrial Database (STAN). The OECD strives for greater consistency and completeness than UNIDO but only covers OECD countries, which now includes Korea and Mexico. Output is measured as real manufacturing value added per employee, converted to \$U.S. at an equilibrium or purchasing power parity (PPP) exchange rate. We used the aggregate manufacturing value added deflator, obtained from the World Development Indicators (WDI) to calculate real value added.

Unfortunately, there are no available estimates of absolute PPP exchange rates for manufacturing for a number of countries. As an alternative, we used the average real exchange rate over the sample period, using manufacturing value added deflators, as a rough indicator of the equilibrium real exchange rate.

In computing capital stocks, we followed Harrigan's (1999) in assuming a useful life of capital goods of ten years ($T = 10$) and a depreciation rate of 15 per cent ($\delta = 0.15$). Finally, we adjusted for varying capital utilization over time by estimating a trend for output by country and industry and adjusting the capital stock figures for deviations from this trend.

Table 1A considers the level of TFP by country and industry for 1988, which is close to the mid-point of our 1979-1997 sample. The overall levels of calculated TFP mostly accord well with intuition. India's TFP is of the order of 10 percent of the U.S. level, and the other

¹¹ Further details on sources and methods are available from the authors upon request.

developing countries in Table 1A such are generally at 10-40% of the U.S. level. Japan's TFP is the closest to the United States and even exceeds the latter in two sectors, while Canada's TFP approaches the level of the United States in a number of sectors. Note that the levels of TFP vary considerably within countries as well. For instance, Singapore's TFP is low in Food Processing and Textiles but relatively high in Electronics and Machinery while TFP in the UK is relatively low in Chemicals and high in Machinery and Transport Equipment.

Appendix Table 1B shows the average annual growth rates of TFP relative to the United States over our sample period, illustrating large disparities across countries, with a number of countries' TFP growing more rapidly than the United States, particularly in East Asia, whereas others, notably in Western Europe, grow more slowly than the United States.

Infrastructure. Appendix Table 2A and 2B show levels and rates of change of factor endowments and infrastructure. The infrastructure structure levels confirm intuition that the wealthier countries have the largest relative stock of infrastructure, with the less developed countries, such as India, Indonesia, South Africa, and Colombia, having much lower levels of infrastructure.

Given that our estimation strategy will focus on differences across time, we show the average annual growth rates of infrastructure and endowments in Table 2B. These data reveal that it is indeed the least developed countries that increased the size of their infrastructure stock most substantially over the sample period. In particular, Indonesia, one of the countries with the most rapid productivity growth, led all other countries in expanding telecommunications and electrical generating capacity. Korea and Turkey, two other countries enjoying rapid productivity growth, also accumulated infrastructure at a particularly rapid pace. Infrastructure growth apparently did not guarantee productivity growth, however, with India being a

particularly stark example. Further, Finland, which enjoyed rapid productivity growth in the sample period did not accumulate infrastructure at a particularly high rate.

Table 3A presents summary statistics for the key variables.

Appendix Table 1A: TFP Level Relative to the US, 1988

	Food	Textile	Wood	Paper	Chem.	Metal	Mach- inery	Electric	Trans. Eq.	Instru- ments
Austria	46	68	65	61	47	65	63	58	56	47
Canada	75	87	86	79	67	79	78	85	75	55
Colombia	46	30	23	38	39	28	24	44	34	24
Finland	46	61	64	64	41	65	66	63	41	56
France	51	79	71	68	53	73	74	63	58	66
Hong Kong	33	32	35	27	17	27	22	23	27	18
India	6	6	6	5	8	10	7	12	5	4
Indonesia	9	9	12	13	10	18	14	17	13	3
Italy	54	83	80	79	57	70	69	70	54	55
Japan	70	87	121	98	86	100	91	73	83	59
Korea	26	29	32	32	22	28	27	26	26	18
Netherlands	53	83	75	65	60	65	62	58	47	51
Singapore	30	25	28	37	50	30	41	31	41	24
S. Africa	17	21	25	30	21	30	41	34	28	17
Spain	49	64	65	72	57	59	54	66	62	46
Turkey	25	25	32	28	30	28	24	29	23	18
UK	47	55	74	70	50	62	60	55	47	42
USA	100	100	100	100	100	100	100	100	100	100

