Have Collapses in Infrastructure Spending led to Cross-Country Divergence in per Capita GDP?

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1. Introduction

One of the most striking facts of postwar economic history is the continuously increasing trend of growing disparities between poor and rich countries. Even though some developing countries, primarily located in the East Asian region, managed during this period to achieve high growth rates in per capita GDPs and to close their gap with the developed world, this was not the general trend in the developing world. As Figure 1 shows, the standard deviation of log per capita incomes has been growing continuously since the early sixties, and now stands 31% higher than in 1960. The advent of market-oriented reforms during the eighties and nineties appears to have done little to reverse this trend: dispersion has grown faster during the 1990s than in any other decade since the sixties.

This paper explores one possible explanation of this great divergence: the decline in the provision of infrastructure that has occured in many developing countries since the eighties. In recent work, Easterly and Servén (2003) have shown that there have been significant declines in public infrastructure investment in a number of Latin American economies that underwent fiscal adjustments during the eighties and nineties. These

[1] This paper was prepared as a background note for the 2006 World Economic and Social Survey of the United Nations Department of Economic and Social Affairs. The author is grateful for that institution's financial support. All errors are my own responsibility.

authors have argued that the growing divergence between East Asia and Latin America can be accounted for in part in terms of their differing investments in public infrastructure. In this paper we will attempt to understand whether this explanation can be taken further to help account for the growing disparities in living standards across the world shown in Figure 1.

The argument is simple. Infrastructure is a public good that produces positive externalities for production. The provision of adequate infrastructure is a necessary condition for private firms to be productive. Even if infrastructure is also provided for its amenity value (i.e. for its direct utility value to individuals) it is obvious that it plays a central role in generating external effects that fundamentally alter the capacity of the economy to produce goods and services. Just imagine an economy without roads or telephones to think about the impact that infrastructure has on productivity. A number of authors, going back to Arrow and Kurz (1970) have modeled this idea by introducing public capital directly into the production function as a complement to private capital. Investment in infrastructure thus will tend to raise production given the level of private capital and employment. It will also raise the marginal product of private capital (and possibly also of labor), thus raising the incentive to invest. Likewise, declines in the stock of publicly provided infrastructure, at least when they are not offset by an increase in privately provided infrastructure, will tend to lead to declines in output and investment. If poor and middle-income countries cut back investment in infrastructure and we assume the stocks of developed countries are held fixed, this should lead to a decline in their steady-state levels of income and thus to an increase in world dispersion of incomes.

The argument is indeed simple, but is it true? Is there evidence of substantial effects of infrastructure investment on productivity and growth? And can the decline in infrastructure investment in less-developed countries account for a significant fraction of growing world disparities?

The rest of the paper will attempt to answer these questions. Section 2 will tackle the existing empirical evidence. As in many fields of applied economics, the evidence regarding the effects of infrastructure on productivity and growth is open to multiple interpretations, and analysis of the same data has led some economists to conclude that this effect is very large and others to conclude that it is nonexistent. Section 2 will attempt to make sense of this debate and to understand why there is so much disagreement.

Section 3 will then use a simple aggregate production function framework to understand the quantitative magnitude of the possible links between infrastructure and growth. We will use the range of estimates derived from our theoretical survey of the literature to estimate the effect of infrastructure investment on income dispersions.

The conclusions of that section are somewhat disappointing for advocates of an infrastructure hypothesis to account for growing income divergences. My estimates imply that at best changes in public investment have been a minor contributor to the gap between rich and poor countries, accounting for no more than 12% of the increase, and possibly much less. However, the majority of estimates do point towards a positive contribution of infrastructure trends to growing dispersion, suggesting that it may be part of the explanation, though far from being the primary factor.

2. Is public investment in infrastructure relevant for private sector productivity?

Any attempt to link trends in infrastructure provision with broader trends in per capita incomes must start out from a discussion of the vast amount of empirical research linking these two forces. Theoretically, the idea that public capital can have an effect on productivity growth and capital accumulation goes back at least as far as the theoretical models of Arrow and Kurz (1970) and Ogura and Yohe (1977). These authors considered a production function of the form

$$Y = F(G, K) \tag{1}$$

where G is the public capital stock and K is the private capital stock.[2] It is straightforward to add labor to this production function to obtain the more commonly used specification (see, e.g., Barro, 1990):

$$Y = F(G, K, L) \tag{2}$$

with L denoting aggregate employment. Two key questions emerge from this framework that are of relevance to our study. The first one is about the magnitude of F_G: how large is the expected effect on aggregate output from increasing the provision of public capital? The second one is about the magnitude of the cross-derivatives F_{KG} and F_{LG}, which will tell us how strong are the compementarities between public capital and private capital or employment. To the extent that private capital accumulation is endogenous, as it is in most growth models, then F_{KG} will influence the growth rate of the economy and its steady-state. Since a positive value of F_{KG} raises incentives for the accumulation of

[2] Previous to the work of these authors the common assumption had been that public and private capital were either substitutes or that their effects were independent. See the discussion in Ogura and Yohe (1977).

physical capital, studies of its magnitude are often framed within the context of disentangling the existence of crowding-out vs. crowding-in effects.

a. Evidence from the United States

Empirical studies of the relationship between public investment and productivity growth were rare before the late eighties. A series of studies by David Aschauer (1989a, 1989b, 1990) changed this. Aschauer argued that the inclusion of public investment in a production function like (2) was key for understanding the behavior of US productivity. Indeed, Aschauer argued that fully 57% of the post-1970 US productivity slowdown could be explained by the decline of infrastructure investment during the same period, spurring talk of the deficit in infrastructure provision as "America's Third Deficit"

Aschauer's evidence was three-fold. In his first paper on this topic (1989a) he presented time-series evidence linking productivity growth between 1949 and 1985 and different types of public capital. He found that a measure of "core infrastructure" which included highways, mass transit, airports, electrical and gas facilities, water, and sewers had a highly significant effect on both labor and multifactor productivity. The decline in US infrastructure investment after 1970 had led, according to Aschauer's calculations, to a decline in TFP growth of 0.8 percent a year – a very large effect.

Aschauer's second and third papers (1989b,1989c) complemented this evidence with cross-sectional evidence from US states and with panel data from 7 OECD economies. The results of these studies were consistent with the time-series US evidence: infrastructure spending was found to have a significant positive effect on productivity.

The estimated returns to investment in public infrastructure were between two to five times the returns to private investment. Alicia Munell expanded on Aschauer's studies in two directions. In Munnell (1990a) she refined Aschauer's calculation by adjusting labor inputs to take account of changes in the age/sex composition of the labor force and updating the sample period. In Munnell (1990b) she proceeded to build state-level estimates of the public and private capital stock which had been previously unavailable (Aschauer had used public investment). She used this data to estimate state-level production functions, finding again a significant effect of public investment on productivity growth, albeit with somewhat smaller quantitative effects. She also estimated the effect of public investment on private investment, to test whether the former crowded-out the latter or not. It turned out that the complementarities in the estimated production function were so large so as to generate significant "crowding-in" effects through which the provision of greater public capital led to greater private productivity and greater public investment.

The results of Aschauer and Munnell's research generated considerable excitement and immediately spilled over into discussions in the policy arena. The US Council of Mayors called for a massive increase in infrastructure spending in a 1992 report. Bush Transportation Secretary Samuel Skinner and New Jersey Governor James Florio made similar calls.[3] The Clinton-Gore campaign seized on this political consensus by making its $20 billion "Rebuild America" program of massive infrastructure investments the centerpiece of its economic plan (Clinton and Gore, 1992).

Almost simultaneously, however, a number of economists started questioning the Aschauer and Munnell results. Critics raised three basic objections. In the first place, it

[3] See the discussion in Munnell (1992).

appeared that the Aschauer-Munnell results implied implausibly high rates of return for investment in public capital. In the second place, it was argued that the time-series results could be due to spuriously coincident common trends. Third, increases in public capital stocks could be the result of higher public investment caused by higher income levels or by an omitted third variable, so that a positive relationship between public capital and productivity could be the result of misspecification of a more complex process possibly involving reverse causation.

