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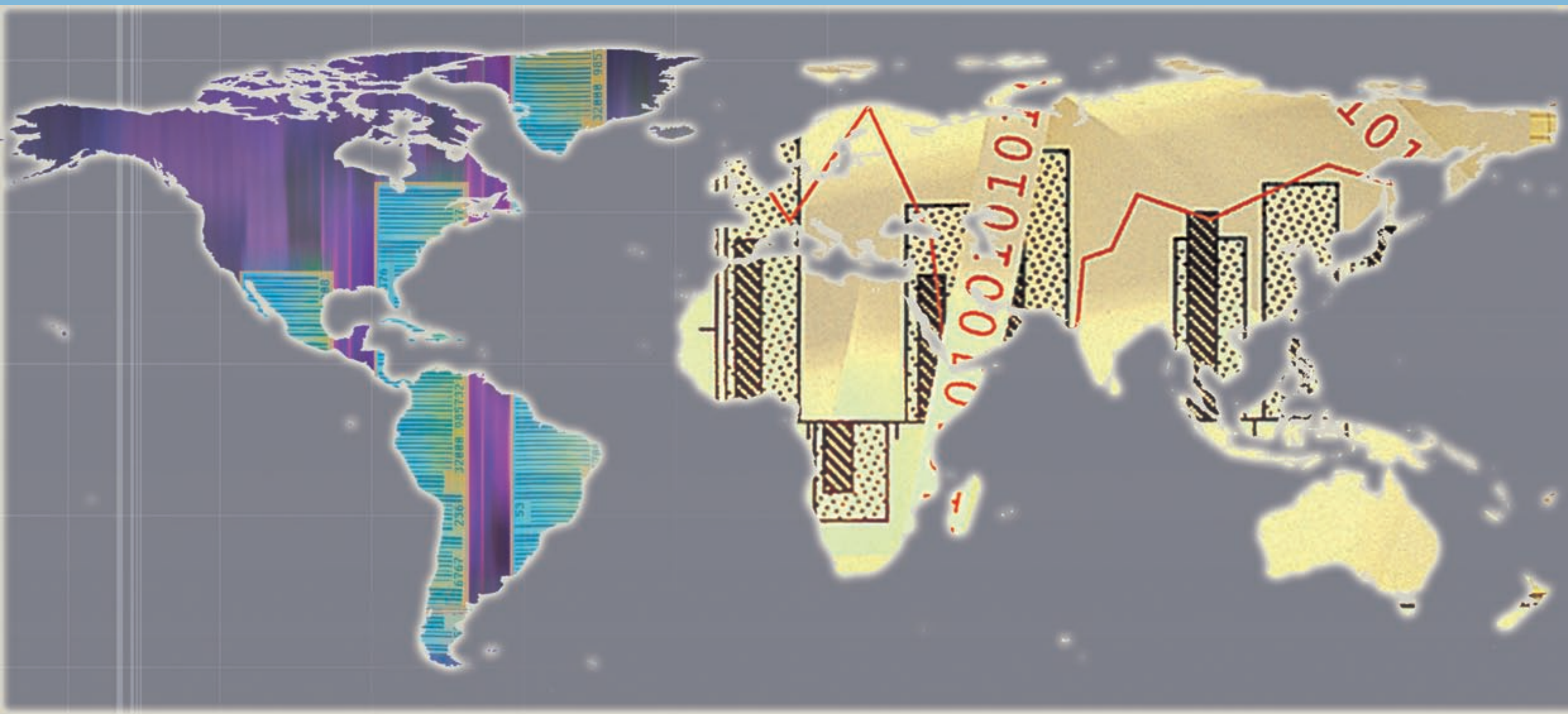

Energy Infrastructure and Industrial Development

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Anders Isaksson
Research and Statistics Branch
Programme Coordination and Field Operations Division
UNIDO

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Abstract

The purpose of this paper is to estimate the importance of energy infrastructure on cross-country differences in manufacturing levels as well as differing rates of industrialization. It addresses statistical issues such as reverse causality, endogeneity bias and omitted state-dependent variables. In addition to estimating the impact for the sample as whole—79 countries observed from 1970 to 2000—the sample of countries is divided into four groups, based on income levels to proxy for different stages of development. In addition, a group of Asian fast-growers is examined. The results indicate that energy infrastructure in an economically meaningful way helps to explain why some countries have managed to industrialize while others have been less successful. Energy infrastructure is positive and significant across all income groups as well, but, as expected, there are important differences. The impact is greatest for the poorest economies and fast-growing Asian tigers. Energy infrastructure also offers an explanation for differing industrial growth rates.