Appendix Table 1B: TFP Growth Relative to the US, Average Annual

	Food	Textile	Wood	Paper	Chem.	Metal	Mach- inery	Electric	Trans. Eq.	Instru- ments
Austria	0.0	1.2	0.0	0.5	-0.1	2.0	-0.6	0.8	1.8	0.4
Canada	-0.9	-1.3	-1.0	-2.8	0.4	-0.1	-2.2	-2.0	-1.3	0.4
Colombia	-0.2	-1.4	0.1	0.6	0.9	1.7	-2.2	-0.2	1.8	4.4
Finland	0.5	1.5	1.5	0.6	1.5	1.9	0.9	1.8	0.9	2.5
France	-1.1	0.6	0.8	-0.5	-0.3	1.5	-1.9	-0.2	0.8	0.7
Hong Kong	1.0	1.6	1.9	0.7	3.0	3.5	1.8	1.8	2.3	2.2
India	1.0	1.6	1.9	-0.5	0.3	-0.9	0.5	-0.6	0.0	-0.5
Indonesia	0.4	4.8	3.4	2.5	1.2	4.8	-0.1	2.2	8.0	-0.3
Italy	-1.3	0.2	0.0	-1.1	1.0	0.4	-1.2	-1.4	-0.3	0.4
Japan	0.3	0.0	0.4	0.5	0.6	1.2	-0.6	-1.8	0.9	1.4
Korea	3.3	5.7	4.3	4.1	3.5	6.8	5.5	5.0	6.1	5.5
Netherlands	-0.2	0.0	-1.5	-0.6	-0.1	-0.7	-1.2	-2.8	-0.6	-2.8
Singapore	-0.2	1.9	0.2	1.9	1.0	0.7	1.6	-0.2	0.0	4.6
S. Africa	-1.3	-1.7	-0.5	-0.8	-0.8	0.5	-4.1	-4.0	0.0	-1.3
Spain	-0.2	-1.6	-2.5	0.1	-0.1	0.9	-0.4	-1.1	-2.3	-0.4
Turkey	1.7	0.1	1.6	1.9	1.7	1.6	1.9	1.1	3.2	3.4
UK	-1.4	-0.7	-1.5	-1.5	-1.6	-0.7	-1.8	-2.5	-0.2	-0.3
USA	0	0	0	0	0	0	0	0	0	0

Appendix Table 2A: Factor Endowments and Infrastructure in Levels, 1989, in relation to USA = 100

	Road Density	Phone/ Pop.	Electrical Capacity	Labor Force	Share Low Skill	Mod. Skill	High Skill	Capital per Worker	Arable Land/ Pop
Austria	103	77	79	3	340	123	19	140	25
Canada	66	102	113	11	180	72	98	76	213
Chile	7	9	13	4	560	70	26	14	25
Colombia	3	13	10	11	750	40	16	12	13
Finland	62	98	82	2	400	96	35	148	63
France	114	90	67	20	520	79	26	131	38
Hong Kong	3	81	43	2	480	89	23	95	0
India	10	1	3	286	820	30	9	2	25
Indonesia	7	1	2	61	800	32	5	5	13
Italy	45	70	39	19	600	66	21	98	25
Japan	41	80	48	52	360	94	47	219	13
Korea	7	52	20	15	350	111	30	45	13
Netherlands	55	85	43	6	390	96	37	131	13
Singapore	7	64	38	1	660	62	12	24	0
South Africa	14	56	33	10	730	51	7	117	50
Spain	34	56	46	13	700	51	19	79	50
Turkey	7	20	11	19	830	26	12	5	63
U.K.	45	81	41	23	490	81	33	69	13
U.S.A.	100	100	100	100	100	100	100	100	100

Appendix Table 2B: Average Annual Growth Rates of Factor Endowments and Infrastructure