The first point was made forcefully by Gramlich (1994). He noted that the Aschauer elasticity estimates implied rates of return on public investment as high as 100%. In this logic, public investment would basically pay for itself. But if this was true, asked Gramlich, would private investors not "be clamoring to have the public sector impose taxes or float bonds to build roads, highways, and sewers to generate these high net benefits?" Although he admitted that such clamor was "hard to measure", Gramlich argued that if anything what could be observed was quite the contrary: private investors were more often heard arguing that tax rates were, if anything, too high.

The second point was made by a number of critics, and paralleled a general preoccupation with the pervasiveness of spurious trends in econometrics that followed on Granger and Newbold's (1974) article pointing out the invalidity of standard t-tests to evaluate the relationship between non-stationary variables. Aaron (1990), Hulten and Schwab (1991), Jorgenson (1991) and Tatom (1991) all made this point. Hulten and Schwab (1991) and Tatom (1991) also argued that if one first-differenced the data, thus doing away with any common trends that could cause a spurious relationship, Aschauer's estimated positive and significant effect of public investment on productivity disappeared. Tatom (1991) went one step further and tried to discern whether there was indeed a long-run relationship between public capital and productivity using the appropriate methodology for seeking such relationships between non-stationary variables: by testing for the existence of a cointegrating relationship. He found no evidence that such a long-run relationship existed. Tatom (1993) also tested for Granger causality to discern whether change in the public capital stock preceded changes in productivity. His evidence pointed to reverse causation: while neither changes in the public capital stock nor investment were found to Granger-cause productivity growth, TFP was found to Granger-cause changes in the public capital stock and public investment rates.

The third objection was raised by Holtz-Eakin (1994). This author revisited the Aschauer-Munnell results with the use of panel data on state-level gross-state product data as the dependent variables and Munnell's (1990b) public sector capital stocks. The key distinction between Holtz-Eakin (1994) and previous studies is that the latter controlled for state-specific effects. Holtz-Eakin (1994) showed that Hausmann specification tests reject the hypothesis that the state-effects are uncorrelated with the regressors, making OLS or random-effects estimates of the productivity-infrastructure link biased and inconsistent. Once one controls for state-specific effects. Holtz-Eakin shows, the productivity-infrastructure link disappears and in some specifications actually turns insignificantly negative.

By the mid-nineties, the pendulum had swung back and the critics of the infrastructure-productivity link appeared to have gained the upper hand. In a 1993 review article in the *National Tax Journal,* Hulten and Schwab argued that "the link between infrastructure and economic performance is, at the margin, **very weak.** Much of the research that followed David Aschauer's work provides little support for the hypothesis that the slowdown in infrastructure spending caused the economy to perform poorly over the last 20 years." (p. 271, emphasis in original).

But did these criticisms really demonstrate that infrastructure had no effect on private sector productivity? Let us look at them in turn. First, there is the argument that the estimated rate of return on public capital in the Aschauer and Munnell studies is implausibly high. This argument begs the question: too high with respect to what? How large would we expect an accurate estimate of this rate of return to yield? It is practically impossible to answer this question without a well-specified political economy model that allows us to understand how public decisions regarding the provision of infrastructure and other public goods are made. One thing is clear: public choice models that can account for an under-provision of public goods are not in short supply, going back at least to Hardin's (1968) "tragedy of the commons". In a recent analysis, Lizzeri and Persico (2001) show that electoral competition commonly leads to an underprovision of public goods, and that the US electoral system – the electoral college – is particularly prone to this bias. The reason is that, even if there are many efficient infrastructure programs lying around, politicians will often have much greater ability to target pork-barrel spending to constituents. The same reasons that make public infrastructure a pure public good – its non-rivalrous and non-excludable nature – also make it extremely difficult for potential beneficiaries to organize in order to pressure for its provision. This argument echoes Olson's (1971) argument about the lack of incentives for collective action to provide collective goods and is well-known in the political economy literature. The Virginia School of public choice emphasized precisely this element of public policy making: that collective decisions would commonly yield suboptimal outcomes.[4] The crux of these arguments is that there is a distinction between socially preferred outcomes and the outcomes that one will see agents defending in the midst of the political process. There is certainly no scarcity of examples of clearly mistaken policy choices that fly in the face of any assumption that governments choose expenditure levels optimally. Obviously, any estimate of a significant deficit in infrastructure provision must be backed by the belief in the existence of distortions in the policymaking process that leads to the underprovision in infrastructure. Likewise, those who, like Gramlich (1994) assert that the estimated rate of returns are implausibly high have in mind a political economy model in which grossly inefficient policy choices are not feasible. Which model is more plausible is a question that one must in the end answer by looking at the data.

In contrast, the objection that Aschauer's results are due to spurious correlations is certainly correct: it is by now broadly recognized that one has little to learn from time-series regressions between non-stationary variables. At best, the Aschauer findings can be characterized as one data point: the coincidence of an increase in infrastructure spending and increasing productivity in the US time series, but not much more. The problem with this objection is that it is not clear that there are many ways in which one can extract much information from relatively short time series such as thise used by Aschauer or his critics. Suppose for example that there is a link between infrastructure and productivity, but that it has an uncertain and variable timing. It could take time for firms to learn how to take advantage of infrastructure improvements, and such timing may depend on the precise type of project and sectors that it affects. Estimating this complex relationship would require a correct specification of the underlying project and

[4] For a review, see Mueller (1999)

sector-specific relationships, which may be much more than can be achieved with existing data. In this case, a prolonged period of infrastructure improvements should be followed by a trend of growing productivity, and a collapse of infrastructure spending, if maintained over time, would lead to a decline in productivity. The simple time-series regression would capture this, and thus one would expect to get results similar to Aschauer's in this context. But one should not be surprised if a first-differenced regression such as that run by Hulten and Schwab (1991), which would simply test whether increases in infrastructure provision lead to increases in productivity in the same year, yields insignificant estimates. The spurious trends criticism is correct in throwing doubt on the inferences that can be drawn from the Aschauer-Munnell results, but they do not establish that the data is inconsistent with the hypothesis of a large effect of infrastructure spending on productivity. There may be no adequate way to draw valid inferences from this data given a small number of observations and a complex underlying economic structure.

In principle, the hypothesis of a long-run relationship between infrastructure and productivity could be appropriately dealt with by searching for a cointegration relationship as done by Tatom (1991). Using the Stock-Watson (1989) procedure for testing for cointegration relationships among variables that have different orders of integration, Tatom fails to find a significant effect of public investment in infrastructure on productivity. Does this imply that there is no long-run relationship between infrastructure and productivity? Not necessarily. One of the characteristics of conventional unit root and cointegration tests is that they tend to have very low power to reject alternative hypotheses under small samples. The Stock-Watson test, as well as other cointegration tests, is basically a multivariate extension of the Dickey-Fuller test for unit roots, which is well-known to have low power in small samples (Christiano and Eichenbaum, 1990, Rudebusch, 1993). In other words, these tests will yield few mistakes when there is a unit root (or when there is no cointegration) but can be mistaken with considerable frequency when there is no unit root (or when there *is* a cointegrating relationship). Since the traditional methods require first evaluating whether the variables in question have unit roots or not and then testing for a cointegrating relationship, they are prone to making two types of mistakes: finding that the variables in question are nonstationary when they are not (and thus leading to conclude that correlations among them are spurious) and tending to find that there is no cointegrating relationship when there is one (leading us to conclude no relationship between the variables when such an effect exists).

These low power properties of tests for nonstationarity tend to emerge in short samples. As sample length is increased, one often finds evidence for stationarity where the tests had previously tended to point towards nonstationarity (Shiller and Perron, 1985, Hakkio and Rush, 1991). For example, results that had found real exchange rates to be nonstationary and led to a rejection of the Purchasing Power Parity hypothesis were later overturned by studies using longer-term data spanning periods as long as two centuries (Lothian and Taylor, 1996). Given that Tatom used a 32-year period for his tests, it may be the case that the time period was simply too short to uncover existing relationships. Indeed, Kocherlakota and Yi (1996) use a longer data set going back to 1925 and do find a robust significant effect of public investment in structures on economic growth.