Keywords: Energy infrastructure, manufacturing, industrial development, cross-country regression.

JEL Classification: C23; D24; H54; L60; L94; N60; O14

1. Introduction

Much of today's prosperity rests on secure and stable access to energy. Without requisite energy infrastructure, modern production grinds to a halt, as can be witnessed in parts of the developing world. Africa is a case in point. For example, only one in four Africans has access to electricity. Yet, less than five per cent of the continent's hydropower potential has been tapped. Evidence on the dependence on energy was also clear from the recent oil price peak in 2008, which spurred innovative activities to come up with alternative energy sources.[1]

With few exceptions, countries that are rich have become so through industrial development, notwithstanding the fact that most of the industrialized countries are already focusing on services, rather than manufacturing. Compared with agriculture and services, manufacturing production is relatively energy-intensive, which implies that industrialization increases demand for energy and, thus, a need for adequate energy infrastructure. From this, the conclusion emerges that some countries are rich while others are not because the former have managed to ensure their access to energy by building infrastructure.

Why is energy important? The most direct role of energy is that of an input to production. In effect, a world without electricity amounts to non-mechanized production. While erratic supplies of electricity disrupt production, voltage fluctuations negatively affect the durability of machines. Better electricity-related infrastructure can, thus, raise the efficiency and durability of physical capital. Furthermore, economic growth and development are closely linked to embodied technological progress and capital accumulation.

Electric utilities combine the services of infrastructure networks with inputs of capital, labour and fuels and sell the output directly to other industries. The unpaid infrastructure inputs are converted to a paid factor of production in the downstream industry. Improvements in the quantity and quality of the infrastructure network

[1] Another example is Latin America, for which Calderón and Servén (2004b, a) show that the continent lags behind the international norm in terms of quantity and quality of infrastructure and that infrastructure is an important determinant of GDP per capita growth.

upstream appears as a cost reduction of the intermediate purchases of electricity downstream or as an improvement in the quality or scope of these services.

In Barro's (1990) seminal endogenous growth paper, government expenditure is introduced as a public good in the production function. The effect is to increase the rate of return to private capital. This, in turn, stimulates private investment and growth. Estache (2006) argues along similar lines. The more sectors that are linked to electricity power generation—such as banking sector—the more important it is for overall output and development. For example, electricity problems mean that output in banking and construction decreases, which has a negative impact on financing and construction of new dams and power plants, which, in turn, reduces energy infrastructure further. Hence, linkages between sectors generate a multiplier effect through which productivity problems are amplified. This is true for other complementary inputs as well, but not all of them are equally important to deal with in terms of their damage to production (Jones, 2008).

One effect of this is to force misallocation of resources to compensate for the low productivity in electricity power generation. This also has consequences for other sectors' ability to accumulate sufficient capital. Reinikka and Svensson (2002) illustrate this in the case of Uganda. Ultimately, the effect depends on the share of energy in gross output, in which it tends to be increasing.

However, the impact of energy goes beyond such direct effects. Agénor and Moreno-Dodson (2006) and Agénor (2009) provide examples of several channels not previously discussed or highlighted in the literature. An indirect effect of energy infrastructure is to provide citizens with education and health services, which, in turn, affect productivity. Access to electricity reduces the cost of boiling water as well as improves hygiene and health. In addition, hospitals are highly dependent on electricity. Electricity increases opportunities to use electronic equipment (e.g., computers) as well as study time, which improve learning. The effect on health and education are also interdependent in that better health increases school attendance and learning ability, and better education increases public awareness and capacity to address health needs. Although education and health issues, on the one hand and sectoral linkages to banking and construction, on the other, appear more important for developing countries, they are central to the question as to why industry levels differ.

Another way to assess the importance of energy infrastructure is to consider what happens when it does not exist or is dysfunctional in terms of providing access to many users and ensuring stable supply. A recent World Bank (Foster, 2008) project on infrastructure found that, in Africa, energy resources are concentrated within a few countries, whose capacity to supply power-deficit markets is hindered by physical and financial barriers to cross-border trade, while their economies are too small for them to develop fully those untapped resources. Furthermore, most African energy markets lack the size to reap the efficiencies of large-scale electricity production.