	Road Density	Phone/ Pop.	Electrical Capacity	Labor Force	Share Low Skill	Mod. Skill	High Skill	Capital per Worker	Arable Land/ Pop
Austria	0.5	3.4	1.2	0.6	-1.0	-0.3	7.9	2.7	-0.9
Canada	-0.3	2.5	0.6	1.7	-1.3	-1.5	1.9	2.0	-1.1
Chile	-1.2	9.7	2.3	2.5	-1.7	1.6	4.4	4.7	-5.3
Colombia	-2.2	7.3	1.6	3.4	-0.7	1.1	4.4	1.1	-5.5
Finland	1.4	2.6	2.0	0.5	-3.1	1.7	3.7	-0.1	-1.0
France	-0.5	4.4	3.1	0.6	-1.4	0.7	4.2	1.3	-0.2
Hong Kong	0.5	4.7	4.9	1.9	-2.9	2.6	4.8	5.4	-4.1
India	1.7	10.3	4.7	2.0	-0.4	2.0	4.0	4.0	-2.1
Indonesia	3.0	14.0	10.0	2.8	-1.0	4.7	8.6	7.1	-1.8
Italy	-0.2	4.1	1.7	0.7	-1.1	1.0	6.1	0.6	-0.9
Japan	2.2	2.5	2.1	0.9	-2.6	1.0	3.3	2.7	-0.8
Korea	6.1	11.0	6.5	2.3	-4.3	2.0	5.6	7.5	-2.1
Netherlands	0.0	3.0	-0.7	1.5	-1.7	0.2	3.5	0.5	0.2
Singapore	-0.7	4.5	3.2	3.1	-3.7	6.2	5.4	5.0	-6.3
South Africa	-0.9	4.3	1.5	2.5	-3.3	3.5	10	-2.2	-1.3
Spain	4.8	6.7	1.1	0.3	1.9	-2.7	1.9	8.6	0.0
Turkey	-0.3	12.8	6.3	2.5	-0.7	3.0	4.7	0.5	-1.8
U.K.	0.0	3.1	-0.6	0.5	-1.4	1.1	2.2	1.7	-0.7
U.S.A.	-0.3	2.6	0.0	1.4	-0.1	-1.8	2.9	1.9	-1.4

Appendix Table 3: Summary Statistics: 3-Year Changes

Variable	Mean	Std. Dev	Min	Max
Endowments (log change)				
Capital	0.127	0.106	-0.159	0.412
Land	-0.009	0.087	-0.677	0.112
Low Skill	-0.004	0.076	-0.338	0.203
Mod. Skill	0.103	0.107	-0.121	0.565
High Skill	0.200	0.134	-0.214	0.872
Infrastructure Measures (log change)				
Road	0.013	0.070	-0.169	0.229
Telecom	0.220	0.152	0	0.836
Power	0.007	0.128	-0.352	0.610
Output Shares (Percentage Points)				
Agr.	-0.719	1.060	-5.222	2.142
Food	-0.057	0.436	-1.116	2.93
Textile	-0.185	0.649	-2.75	3.865
Wood	-0.013	0.271	-0.672	1.664
Paper	-0.015	0.277	-1.406	1.489
Chemical	-0.030	0.506	-1.441	1.985
Metal	-0.054	0.203	-0.617	0.430
Machinery	0.022	0.513	-0.897	4.304
Electronics	-0.019	0.839	-5.728	4.423
Transport Eq.	-0.019	0.333	-0.753	1.254
Sci. Inst	-0.004	0.094	-0.409	0.359
Services	1.628	2.159	-6.736	7.059
TFP Relative To World Average (log change)				
Food	-0.001	0.117	-0.575	0.493
Textile	0.008	0.125	-0.331	0.372
Wood	0.002	0.123	-0.404	0.336
Paper	0.001	0.134	-0.526	0.355
Chemical	-0.002	0.113	-0.372	0.301
Metal	0.004	0.132	-0.425	0.365
Machinery	0.003	0.129	-0.364	0.292
Electronics	0.003	0.132	-0.409	0.328
Transport Eq.	0.010	0.183	-0.482	0.792
Sci. Inst	-0.007	0.188	-0.972	0.492

Appendix 2: The Effects of Infrastructure on TFP in Developed and Developing Countries