The third objection, based on the finding that existing correlations disappear when one controls for state-level fixed effects, could be much more serious. But such a conclusion is not rare in panel data studies of economic performance. Cross-national studies of economic performance often find that the introduction of fixed effects specifications often tends to produce very weak statistical results (Casselli, Esquivel and Lefort, 1999). The reason is that most of the variation in these data sets tends to come from the cross-sectional dimension. Therefore, it can well be the case that one gets insignificant parameter estimates not because the relationship does not exist, but because eliminating all the cross-sectional information leaves us with very little variation.

The use of state-specific effects in panel data studies reflects a preoccupation with omitted variables that might be correlated with the right-hand side variables. It is important to understand that if one wants to understand the **total** (as opposed to the partial) effect of infrastructure spending on economic growth, omitted variable bias is only a problem if one is worried that infrastructure spending is endogenous. To see why, suppose that we were sure that infrastructure spending is exogenous and we believed that increases in the provision of infrastructure led to higher degrees of innovation (perhaps by facilitating communication of ideas). If we were to control for innovation activity and were to find that the effect of infrastructure on productivity growth disappeared, that would only reinforce the evidence that there is a significant effect of infrastructure on productivity growth, and that it runs through the innovation channel. It is only if we believe that infrastructure could be caused by innovation activity, or if we thought that both of them were caused by a third variable, that we would be worried about the bias arising from omitting innovation.[5]

Therefore, it appears that centering directly on the issue of causality may have high payoffs if one wants to disentangle the possible channels operating in the infrastructure-productivity relationship. Fernald (1999) constitutes one of the most careful attempts to carefully estimate reverse causation effects in the study of the US growth-infrastructure link. Fernald starts out from a simple observation: if infrastructure were a significant force behind productivity growth, then we would expect the link between productivity growth and public capital to be greater for industries that use roads intensively. If the building of infrastructure were simply a reaction to income growth or if both were caused by a third factor, in contrast, the effect of road growth on productivity would be uncorrelated with road-intensity. Indeed, Fernald finds that when growth in the stock of roads increases, productivity increases disproportionately in industries that are intensive in the use of vehicles. Fernald's estimates indicate that the growth of infrastructure provision in the United States from 1953 to 1973 had an average rate of return of 104%, quite in line with Aschauer's original estimate. However, Fernald also finds that the rate of return decreased dramatically after 1973. Although he found that there was still a quantitatively and statistically significant positive effect of roads on manufacturing productivity, the effect of infrastructure investment in non-manufacturing productivity turned negative (albeit not significantly so) in the post-1973 period.

[5] In marginally more technical language, omitted variable bias emerges only if there is a correlation between the omitted variable and the included variable. But if the included variable is truly exogenous, this correlation can only reflect a causal effect of it on the omitted variable, and thus form part of the total (as opposed to the partial) effect of it on the dependent variable.

The most logical interpretation of Fernald's results appears to be related to the construction of the interstate highway network in the fifties and sixties. This network was largely completed by 1973, after which the productivity effect of further road building was likely to be negligible. Fernald's results would also explain the reason why studies such as Hotz-Eakin (1994) found no effect of infrastructure capital on productivity using cross-state data. The data used by Hotz-Eakin was only available for the post-1970 period, when the interstate highway system was by and large completed and for which the effect of infrastructure on growth was, according to Fernald, negligible.

An important implication of Fernald's results is that governments in less developed economies in which a network of national roads is lacking may have substantial gains from undertaking such a project. The fact that the US now has very low returns from infrastructure investment at the margin may be a reflection of the fact that it has invested a lot in the past, with substantial realized payoffs. From the standpoint of a poor country that does not have a national highway system, the relevant elasticity estimates would be the pre-1973 estimates, and the lack of such a system may be an important reason for its inability to converge to the level of income of rich countries.[6]

Another paper worth mentioning is Shioji (2001). This paper estimates conditional convergence growth regressions á-la Barro and Sala-i-Martin (1991) on a panel of US regions. The key distinction between his approach and Hotz-Eakin (1994) is that Shioji uses growth as the dependent variable and initial per capita income and the public capital stock as right-hand side variables. The convergence approach, however, allows for

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[6] Fernald's results also underscore the existence of non-linearities in the production function. Aschauer (2000) finds that allowing for this non-linearity radically changes the results: whereby linear estimates of production functions at the cross-state levels deliver an infrastructure effect that disappears when state-effects are introduced, the non-linear effect is robust to the introduction of state-effects and suggests that permanent changes in public capital are associated with permanent changes in economic growth.

estimation of the effect of a public capital stocks on the steady-state level of income, thus taking into account not only its effect on productivity but also its induced effect on GDP via higher private capital accumulation, an effect that is missed by conventional production function estimates. The convergence approach also serves to reduce the effect of certain types of endogeneity bias that arise from using endogenous capital stocks and labor inputs as right-hand side variables in the production function estimation.[7] What is interesting is that *despite controlling for regional fixed effects* Shioji obtains significant effects of infrastucture spending on productivity growth, with elasticity estimates of .08-.14 for the United States. These estimates, while roughly half the values of Aschauer's original elasticity estimate of .24, still imply considerable rates of return for public infrastructure investments of 20-35%. More importantly, the validity of Hotz-Eakin's (1994) claim that the infrastructure-productivity link depends on the omission of state fixed effects appears sensitive to the choice of specification.

As this literature evolved towards a more nuanced understanding of the relationship between infrastructure and productivity growth, the very facts that Aschauer had set out to attempt to explain changed. From 1995 to 2000, output per hour in nonfarm business grew at an average annual rate of about 2 ½ percent compared with increases of only about 1 ½ percent per year from 1973 to 1995. Olliner and Sichel (2003) find that advances in information technology as well as the greater use of IT capital more than account for this increase in productivity. The coincidence of these increments in productivity with the massive investment in the development of the internet, which had its origin as a government project in the US Department of Defence and which received a

[7] Both approaches are still subject to simultaneity bias arising from endogeneity of the pubic capital stock.

huge boost under the Clinton-Gore administration underscores the potentially high payoffs to public infrastructure projects (Blinder, 2000). While it may be true that it would make little sense to build another interstate highway system, as Fernald's work has made clear, that does not mean that the public sector has run out of socially productive infrastructure projects. In the words of Berkeley Lab's Tsu Loken (LBL,1993) "The federal government has a long history of investment in the nation's infrastructure. It built canals in the 18th century, railroads in the 19th century, and interstate highways in the 20th century. Then, about 10 years ago, it began the construction of high-speed computer networks. These networks are the highways of the Information Age."

b. Cross-National Evidence.

In contrast to the US literature, cross-national studies of infrastructure and growth often tend to find positive rates of return to infrastructure investment whatever the methodology used. Debate in this literature has centered on other issues such as the magnitude of the return and the wisdom of investing in infrastructure vis-à-vis other choices that may be faced by the government. The first and most common reference in this literature is Easterly and Rebelo's (1993) analysis of the relationship between economic growth and fiscal policy within the context of Barro-style conditional convergence regressions for a cross-section of countries spanning the 1970-88 period. The aim of the Easterly-Rebelo analysis was to give a picture of the relationship between fiscal policy and growth and it is often cited for its unexpected finding that higher tax rates are not systematically associated with higher growth rates. At the same time, Easterly and Rebelo found that public transport and communication investment was positively correlated with growth. The coefficient was very high and remained positive and significant in instrumental variables estimation, with an estimated elasticity of 0.16. The authors were somewhat puzzled by this high coefficient but mentioned that World Bank studies often found similarly high rates of return for transport and communications projects.

A contrasting view was proposed by Devarajan, Swaroop and Zou (1996). These authors start out from the observation that the finding of a positive coefficient for infrastructure in a production function or growth regression does by itself imply that raising infrastructure investment is an optimal policy. As long as infrastructure is imperfectly substitutable for other public goods, it may be the case that the government is already overinvesting in infrastucture. The authors address this point by looking at the effect of changing the composition of spending from infrastructure to current expenditures. Somewhat surprisingly, they find that this generally has a positive effect on growth, implying that infrastructure may be overprovided.