The power generation capacity in sub-Saharan Africa (SSA) is equivalent to that of Spain. But excluding South Africa reduces the capacity to that of Argentina or one-third of South Asia. A quarter of the region's plants are inoperative. In 1970, SSA had almost three times as much electricity-generating capacity per million persons as South Asia, with similar per capita incomes. Three decades later, South Asia had left SSA far behind, with nearly twice the electricity-generating capacity. The worst situation is for the power sector in Africa, which delivers only a fraction of that found elsewhere in the developing world. Many state-owned utilities barely cover operating costs, requiring state subsidies, which burden the budget. Operating and maintenance costs absorb three-quarters of total spending. Moreover, Africa faces both higher electricity prices and operating costs than other regions (Foster, 2008). Andres *et al.*, (2008) report that, according to the World Bank's investment climate assessments, 55 per cent of survey respondents in Latin America and the Caribbean considered infrastructure to be a major or severe obstacle to the operations and growth of their business. Problems with electricity and transport services especially deter foreign direct investment and export participation.

Electrification attempts in Africa in the 1970s and 1980s largely failed. In some countries, dictators pillaged power stations for parts and fuel, while in others power stations were built but not maintained. Turbines were run at full capacity until they broke and, then, were abandoned. In SSA, concentration tends to be too small, reducing access to electricity. In 2002, for example, access to electricity was estimated at 24 per cent of the total population, compared with 48 per cent in peer low-income countries (Auriol and Blanc, 2009).[2]

The consequences include power outages that average 56 days annually costing manufacturing firms five to six per cent of their revenue and leading to low firm productivity. To compensate for lack of electricity, many firms invest in their own generators. However, small- and medium-sized enterprises (SMEs) cannot afford generators, leading to lost revenues of as much as 20 per cent.[3] At macro level, the implication is deteriorating growth. Another example is India, for which Fernandes and Pakes (2008) show that firms in states suffering from electricity outages experience considerable production losses, as well as being less productive than the average in those states. In addition, capital and labour are more below their optimal levels than in states with less production losses from outages.

This paper focuses on that conclusion. More specifically, an attempt is made to estimate if access to energy is an important explanatory variable for cross-country differences in levels of manufacturing production and, if so, to gauge how important it is. Answering this provides a long-term view of industrial development and, to an extent, of its role for the overall income level. A related but temporally different question is whether increase rate of investment in energy infrastructure triggers faster industrial growth. In other words, do countries that invest more in such infrastructure also experience more rapid industrial development?

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[2] The authors' model suggests that, at low profitability segments, private companies should provide electricity services because the social cost for such provision is too high, which means the alternative is no services at all. At profitable segments, public utilities dominate, however at highly subsidized rates and, thus, prices charged are too low. This leads to losses among public utilities, which, in turn, imply low investment and poor general provision of services. Only the wealthy are served, but they represent a fiscal burden on all.

[3] Some of the references on the impact of unreliable power on the cost of production and welfare losses include Kessides (1993), Lee and Anas (1992), Adenikinju (2005) and Foster and Steinbuks (2009). The last study reports that the extent of own generation in Africa is slightly higher than in the United States and actually lower than in the enlarged European Union. However, in three countries in Africa, own generation accounts for more than 25 per cent of installed capacity, while, for nine others, the figure is between ten and 25 per cent. This is a phenomenon particular to low-income countries and those countries focused on natural-resource industries.

Most empirical work on the impact of infrastructure use public capital as a proxy. This is reasonable if one is concerned with infrastructure as a whole. However, if the focus is a certain aspect of infrastructure, such as energy, public capital needs to be replaced by some other indicator. In this paper the capacity to generate electricity is used to proxy for energy infrastructure. Furthermore, the variable on which the impact is assessed is usually some aggregate measure, for example GDP or labour productivity. Few papers focus on the relation between output and energy infrastructure at sectoral levels. The implication is that of drastically reducing the volume of previous work that is directly comparable to the question posed here. This paper, therefore, contributes to a meagre literature by shifting the focus from the total economy level to manufacturing and linking that to the impact of energy infrastructure.

The results suggest that both answers are affirmative of the notion that energy infrastructure and its growth are important for explaining cross-country level differences in industry and the pace of industrial development. The impact is economically meaningful and reflects the important complementary role that energy plays for production. While the policy implications for countries trying to catch up with the leaders may seem obvious—that is, it is productive to invest in energy infrastructure—they have to be compared to alternative investments that may have higher rates of return. Nevertheless, there is some evidence that for relatively poor countries investment in energy infrastructure is worthwhile, while for already industrialized economies such investments may not be as urgent compared with the alternatives.