Tables 4A and 4B report the effects of infrastructure on TFP for developed and developing countries, respectively. For both groups of countries, roads have much clearer effects on TFP than the other two types of infrastructure, but more so for developed countries. For developed countries, Roads have positive and statistically significant coefficients in all industries, whereas for developing countries, the coefficients on Roads are positive in all cases, but smaller and statistically significant in 5 out of 10 industries. In the case of Power, the results are again much stronger for developed than developing countries, with Power having a positive and significant effect in 7 out of 10 industries for the former but in only one industry (Food) in the case of developing countries. On the other hand, Telecoms have clearer effects on TFP in developing countries, where the coefficient is positive in all but one instance and statistically-significant in 3 industries, whereas in developed countries, the sign on Telecoms is negative in 6 industries and positive and statistically significant in only one. This could reflect the increasing importance of telecommunications in developing countries, especially with regard to the boom mobile telephones.

**Appendix Table 4A: TFP Growth as a function of Infrastructure Growth,
Developed Countries**

Industry	Roads	Telecoms	Power
Food	0.89 ^{***} (0.20)	-0.23 [*] (0.14)	0.12 (0.12)
Textiles	0.80 ^{***} (0.20)	0.02 (0.15)	0.48 ^{***} (0.13)
Wood	0.80 ^{***} (0.26)	-0.06 (0.19)	0.37 ^{**} (0.17)
Paper	0.81 ^{***} (0.22)	-0.03 (0.16)	0.30 ^{**} (0.14)
Chemicals	0.53 ^{**} (0.24)	-0.03 (0.17)	0.23 [*] (0.16)
Metal Prod.	1.12 ^{***} (0.22)	-0.14 (0.16)	0.39 ^{***} (0.14)
Machinery	0.65 ^{**} (0.23)	0.25 [*] (0.17)	0.00 (0.15)
Electronics	0.76 ^{***} (0.21)	0.16 (0.15)	0.36 ^{***} (0.14)
Transport	1.01 ^{***} (0.30)	-0.06 (0.22)	0.22 (0.20)
Instruments	0.79 ^{***} (0.26)	0.03 (0.19)	0.34 ^{**} (0.17)
Test-Coeff. Jointly Zero (p-value)	46.10 (0.000)	16.30 (0.092)	35.70 (0.000)
Test-Coeff. Equal (p-value)	12.73 (0.175)	16.25 (0.062)	31.30 (0.000)

Notes: N=55 for all industries. Standard errors in parentheses. Superscripts *, **, and *** indicate that coefficient is individually significant at 10, 5, 1 percent level respectively. Coefficients on time dummies are suppressed.

**Table 4B: TFP Growth as a function of Infrastructure Growth,
Less Developed Countries**

Industry	Roads	Telecoms	Power
Food	0.56 ^{**} (0.28)	-0.02 (0.17)	0.28 [*] (0.20)
Textiles	0.62 ^{***} (0.25)	0.08 (0.15)	-0.20 (0.18)
Wood	0.25 (0.24)	0.05 (0.15)	-0.32 ^{**} (0.18)
Paper	0.09 (0.23)	0.23 [*] (0.14)	-0.26 [*] (0.17)
Chemicals	0.48 ^{**} (0.23)	-0.12 (0.14)	0.08 (0.17)
Metal Prod.	0.32 (0.27)	0.12 (0.17)	-0.19 (0.20)
Machinery	0.75 ^{***} (0.24)	0.10 (0.15)	-0.31 ^{**} (0.17)
Electronics	0.42 [*] (0.29)	0.04 (0.18)	-0.58 ^{***} (0.21)
Transport	0.45 (0.35)	0.38 ^{**} (0.22)	-0.07 (0.26)
Instruments	0.06 (0.36)	0.32 [*] (0.22)	-0.61 ^{**} (0.27)
Test-Coeff. Jointly Zero (p-value)	20.42 (0.026)	12.69 (0.242)	20.38 (0.026)
Test-Coeff. Equal (p-value)	14.87 (0.095)	12.34 (0.195)	19.76 (0.020)

Notes: N=45 for all industries. Standard errors in parentheses. Superscripts ^{*}, ^{**}, and ^{***} indicate that coefficient is individually significant at 10, 5, 1 percent level respectively. Coefficients on time dummies are suppressed.