Both the Easterly and Rebelo (1993) and the Devarajan et al. (1996) findings related the growth rate to public investment rates. More recent work has concentrated on the relationship between growth and stocks of infrastructure. Sanchez-Robles (1998) found a significant effect on growth of a principal-components index of infrastructure stocks based on kilometers of railways and roads, energy capacity and number of telephones per capita. Easterly (2001) finds a similar effect for telephone lines. Demetriades and Mamuneas (2000) specialize to the analysis of OECD economies. Instead of estimating a reduced form growth equation they estimate a multi-equation model including a profit function, factor demand functions and accelerator equations.

Their framework allows them to distinguish between short-run and long-run rates of return on public capital. The short-run rate of return will differ form the long-run rate of return because of the endogenous adjustment of private capital and equilibrium prices. The short-run rates of return range from 11% in the United States to 27% in Italy, whereas the long-run rates are much higher, ranging from 29% in the United States to 38% in Italy. Roller and Waverman (2001) take a similar approach but concentrate on the effect of telecommunications infrastructure in OECD countries. They also find significant effects, particularly after a basic threshold of infrastructure provision is achieved.

Although most estimates of production functions or growth regressions at the cross-national level deliver positive effects of public infrastructure provision, the relevant policy question may not be whether infrastructure enters positively into the production function, but rather whether the return from increasing it outweighs its cost of provision. For example, Canning (1999) estimated the return to electricity generation and transportation routes to be no different from the private returns (although he did find that telephones per worker had a substantially higher return). He argues that this result raises doubts about the wisdom of financing infrastructure provision with distortionary taxation.

The evidence here appears to be somewhat mixed. Esfanhani and Ramírez (2003) estimate a multi-equation model of growth and infrastructure investments with separate equations for GDP growth and infrastructure capital accumulation. They find significant effects of infrastructure services to GDP growth which, in general, exceed the cost of provision of those services. The elasticity estimates are particularly robust and stable and imply elasticities between 0.08-0.10 for telephones and 0.13-0.16 for electricity generation. Calderón and Servén (2005) use a data set measuring infrastructure stocks and the quality of infrastructure services to evaluate the effect of infrastructure provision on growth. They use a variety of GMM estimators with lagged variables and some exogenous variables such as population density, urban population and labor force as instruments. They find statistically and economically significant effects of infrastructure provision on economic growth. To take one illustrative example, if infrastructure levels in Peru (which is at the 25^{th} percentile of infrastructure stocks in Latin America) were to rise to those of Chile (which is at the 75^{th} percentile) its growth rate would increase by 1.7 percentage points according to the Calderón and Servén estimates.

On the other hand, Canning (1999) and Canning and Pedroni (2004) have argued that there is evidence of overprovision of infrastructure in many developing countries. In both cases, cointegration methods are used to distinguish the effect of infrastructure on growth from the reverse causation effect. For example, Canning and Pedroni use an error-correction model to estimate the bidirectional causation effects, which is tantamount to identifying temporal precedence with causality – in the style of Granger causality tests. Their theoretical basis is a Barro (1990) style endogenous growth model with public goods with a fixed savings rate. They find no effect of infrastructure on long-term growth on average, although they do find that this is not true for all countries and that in some there is evidence of overprovision while in others there is evidence of underprovision.

Thus the evidence on infrastructure stocks parallels the earlier work on investment flows. On the one hand, there are a number of reduced form estimates that imply a positive effect of infrastructure provision on growth. On the other hand, a set of studies argue that infrastructure may be overprovided. Is there a way to make sense of these conflicting results?

The key source of differences in these results is that while the bulk of researchers have attempted to estimate the direct effect of increasing infrastructure provision, holding everything else fixed, on economic growth, Devarajan et al. (1996), Canning (1999) and Canning and Pedroni (2004) actually carry out a different exercise: to calculate the effect of reducing other types of expenditure to increase infrastructure investments. In the case of Devarajan et al. (1996), the experiment is to reduce other types of public expenditures which include education and health spending. This is obviously a much higher hurdle than that of simply evaluating whether public infrastructure spending is productive. The Canning (1999) and Canning and Pedroni (2004) exercises are different: they imply studying the effect of an increase in public capital *holding total investment constant*. In other words, they assume that any increase in the public capital stock is accompanied by an identical decline in the private capital stock. In Canning and Pedroni (2004), for example, this feature is built into the model by assuming a constant national savings rate, an element which is not a characteristic of the Barro (1990) model.

This gets back to the issue of crowding-out. Canning (1999) and Canning and Pedroni (2004) basically build crowding-out into their models. It is hard to see why this would be a sensible modeling assumption, particularly when evidence for such an effect is hard to find. For example, Ahmed and Miller (2000) actually find that public investment in transport and communications robustly *raises* private investment levels in the cross-national evidence. If public and private capital are complements, an increase in infrastructure will raise the rate of return on private capital and thus induce an increase in the stock of private capital. This effect could be substantial, particularly in an open economy. But even in a closed economy, if one were to use the simple assumption that the private (as opposed to the *national*) savings rate is constant an increase in public investment would lead to a reduction in private investment equal to the marginal propensity to save times the increase in public investment.

Although all of these studies attempt to deal with endogeneity, none of the solutions that they adopt are immune to criticism. Esfanhani and Ramírez address the issue through the specification of separate equations for infrastructure investment and growth, but many of their exclusion restrictions appear quite arbitrary from a theoretical point of view. Calderón and Servén's (2005) choice of demographic variables as instruments implies assuming that variables such as the urbanization rate and population density are excludable from the growth equation. Canning and Pedroni's (2004) method for identification, while apparently novel, relies on associating temporal variations with causality, even though the long gestation lags associated with many infrastructure projects would appear to imply that these are likely to have significant effects on expectations even before they are constructed.

In my view, it is unlikely that a satisfactory solution to the endogeneity problem will be found for estimation of the relationship between infrastructure and growth in the cross-country framework. Truly exogenous and excludable instruments are difficult to find in cross-country work in general, and it is hard to think of an exogenous source of cross-country variations in infrastructure stocks. Furthermore, even with appropriate instruments, the pervasive non-linearities which appear to be present in the cross-national data can wreak havoc with instrumental variables estimates (see Rodríguez, 2005).

Given the potentially relevant multidimensional interactions with other regressors in the relationship of infrastructure and growth, the linearity assumption seems somewhat hard to defend.

Finding successful answers to the endogeneity problem in these estimations may require shifting to careful analysis of the within-country evidence, as Fernald (1999) has done for the US. In a recent paper, José Pineda and I (Pineda and Rodríguez, 2005) have attempted to address the endogeneity issue through the use of firm-level data from the Venezuelan *Encuesta Industrial*. We take advantage of the 1994 creation of the Intergovernmental Decentralization Fund which allocated a portion of VAT revenues for infrastructure investment to state and local governments based on their initial development levels, total populations and land area. As this rule was held fixed over time, it generated variations in transfers to regions that depended on the interaction between the parameters of the rule and national VAT collection, both of which can be taken to be exogenous at the state level. This exogenous source of variation allowed us to estimate the effect of state infrastructure investments on firm-level productivity growth in Venezuelan manufacturing. Our elasticity estimates of .33-.35 are substantial. Curiously, they are remarkably similar to Fernald's estimate of .38 for the manufacturing industry in the US data.

c. Discussion

Empirical work on US and cross-country data is subject to multiple interpretations. Many well-known studies have obtained positive and significant effects of infrastructure on productivity. On the other hand, most of those studies have been the subject of extensive criticism, a great deal of which has been technically right. In my view, however, there are too many pieces of evidence that point towards significant effects that it is difficult to ignore, them. While it is true that one time series correlation is not much evidence of anything, the fact that the positive relationship emerges in many cross-sections, both within the US and at the cross-country level, could only be discounted with a very convincing endogeneity argument. I have yet to see that argument, and the attempts that have been made to take the case for endoegeneity seriously, such as Fernald (1999) or my recent work with José Pineda(2005), have not found substantial evidence that reverse causation is driving the relationship. Ultimately, however, the reading of the evidence must also rely on our basic understanding of the world and a fair bit of common sense. If it were true that public infrastructure were unproductive, one should be able to imagine a world with substantially lower levels of public infrastructure (e.g., the US without an interstate highway system) and argue that private capital would yield the same returns under those conditions than it does now. Personally, I find that kind of world very hard to imagine.