The paper, then, proceeds with a review of the limited empirical literature on the impact of energy infrastructure on manufacturing (Section 2), discussion of the empirical model used in this paper (Section 3) and descriptive discussion of the data used in Section 4. The econometric results are analyzed in Section 5, while Section 6 concludes the paper.

2. Review of the empirical literature

The empirical literature on the impact of infrastructure on output and productivity tends to focus on the one hand, on public capital and, on the other, aggregate performance indicators such as GDP growth. There is little work on direct measures of energy infrastructure and sectoral performance. While the literature on public capital and GDP growth is vast, in this section, the review concentrates on studies where energy infrastructure and performance indicators are present.

Aschauer's (1989) paper on public capital and GDP growth in the United States essentially marks the genesis of the literature.[4] The discussion and subsequent attempts to resolve those issues was essentially triggered by the large estimated elasticity that he obtained. The implication was that an investment would pay for itself in less than two years. While some researchers (e.g., Munnell, 1992) found support for Aschauer's results, many others questioned them. For example, Gramlich (1994) in his review of the literature asked why, with such a large return, everyone not begins to invest in infrastructure.

Others related the large estimate to questionable econometric practices. The large estimate could, for example, stem from failure to account for omitted state-dependent variables, reverse causality and non-stationary data. Hence, the correlation between public capital and GDP would be spurious. But inflated estimates might be expected because of externalities and network effects, at least at more disaggregated levels. The question is how large an estimate is acceptable.

Canning and Pedroni (2004), covering 43 countries from 1950 to 1992, address the issue of spurious regression and reverse causation by testing whether output per capita and energy infrastructure are co-integrated. They find that this is the case but that causation runs in both directions. Furthermore, they also find cross-country heterogeneity in terms of causality—in some countries causation is bi-directional, while in others it is uni-directional—but not regarding the sign of the long-run parameter. On average, the estimated value is close to zero and, statistically actually insignificantly different from zero, but positive. Clearly, this result differs markedly from large estimates, such as that obtained, for example, by Aschauer. Another result is that countries tend to be close to the optimal level of energy infrastructure, albeit

[4] His analysis was later extended to cross-country samples of developing countries (Aschauer, 2000) and Mexico (Aschauer and Lachler, 1998).

with some evidence of under-provision in some countries. The observed heterogeneity suggests the need also to examine country groups. In this paper, the issue of country groups is revisited, on the implicit assumption that their co-integration result also holds for manufacturing.

Unlike the former paper, Esfahani and Ramírez (2003) develop a structural model of infrastructure and output growth that takes into account institutional and economic factors that mediate in the infrastructure-GDP interactions. The data cover 75 countries, from 1965 to 1995, which are used in decadal averages providing a maximum of three observations for each country. They find that the contribution of power and telecom services to GDP is substantial—with implied elasticity ranging from 0.13 to 0.16—and generally exceeds the cost of provision of these services. However, the realization of this potential depends on institutional and economic characteristics, which affect steady-state asset-GDP ratios as well as adjustment rates when asset-GDP ratios diverge from their steady-state.

The steady-state elasticity of infrastructure with respect to total investment is greater than one, that is, countries that manage to invest more do so particularly in infrastructure sectors. In other words, factors that prevent countries from investing at high rates tend to hinder particularly investment in infrastructure. Among those is government credibility, which affects growth mainly by speeding up the rate of adjustment rather than the steady-state asset-income ratios. This means that in the long run governments can manage to invest in infrastructure; in the short and medium run, this is more difficult and might require external assistance.

Hulten and Isaksson (2007) suggest that at different stages of development different kinds of infrastructure are important for explaining differences in income and productivity levels, that is, they are interested in addressing cross-country heterogeneity. To this end, for 112 countries between 1970 and 2000, they regress total factor productivity levels on, *inter alia*, electricity-generating capacity. They divide the countries into five groups, according to the World Bank's income classification, assuming that income levels provide an adequate proxy for development stage. In addition, they create two groups of fast-growing economies, the original four East Asian tigers and second-generation Asian fast growers including China and India.

For the sample as a whole and based on the fixed-effects estimator, energy infrastructure is positively related to TFP, with a coefficient of 0.12. In other words, a 10 per cent increase in energy infrastructure is associated with a 1.2 per cent increase in TFP. For country groups, the OLS estimator produces positive, but not always statistically significant, coefficients for all country groups. By contrast, the fixed-effects estimator yields very different results. First, the parameter is statistically significant only at income levels starting from lower-mid, which, as expected, falls with increasing income. This result points to the existence of possible threshold effects suggesting that the impact is greater for developing countries. Secondly, the parameter is negatively signed for both groups of rapid Asian fast-growers, and significantly so for second-generation tigers. The notion of differing impact of energy infrastructure at different stages of development is appealing and is taken up in the present paper too.