3. Per Capita Divergence and Infrastructure Stocks

The previous discussion has made clear that there are channels through which a collapse in the provision of infrastructure in developing countries can lead to growing divergence in per capita incomes across countries. We have seen that there are good reasons to read the empirical evidence as showing that public infrastructure provision enters positively in the production function. We also know that during the eighties, a number of developing countries implemented stringent fiscal adjustment programs that were associated with significant cutbacks in infrastructure provision. This fact has been emphasized in recent work by Easterly (2001) and Easterly and Servén (2003), who have argued that this type of adjustments end up being so costly in terms of foregone pubic revenues that they are actually not real but rather illusory adjustments. If we believe the evidence on the positive effect of infrastructure provision on productivity, we would expect this process of retrenching public sector investment in developing countries to have contributed to the observed divergence of per capita incomes across countries.

Does the empirical evidence support this story? We now turn to examining whether this is the case by attempting to calculate the extent of per capita income dispersion that could have been caused by changes in the distribution of infrastructure stocks across countries. Obviously, these calculations will depend on the magnitude of the elasticity of production with respect to infrastructure. In the limit, if we believe that this elasticity is zero or close to zero, as argued by Hotz-Eakin (1994), then the production function does not depend on infrastructure and variations in infrastructure stocks would have no effect on divergence. The purpose of this section is to explore whether the range of estimates presented in the literature, which go from this lower bound of zero to values around 0.3, would help in attributing an important role to infrastructure stocks in divergence of per capita incomes.

There is an initial difficulty with this argument. Despite the prevalence of fiscal adjustments that emphasized retrenchments in government investment in middle and low-income economies, the dispersion of per-worker infrastructure stocks across the world has not increased since the sixties. On the contrary, as we show in Figure 2, for most indicators of infrastructure stocks, inter-country dispersion has been declining substantially. It would thus appear on first sight that growing inequalities in infrastructure provision cannot be a cause behind growing inequalities in world incomes because the distribution of infrastructure provision has actually been growing *less* unequal.

Figure 3 gives an illustration of why this is the case. It plots the length of roads per square kilometer in six developing countries that experienced substantial decelerations in their growth of road infrastructure, together with the United States. As one can observe from the graph, while the group of developing countries saw its stock of infrastructure stagnate after the mid-eighties, so did the United States, so that the dispersion between these economies did not increase. Recall that the decline in infrastructure investment in the US was precisely what spurred Aschauer's original research on the productivity slowdown. This declining rate of infrastructure growth in developed countries is a more general feature: while the average annual growth rate of the stock of roads was 1.18% between 1960 and 1980, it fell to 0.87% between 1980 and 1995. When this is coupled with the fact that some regions, in particular East and South Asia, had significant increases in their growth rates of the stock of roads (see Table 1), one can understand why the dispersion of infrastructure stocks did not increase during this period.

Is this fact the nail in the coffin of an infrastructure-based explanation of increasing divergence? Not quite. A lower dispersion of infrastructure stocks does not necessarily lead to a lower dispersion of per capita incomes. The reason is that if the dispersion is reduced by increases in the provision of infrastructure in high-income countries that happened to start out with low infrastructure provision, then it could lead to higher inequalities in the world distribution of per capita incomes. In order to make this argument clear, it is useful to look at it more formally.

Let us start out from a Cobb-Douglas production function expanded to include the external effects generated by infrastructure:

$$Y = AG^{\beta} K^{\alpha} L^{1-\gamma} \tag{3}$$

where Y is GDP, G denotes the stock of public infrastructure capital, K the private capital stock, and L the labor force. Let us use as our measure of dispersion the standard deviation of logarithms:

$$s_y = \frac{\sum_i (y - \overline{y})^2}{N} \tag{4}$$

where we have let lower cases denote natural logarithms. Substituting (1) into (2) gives:

$$s_y = \left(\frac{\sum_i (y_i - \overline{y})^2}{N} \right)^{1/2} = \begin{pmatrix} \beta^2 s^2{}_g + \alpha^2 s^2{}_k + \gamma^2 s^2{}_l + \\ \beta\alpha \operatorname{cov}(g,k) + \alpha\gamma \operatorname{cov}(k,l) + \beta\gamma \operatorname{cov}(g,l) \end{pmatrix}^{1/2}$$

or:

$$s^2{}_y = \beta^2 s^2{}_g + \alpha^2 s^2{}_k + \gamma^2 s^2{}_l + \beta\alpha \operatorname{cov}(g,k) + \alpha\gamma \operatorname{cov}(k,i) + \beta\gamma \operatorname{cov}(g,l) \tag{5}$$

Where *cov(i,j)* denotes the square root of the empirical covariance between *i* and *j*. The evolution over time of s_y will be given by:

$$\begin{aligned} \frac{ds_y}{dt} &= \beta^2 \frac{s_g}{s_y}\frac{ds_g}{dt} + \alpha^2 \frac{s_k}{s_y}\frac{ds_k}{dt} + \gamma^2 \frac{s_l}{s_y}\frac{ds_l}{dt} \\ &+ \beta\alpha \frac{1}{2s_y}\frac{d \operatorname{cov}(g,k)}{dt} + \alpha\gamma \frac{1}{2s_y}\frac{d \operatorname{cov}(k,l)}{dt} + \beta\gamma \frac{1}{2s_y}\frac{d \operatorname{cov}(g,l)}{dt} \end{aligned} \tag{6}$$

As we can see, dispersion of incomes across countries will be influenced by changes in infrastructure provision through two effects. In the first place, changes in the distribution of infrastructure stocks will have a direct effect on s_y through changes in the dispersion of infrastructure stocks $\beta^2 \frac{s_g}{s_y}\frac{ds_g}{dt}$ But there will also be an indirect effect given by $\beta\alpha \frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,k)}{dt} + \beta\gamma \frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,l)}{dt}$ that depends on changes in the empirical covariances between infrastructure and other capital stocks. The aggregate effect will be:

$$\beta^2 \frac{s_g}{s_y}\frac{ds_g}{dt} + \beta\alpha \frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,k)}{dt} + \beta\gamma \frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,l)}{dt} \tag{7}$$

Note that this expression reflects the fact that an increase in the correlation between infrastructure and other factors of production will lead, *ceteris paribus*, to an increase in dispersions of pre capita incomes. To understand the intuition for this, imagine that there were high levels of inequality in infrastructure stocks but that countries with lower physical capital stocks tended to have greater levels of infrastructure. This would mean that countries that would tend to be poorer than average due to their capital stocks would be less poor because of their high levels of infrastructure. In the same way, declines in the correlation between capital stocks and infrastructure stocks imply that one is more likely to find cases of capital-poor countries with high infrastructure stocks, and thus to observe decreasing dispersion.

Are these offsetting forces enough to counteract the direct effect of falling dispersion? Figures 3 and 4 suggest that they may be. They display sustained increments in the correlations both between infrastructure stocks and physical capital stocks and between infrastructure stocks and labor force participation rates. In other words, it appears that for most indicators of infrastructure stocks both $\beta\alpha \frac{1}{2s_y} \frac{d \operatorname{cov}(g,k)}{dt}$ and $\beta\gamma \frac{1}{2s_y} \frac{d \operatorname{cov}(g,l)}{dt}$ are greater than zero, so that in principle it is possible for the total effect of infrastructure to be leadings towards higher dispersion of per capita incomes.

Table 2 shows the result of three calibration exercises in which we assume different values for β,α and γ to see whether the indirect effects do outweigh the direct effects. In particular, we set α=1/3 and β=2/3, as is standard practice. The reported results tend to be robust to different values of the capital and labor share. Given our review of existing empirical estimates of β, we expect it to be between 0 and 0.3, so that we use 0.10, 0.20 and 0.30 for our simulation (β=0 simply leads to zero effect as infrastructure becomes irrelevant for production). We consider six indicators of infrastructure stocks: telephone mainlines per 1000 workers, tehephone mainlines and mobile lines per 1000 workers, Gigawatts per 1000 workers, kilometers of roads per square kilometer, kilometers of roads and railroads per square kilometer, and the percentage of paved roads. The data are taken from Calderón and Servén (2005).[8] Capital stock estimates are from Butzer, Mundlak and Larson (2003) and labor force, population and per capita PPP GDP are taken from World Bank (2005).

As shown in Table 2, the direct effect $\beta^2 \frac{s_g}{s_y} \frac{ds_g}{dt}$ is always negative. This simply reflects the fact that, as shown in Figure 2, the dispersion of infrastructure stocks has been decreasing over time. The contribution of this direct effect ranges from between -

[8] We do not use waiting time nor generation and distribution losses because they are not available for all of our period.

0.16% and -0.41% for β=0.1 to between -1.12% and -3.73% for β=0.3. However, this is offset by the indirect effects $\beta\alpha\frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,k)}{dt}$ and $\beta\gamma\frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,l)}{dt}$, which are increasing in all but one case. For five of the six indicators, the total result is to predict an increase in dispersion between 1964 and 1994 when β=0.10 or 0.20. The picture is a bit more mixed as β=0.30 because the magnitude of the direct effect becomes much larger, so that in that case three of the six indicators actually predict a *decrease* in dispersion of per capita GDP levels arising from changes in the distribution of infrastructure stocks.[9]

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[9] The preceding argument has assumed that changes in the dispersion of the public capital stock have no effect on the dispersion of private capital stocks. However, as we have argued before, it is likely that changes in *g* induce changes in *k* so that we may be excluding an important source of variation in our calculations. How relevant this effect is will depend on the relative importance of changes in *g* in determining variations in *k*. For example, suppose that *g* is the *only* source of variations in *k*. Total dependence of *k* on *g* would emerge in a model with a constant private savings rate in which government spending is financed by a tax on consumption. The steady state condition would then be $k=\frac{1}{1-\alpha}(\ln(n+\delta)-\ln(sA)-\beta g)$ and the variance and covariance terms would be modified as follows:

$$\begin{aligned} s^2{}_k &= \sum_i \frac{(k_i-\bar{k})^2}{N} = \frac{1}{(1-\alpha)^2}\beta^2\sum_i\frac{(g_i-\bar{g})}{N} = \frac{1}{(1-\alpha)^2}\beta^2 s^2{}_g \\ Cov(k,g) &= \sum_i \frac{(k_i-\bar{k})(g_i-\bar{g})}{N} = \frac{1}{1-\alpha}\beta s^2{}_g \end{aligned} \quad . \tag{9}$$

Substituting and collecting terms give us an aggregate effect attributable to changes in *g*:

$$\beta^2\frac{s_g}{s_y}\frac{ds_g}{dt}+\left(\frac{\beta^2\alpha}{1-\alpha}+\frac{\alpha^2\beta^2}{(1-\alpha)^2}\right)\frac{s_g}{s_y}\frac{ds_g}{dt}+\beta\gamma\frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,l)}{dt} \tag{10}$$

Which is similar to (7) above but with $\beta\alpha\frac{1}{2s_y}\frac{d\,\mathrm{cov}(g,k)}{dt}$ replaced by $\left(\frac{\beta^2\alpha}{1-\alpha}+\frac{\alpha^2\beta^2}{(1-\alpha)^2}\right)\frac{s_g}{s_y}\frac{ds_g}{dt}$. But whereas the increasing correlation between *g* and *k* makes the former positive, the latter term now becomes negative because of falling dispersions of infrastructure stocks. In other words, given the empirical correlations that we see in our data (*dcov(g,k)/dt*>0 and ds_g/dt<0), allowing for induced accumulation actually lowers the predicted increase in dispersion, heightening the puzzle.

Even though many of the estimates point towards a positive contribution of changes in infrastructure stocks towards growing world dispersion of per capita incomes, all of the estimated effects are quantitatively small and do not speak for a major role of infrastructure provision in accounting for growing world inequality. Most of the estimates predict changes of less than one percentage point in the standard deviation of log incomes, and the highest estimate is of only 2.38 percentage points. But the increase plotted in Figure 1 for this time period is of 21.59 percentage points. In other words, even with the most optimistic assumptions, changes in the distribution of world infrastructure capital stocks could account for approximately one-tenth of changes in the world dispersion of incomes.

4. Conclusions

This paper has reviewed the empirical evidence supporting the assertion that the collapses in infrastructure investment that occurred during the eighties and nineties in many developing countries are a major force behind growing disparities in world incomes. While we have argued that the empirical evidence supports the existence of a positive effect of infrastructure provision on productivity and growth, we find little evidence that the retrenchments in infrastructure provision have played a major role in growing disparities. The basic reason is that most developed countries also experienced a deceleration in their accumulation of infrastructure stocks during this period, allowing some developing countries to catch up and others not to fall behind in terms of infrastructure provision. Although there are some channels through which changes in the distribution of infrastructure stocks have contributed to growing dispersion of world incomes – in particular the growing correlation between infrastructure provision, capital abundance and labor force participation – our calculations indicate that at best infrastructure has been a minor contributor to the growing divergence in living standards across the world.

These results should not be taken to imply that developing countries should view investment in infrastructure as unimportant in a strategy for catching up with richer economies. We have argued that a balanced reading of the empirical evidence leads to the conclusion that infrastructure provision does have a significant effect on living standards and productivity. Even if decelerations in the rate of accumulation of infrastructure stocks have not been the culprit of growing dispersions, policies centered on infrastructure provision could play a major role in reversing this tendency.

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Table 1: Key Infrastructure Indicators as a percentage of leading region

Telephone Mainlines per 1000 workers	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**1990**	**1995**
Developed	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
East Asia	7.60%	10.17%	14.46%	18.84%	24.74%	29.86%	35.51%	41.06%
Eatern Europe and Central Asia	13.21%	14.90%	17.82%	21.12%	23.72%	29.39%	36.76%	46.98%
Latin America	17.31%	15.92%	15.06%	14.17%	14.00%	15.24%	17.54%	23.56%
Middle East and North Africa	15.26%	19.22%	21.36%	23.21%	28.67%	32.14%	35.43%	39.82%
South Asia	0.94%	0.94%	0.90%	0.88%	0.96%	1.17%	1.68%	3.05%
Sub-Saharan Africa	2.95%	2.65%	2.43%	2.30%	2.41%	2.62%	3.05%	4.31%
Telephone Mainline and Mobile Phone Lines per 1000 workers	1960	1965	1970	1975	1980	1985	1990	1995
Developed	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
East Asia	7.60%	10.17%	14.46%	18.84%	24.69%	29.72%	36.03%	43.47%
Eatern Europe and Central Asia	13.21%	14.90%	17.82%	21.12%	23.67%	29.02%	35.09%	39.09%
Latin America	17.31%	15.92%	15.06%	14.17%	13.98%	15.04%	16.88%	20.94%
Middle East and North Africa	13.10%	15.13%	16.16%	17.85%	23.51%	26.50%	29.97%	28.90%
South Asia	0.94%	0.94%	0.90%	0.88%	0.96%	1.15%	1.61%	2.46%
Sub-Saharan Africa	2.95%	2.65%	2.43%	2.30%	2.41%	2.58%	2.93%	3.94%
Gigawatts per 1000 workers	1960	1965	1970	1975	1980	1985	1990	1995
Developed	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
East Asia	7.43%	9.29%	12.35%	15.09%	18.25%	23.35%	26.42%	31.45%
Eatern Europe and Central Asia	31.27%	33.60%	37.71%	41.47%	45.10%	51.97%	49.13%	43.15%
Latin America	15.44%	15.93%	18.66%	19.57%	21.18%	24.58%	26.00%	26.06%
Middle East and North Africa	19.77%	19.27%	22.98%	31.65%	45.02%	51.81%	54.90%	53.38%
South Asia	1.30%	1.58%	1.57%	1.67%	1.98%	2.93%	3.54%	3.65%
Sub-Saharan Africa	4.17%	3.54%	3.45%	3.52%	3.85%	3.85%	3.42%	3.12%
Roads per sq. km	1960	1965	1970	1975	1980	1985	1990	1995
Developed	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
East Asia	47.47%	54.33%	57.51%	59.67%	64.15%	70.35%	73.59%	77.45%
Eatern Europe and Central Asia	54.82%	65.86%	64.86%	61.14%	59.81%	62.02%	69.92%	74.41%
Latin America	14.95%	16.15%	18.21%	20.59%	21.52%	22.22%	21.91%	21.31%
Middle East and North Africa	7.51%	8.35%	9.38%	9.82%	11.46%	13.07%	13.35%	13.94%
South Asia	12.15%	14.63%	16.26%	17.67%	18.85%	20.97%	22.90%	36.36%
Sub-Saharan Africa	11.06%	12.01%	11.84%	11.75%	12.02%	12.22%	12.17%	12.11%