In a recent study on South Africa, Fedderke and Bogetic (2009) investigate the impact of energy infrastructure, measured as gigawatt hours of generated electricity. The authors distinguish between direct and indirect effects, where the former concerns labour productivity growth and the latter total factor productivity growth, both based on value added production functions. The data they use are aggregate and three-digit manufacturing sector data with observations from 1970 to 1993. Only results for the manufacturing sector will be reported here.

Based on instrumental-variables regression, generally, the authors find that the elasticity of labour productivity with respect to energy infrastructure is higher than in the non-instrumented case, i.e., instrumentation tends to inflate the estimates, while the expectation might have been the opposite. The elasticity of power generation is 0.06 and statistically significant. In other words, a 10 per cent increase in power generation boosts labour productivity by 0.6 per cent, which is not a very large effect.[5] In the case of TFP growth, the elasticity is only 0.04. This suggests that energy infrastructure in South Africa does not seem to exert a strong influence on productivity.

Based on Barro (1990), Noriega and Fontenla (2005) develop a model for Mexico where public and private capital are complements. Evidence for the role of electricity-generating capacity is, then, sought by way of time series econometrics—bivariate vector autoregression—and long-run derivatives from 1950 to 1994. The impulse-response analysis shows that shocks to energy infrastructure become positive after two to three years and have a significant effect on real output per worker only after seven. This effect proves to be permanent for the time horizon of the 20 years under consideration. In the case of Mexico, the impact of energy infrastructure becomes evident only after a rather long lag. If generalized to other countries, a contemporaneous regression might not be able to capture the effect.

Using principal components analysis, Calderón and Servén (2004) construct an infrastructure composite consisting of information on telecommunications, electricity-generating capacity and roads for 121 countries between 1960 and 2000. In addition, they construct an indicator of infrastructure quality services based on waiting time for telephone main lines, percentage of transmission and distribution losses in the production of electricity and share of paved roads in total roads. They, then, regress growth of GDP per capita on a set of controls and the two infrastructure composites employing several estimators including their preferred GMM-systems estimator of Blundell and Bond (1998). They also consider each of the infrastructures individually. Independent of estimator, the stock of infrastructure enters significantly, with a positively signed coefficient, while the quality composite is only significant in one case but with a clearly smaller parameter. Electricity-generating capacity alone is also

[5] This is much smaller than what the authors obtain for the aggregate economy, in which the elasticity ranges from 0.2 to 0.5 depending on specification. The reason for the difference is probably the important role that the mining sector plays in South Africa.

statistically significant, but its significance seems to be sensitive to the inclusion of roads and railways. Power quality is statistically insignificant.[6]

Moving from macro to micro data, Dethier, Hirn and Straub (2008) survey the Business Climate Survey Data to explain enterprise performance in developing countries. Their study covers as many as 55 enterprise surveys. Of electricity, telecommunications and transportation, electricity emerges as the most serious infrastructure problem, especially in the poorest countries. Electricity constraints decrease in perceived severity as GDP per capita rises. This result seems to be true for Guatemala, Honduras and Nicaragua as well as in five Eastern European countries, but not in China, where technological infrastructure constraints are more important.

However, the latter result is contradicted by Dollar, Hallward-Driemeier and Mengistae (2005), which find that power losses have a significantly negative effect on productivity in Bangladesh, China, India and Pakistan. Reinikka and Svensson (2002) show that in Uganda, private investment, employment and probability to export are negatively related to power interruptions, except when firms own their generators.

One paper that focuses on both energy infrastructure and manufacturing is that by Hulten, Bennathan and Srinivasan (2003). The authors analyze the Indian manufacturing sector from 1972 to 1993 and try to isolate the role of spillovers, or network externalities on productivity. The measure of energy infrastructure is electricity-generating capacity. Increasing the capacity at one point in an existing system may have effects throughout the entire network by extending critical links or removing bottlenecks.[7] Their approach centres on total factor productivity rather than real output and is inspired by the work of, for example, Hulten and Schwab (1991). If such extensions or removals lead to expansion of product and factor markets, economies of scale and scope, competition and specialization, productivity may

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[6] Calderón (2004) repeats the exercise for 93 countries for 1960-2005 for the composites of infrastructure stock and quality and essentially confirms the results of Calderón and Servén (2004).