Table 1: Key Infrastructure Indicators as a percentage of leading region (Continued)

Roads and Railroads per sq. km	1960	1965	1970	1975	1980	1985	1990	1995
Developed	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
East Asia	22.25%	32.70%	40.73%	44.24%	50.59%	57.32%	60.14%	63.69%
Eatern Europe and Central Asia	30.32%	40.01%	41.59%	40.24%	40.77%	41.52%	46.15%	48.69%
Latin America	2.90%	3.28%	3.63%	3.94%	4.47%	4.66%	4.75%	5.03%
Middle East and North Africa	8.84%	10.00%	10.96%	11.18%	12.15%	13.21%	12.79%	13.52%
South Asia	14.09%	14.09%	14.32%	14.99%	16.25%	17.33%	18.12%	24.10%
Sub-Saharan Africa	6.63%	8.96%	9.39%	8.59%	8.25%	8.02%	7.90%	7.87%

Inverse of Waiting Time	1960	1965	1970	1975	1980	1985	1990	1995
Developed				98.44%	99.02%	99.49%	100.00%	100.00%
East Asia				99.41%	98.71%	99.21%	97.43%	97.79%
Eatern Europe and Central Asia				95.10%	92.88%	90.65%	90.89%	93.81%
Latin America				98.77%	98.02%	97.58%	97.71%	98.93%
Middle East and North Africa				99.02%	98.60%	98.30%	97.38%	95.98%
South Asia				99.14%	98.12%	96.15%	92.66%	90.38%
Sub-Saharan Africa				100.00%	100.00%	100.00%	99.95%	99.49%

One minus fraction of Generation and Distribution Losses	1960	1965	1970	1975	1980	1985	1990	1995
Developed			100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
East Asia			97.82%	96.91%	96.96%	96.32%	96.58%	97.91%
Eatern Europe and Central Asia			99.64%	99.55%	98.69%	98.07%	97.08%	96.25%
Latin America			96.54%	94.91%	93.33%	90.88%	89.19%	89.31%
Middle East and North Africa			98.66%	97.18%	96.71%	96.37%	97.41%	96.49%
South Asia			85.35%	83.12%	84.33%	84.48%	85.43%	86.15%
Sub-Saharan Africa			98.64%	99.12%	96.42%	95.51%	94.50%	94.54%

Paved Roads as % of Total Roads	1960	1965	1970	1975	1980	1985	1990	1995
Developed	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
East Asia	53.13%	58.76%	63.65%	61.31%	62.66%	63.63%	66.25%	67.22%
Eatern Europe and Central Asia	45.30%	51.25%	53.02%	55.13%	58.80%	57.59%	57.41%	55.90%
Latin America	28.67%	26.82%	27.21%	25.83%	26.03%	26.55%	29.06%	31.19%
Middle East and North Africa	95.02%	96.80%	85.88%	84.36%	85.28%	81.90%	80.33%	78.28%
South Asia	80.32%	73.09%	67.71%	74.24%	68.80%	66.01%	64.00%	58.43%
Sub-Saharan Africa	14.99%	17.09%	20.12%	22.37%	24.08%	24.88%	26.06%	25.54%

Table 2: Estimated Effects of Dispersion in Infrastructure Stocks on World Dispersion of per capita incomes, 1965-94

Calibrated Change	*Divergence in Infrastructure*	*Correlation with Capital Stocks*	*Correlation with Labor Force Participation*	*Total Effect*	*Increase in World Dispersion*	*Percentage Attributable to Infrastructure*
Beta=0.10						
Telephone Mainlines	-0.16%	0.68%	0.43%	0.95%	21.59%	4.39%
Telephone Mainlines + Mobile Lines	-0.12%	0.73%	0.44%	1.04%	21.59%	4.84%
Gigawatts	-0.15%	0.38%	0.23%	0.46%	21.59%	2.15%
Roads	-0.21%	-0.01%	0.13%	-0.09%	21.59%	-0.41%
Roads and Rails	-0.39%	0.59%	0.26%	0.46%	21.59%	2.12%
Paved Roads	-0.41%	0.83%	0.29%	0.71%	21.59%	3.30%
Beta=0.20						
Telephone Mainlines	-0.62%	1.35%	0.85%	1.58%	21.59%	7.33%
Telephone Mainlines + Mobile Lines	-0.50%	1.47%	0.87%	1.84%	21.59%	8.51%
Gigawatts	-0.59%	0.77%	0.45%	0.63%	21.59%	2.94%
Roads	-0.84%	-0.02%	0.26%	-0.60%	21.59%	-2.77%
Roads and Rails	-1.55%	1.17%	0.52%	0.14%	21.59%	0.64%
Paved Roads	-1.66%	1.66%	0.59%	0.60%	21.59%	2.76%
Beta=0.30						
Telephone nes	-1.40%	2.03%	1.28%	1.91%	21.59%	8.83%
Telephone Mainlines + Mobile Lines	-1.12%	2.20%	1.31%	2.38%	21.59%	11.03%
Gigawatts	-1.32%	1.15%	0.68%	0.51%	21.59%	2.36%
Roads	-1.90%	-0.03%	0.39%	-1.53%	21.59%	-7.09%
Roads and Rails	-3.49%	1.76%	0.78%	-0.96%	21.59%	-4.43%
Paved Roads	-3.73%	2.50%	0.88%	-0.35%	21.59%	-1.61%

Figure 1: Standard Deviation of log per capita incomes, 1960-2001

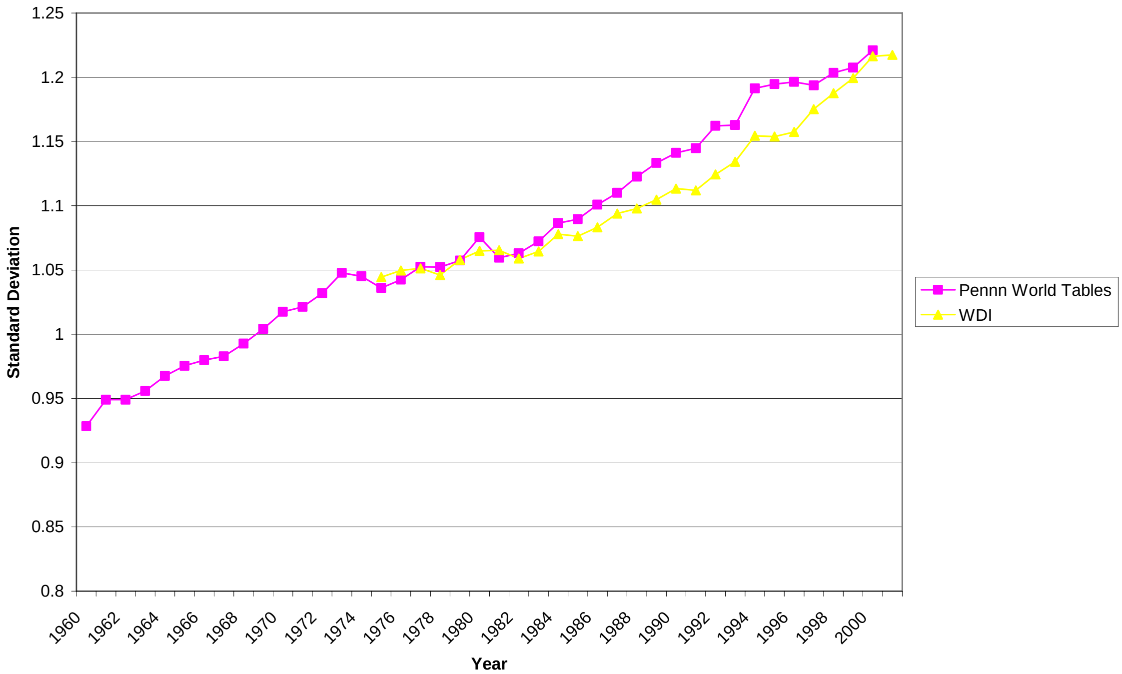

Figure 2: Dispersion in Infrastructure Stocks

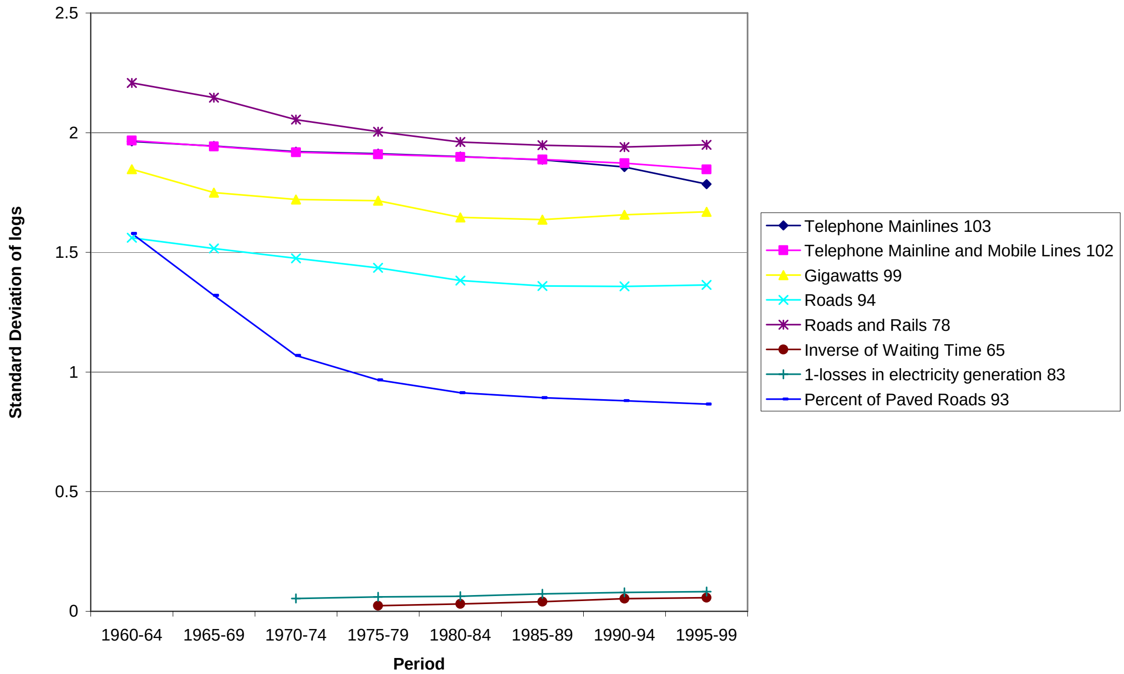

Figure 3:Roads per sk. km, 1960-2000, Selected Countries

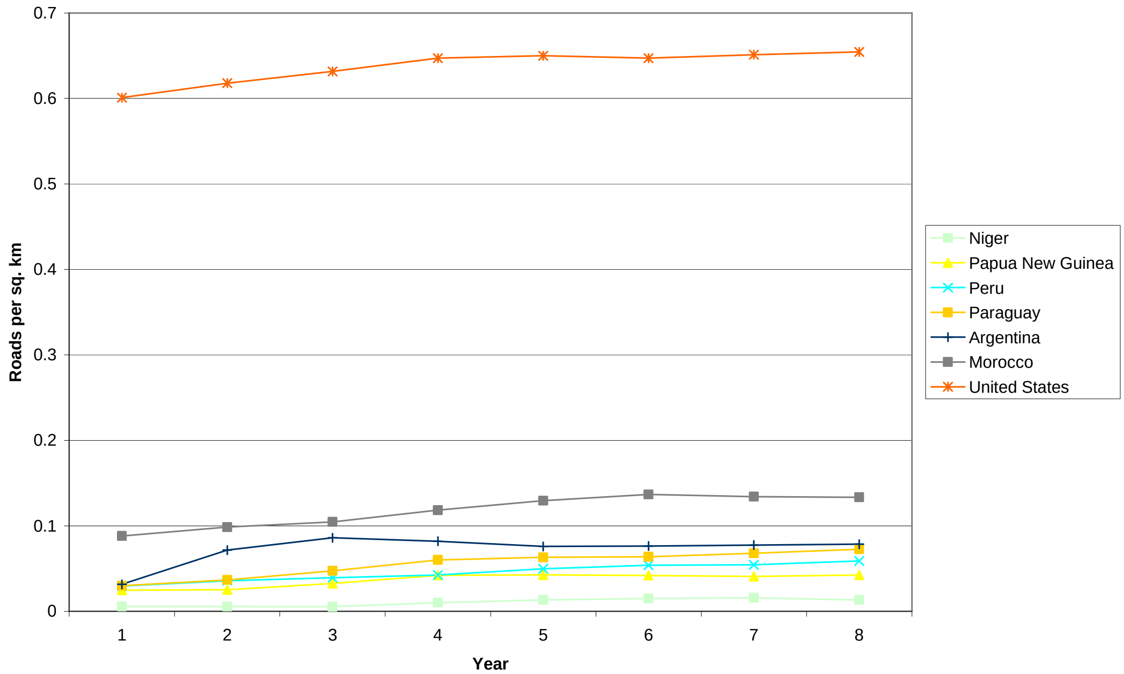

Figure 4: Covariance between logs of infrastructure and physical capital stocks

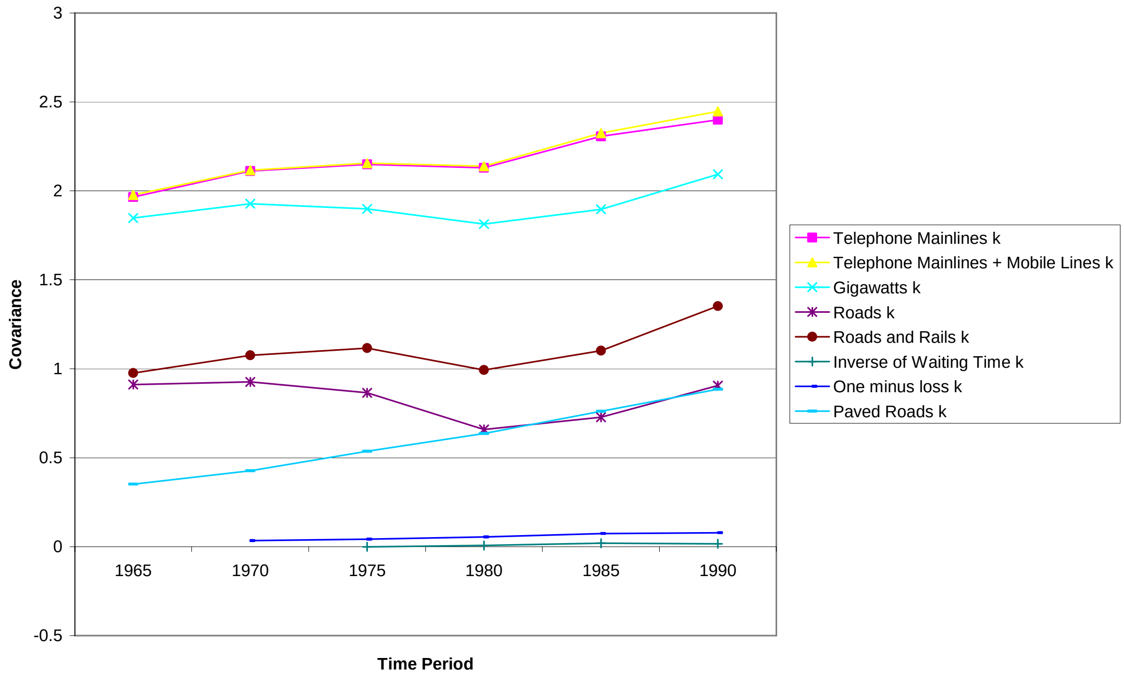

Figure 5:Covariance between Infrastructure Stocks and Labor Force Participation