[7] On the other hand, unless bottlenecks are attended to congestion, could be seen as representing a negative externality as the number of users increase.

increase. These effects occur outside the market place and are not mediated by prices and, thus, are external to firms on the network.

Using the fixed-effects estimator, the authors find an externalities-elasticity of 2.4 per cent—1.9 per cent when including highways as well—for the whole time period in the base model.[8] When extending this model to allow for spillover across state boundaries, the elasticity increases to 6.8 per cent. The gross marginal product of energy infrastructure is much below that of private capital suggesting that the estimated impact is not exaggerated. However, when accounted for in a sources-of-growth framework, the effect is 30 per cent of total productivity when simultaneously accounting for roads, which is considerable.[9] Finally, the authors surmise that the effect of infrastructure investment and attendant externalities depends on the degree of development of the network, where a greater effect is expected in a relatively undeveloped network.

Adenikinju (2005) and Lee and Anas (1992) rely on firm-level data to show that a considerable percentage of Nigerian firms regard power and voltage fluctuations as major obstacles to their operations. In fact, in terms of business obstacles, electricity takes first place. Power failure or voltage fluctuations occur several times a week, each lasting for some two hours, without prior warning. Costs imposed on firms include idle workers, spoiled materials, lost output, damaged equipment and restart costs. To counter these costs, private firms provide electricity, but this increases set-up costs for manufacturing firms. Evidence suggests that manufacturing plants in Nigeria spend on average nine per cent of their variable costs on infrastructure, with electric power accounting for half. Cost shares are higher for small firms, for which private infrastructure provision is as much as 25 per cent of physical capital costs. This would seem to be in line with Escribano, Guasch and Pena (2008), who argue that, in most SSA countries, 30-60 per cent of the adverse effects on firm productivity is caused by deficient infrastructure. Of this amount, for half of the countries, the power sector constitutes 40-80 per cent of the infrastructure impact.

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[8] This is the impact over and above the direct effect of infrastructure on manufacturing productivity.

[9] The term total productivity is used because the calculation is done within a gross output rather than value added framework.

To summarize, macro as well as micro studies appear to show that energy infrastructure is important for GDP growth and, in a few cases, for manufacturing. There are serious econometric issues involved in estimating the impact and papers seem to address one or several of those. Except for Hulten and Isaksson (2007), no study considers differences in stage of development, although Canning and Pedroni (2004) demonstrate that cross-country heterogeneity may be significant. No study directly examines the long-run determinants of industry or growth of industry.[10] These are the issues that this paper addresses.

3. Modelling industrial development

The econometric growth literature is well known and has produced a plethora of possible determinants correlating with growth. However, it is impossible to account, at the same time, for all of the variables relevant for some countries or period of time. By first analyzing the importance of energy infrastructure for levels of manufacturing, an approach is to connect to the levels literature.

This literature seems to have evolved partly in response to the problems faced by growth econometrics as well as to the wish to better understand long-term development. It has given rise to an intense discussion on which long-term, or deep, determinant is the most important. The contenders in this respect are, primarily, measures of institutions or institutional quality (e.g., represented by Acemoglu, Johnson and Robinson, 2005), geography (e.g., Sachs, 2003), human capital (e.g., Glaeser et al, 2004) and international integration, the last often in the form of trade (e.g., Frankel and Romer, 1999). In addition to these controls, the literature on structural change and industrialization (e.g., Lewis, 1954 and Hirschman, 1958) emphasizes linkages between manufacturing, or modern, and agriculture, or traditional, sectors as well as within manufacturing.

[10] Because of industry's prominent role in furthering total-economy growth, one may argue that analysis focused on GDP growth implicitly covers industry. While this probably holds true, such studies fail to isolate the impact of energy infrastructure on manufacturing growth, which is bound to differ from both growth of GDP and that of other sectors.

Starting with deep determinants, increased human capital leads to improved productivity, both in sectors and overall. It allows for operating more complicated tasks and producing outputs with "high-skill" contents. Human capital implies positive externalities along the lines of Lucas (1988). Foreign direct investment (FDI) tends to locate in human capital rich places. Benefiting from FDI knowledge externalities and technology transfer requires that domestic firms have sufficiently high human capital levels, i.e., absorptive capacity. Widespread human capital also increases the scope for new technologies to be, in the words of Basu and Weil (1998), appropriate. Industries unable to learn, adopt and adapt new techniques and technologies will be unable to move up value chains.

Institutions and their quality play a major role in development. Unless ownership of property used as collateral, or the ensuing property from investment, can be secured, incentives to invest will be thwarted and investment held back. To this end, impartiality of courts is crucial. Institutions reduce the uncertainty of economic interaction, increasing market efficiency and promoting long-term large investments (North, 1990). Also, Rodrik *et al.*, (1994) discuss how institutions can create incentives that lead to innovation and new technologies. Many of such activities are intrinsic to manufacturing production, drive industrial development and, thus, increase the contribution of industry to aggregate productivity performance. The role of institutions for industrialization is highlighted in, for example, Botta's (2009) model on structural change and economic growth.

Countries without coastline or sea navigable rivers find it relatively difficult to develop. Likewise, location in the tropics or disease-stricken areas entails similar difficulties. This indicates that geography influences industrial development. One may conjecture that the direct impact of geography on industrial development is probably smaller than on agriculture, since manufacturing is much less intensive in its use of land. However, industry suffers indirectly through its linkages with agriculture. Through proximity to buyers, geography, also affects exports, with the longer the distance being in inverse proportion to the export opportunity. Furthermore, geographic conditions, such as topology, may hinder the transport of goods to market.

International integration, which here is proxied by manufacturing exports, represents another determinant. Limited domestic markets hinder industrial development in many developing countries. Opening up to exports and creating export opportunities offer scale effects. Moreover, producing at larger volume helps firms to reap the benefits of economies of scale by, for example, being able to lower unit costs of material by buying large amounts or producing at minimum efficient scale. Although evidence is limited, there seems to be some scope for learning from exporting, at least for low-income countries (Bernard et al, 2007). In addition, competition with foreign producers may force domestic firms to become more efficient. Working with customers in industrialized countries may give access to knowledge externalities. Earning foreign exchange increases the ability to import capital goods and materials from abroad at international prices that may be lower than those offered at home.

One of the determinants often overlooked is the role of agriculture in furthering industry, with statistical links between the two sectors apparently the norm, rather than the exception. On the one hand, improved agricultural productivity can be viewed as releasing resources, especially labour input, to manufacturing. Jorgenson (1961) and Sachs (2008) state that without technological progress in agriculture, a modern sector might not even prove viable. Only when agricultural productivity is high—implying that a farm family can feed many urban citizens so that not each resident has to feed itself—can a significant share of the population become urbanized and engage in manufacturing production. Agriculture can, then, be seen as *pushing* industrial development. However, if migration leads to food production shortages or the two sectors' marginal productivities converge, agricultural growth may actually constrain that of manufacturing (Fei and Ranis, 1961).

A sectoral link can also develop because manufacturing productivity exceeds that of agriculture and, therefore, *pulls* labour out of the latter sector. The "standard" view holds that the marginal productivity of labour in the leading modern sector is higher than in the laggard one. This occurs because of the unlimited supply of labour available to agriculture rendering its marginal productivity low and, sometimes negligible. Labour, therefore, has a wage incentive to migrate from agriculture to manufacturing allowing the latter to grow further and develop the economy (Lewis, 1954). Whichever effect dominates, the link between the sectors has to be accounted for.

There are additional reasons for linking the two sectors. In agriculture-based economies, the agricultural sector's exports provide foreign exchange, which can be used to import material and capital goods for industry. Furthermore, with a functioning banking sector, successful agricultural savings can be channelled into and invested by industry. Redistribution of agricultural surplus can also be taxed and provided as support to manufacturing. Industrialization also increases demand for agricultural goods (Johnston and Mellor, 1961). Agriculture is also a client of manufacturing, with fertilizers, for example, being important inputs for agricultural production. Backward linkages are, thus, important. A slow-growing agricultural sector can act as a drag on manufacturing. The expected estimated coefficient is, therefore, not unequivocally positive. While agricultural performance and industrial development are linked, it is beyond the scope of this paper to sort out the causal direction of the link as well as whether that link is positive or negative.[11]

3.1. Econometric modelling strategy

In several instances the large estimated infrastructural impact has been explained with econometric flaws. Among the more common complaints are spurious correlation due to non-stationary data that do not co-integrate, infrastructure being endogenous with respect to the variable being explained, causality running from, say, GDP in the direction of infrastructure rather than from energy infrastructure to GDP and omitted variables.

[11] Alvarez-Cuadrado and Poschke (2009) find evidence in support of manufacturing-led structural transformation. By contrast, Awokuse (2009) uses a multivariate causality framework in a panel setting, to support the notion that agriculture is an engine of economic growth, suggesting that agricultural labour productivity should be driving manufacturing performance. Pinstrup-Andersen and Shimokawa (2006) discuss how insufficient infrastructure is one of the key bottlenecks for utilization of agricultural research and technology, by limiting farmers' options and agricultural output. With good rural infrastructure, economic returns to research and technology tend to be high.

One way to address spurious correlation is by estimating the relation between manufacturing and energy infrastructure using first differences. This is, for example, the approach of Hulten and Schwab (1991). Although applying first differences indeed addresses non-stationarity in the data, it removes the long-run relation between the variables of interest. More specifically, instead of estimating the impact of increasing the stock of energy infrastructure on, for example, industry, it is the impact of increasing the growth rate of infrastructure on industrial development that is estimated. In other words, the analysis shifts from levels and long-term to one of growth and short-term. Unfortunately, there is no reason to believe that the short-term impact should be the same as that of the long-term.

Instead of using first differences, one may apply co-integration techniques, which allow for estimation of long-term relations (see, for example, Canning and Pedroni, 2004). In this paper, the results obtained by Canning and Pedroni (2004) are exploited in the sense that their results are assumed to hold true, that is, manufacturing and energy infrastructure are assumed to cointegrate.

The second serious critique levelled concerns reverse causality, i.e., that the estimated relation shows that higher income leads to increased investment rather than the opposite or, at least, the estimated coefficient includes bi-directional causation. That the coefficient becomes inflated because of bi-directionality seems reasonable to expect. Related to this, energy infrastructure may be endogenous with respect to industry, so that industry is an explanatory variable of energy infrastructure, in addition to any causal concerns. This paper devotes significant efforts to test and account for the endogeneity of energy infrastructure.

This can be done in several ways. Calderon and Serven (2004) apply SYS-GMM in a growth framework to account for endogeneous infrastructure and find that the relation is robust to such adjustment. Another example is Fernald (1999), who uses the Seemingly Unrelated Regression Estimation (SURE) technique and concludes that transport infrastructure, at least in the case of the U.S., relates significantly to output.

Some researchers, for example Holtz-Eakin (1994), have used simpler panel data estimation techniques, such as the fixed-effects (FE) estimator, to investigate the relation. One advantage of the FE estimator is that it takes into account the effect of omitted variables that may be correlated with infrastructure. Failing to do so affects the estimated coefficient. Moreover, because energy infrastructure is likely to be tax-financed, richer countries tend to have bigger stocks of such infrastructure. To some extent, FE helps mitigate the adverse consequences of endogeneity bias, for example, if foreign aid used to finance public investment is allocated predominantly to the poorest developing countries. But there is a problem with the FE estimator in that it only estimates the within country relation. As such, it ignores statistical variation between units, which, in some cases, is the most relevant.

This paper attempts to account for both between and within variation, while addressing endogeneity bias, reverse causation and omitted variables. To tackle the former, FE and random-effects (RE) estimators are employed. The other issues are dealt with by application of instrumental variables (IV) versions of FE and RE. These estimation methods are applied to levels and growth regressions. The country-specific effects can be interpreted as omitted initial conditions, for example, the initial stock of infrastructure and other variables included and excluded such as geography or cultural traits, or, more generally, as a way to account for the initial development level.

This paper hypothesizes that the marginal effect of energy infrastructure is larger for relatively poor countries. The notion underlying this hypothesis is that when the stock of infrastructure is small, which is the case in low-income countries, each additional investment of infrastructure is relatively large. For example, if there is only one power station, adding another implies a 100 per cent increase, while in developed economies another power station could imply a marginal increase. Based on the assumptions of diminishing returns to scale and, for simplicity, that the level of infrastructure is proportional to that of income, the estimated impact of energy infrastructure on manufacturing should decrease linearly as income increases. To examine whether this is, indeed, the case, the approach of Hulten and Isaksson (2007, 2008) is followed. That is, the group indicator applied is the income level in year 2000, which leads to what they term meta-countries. These meta-countries are: high income, upper-mid income, lower-mid income, low-income and tigers, where the last distinguishes the first- and second-generation Asian fast-growers.

To give an initial impression, the first estimation is a simple OLS of manufacturing value added per capita on a set of explanatory variables:

$$MVApc_{it} = \beta' X_{it} + \lambda' Z_{it} + \varepsilon_{it}\ , \tag{1}$$

where X is a vector including agricultural labour productivity, manufacturing exports, human capital, institutions and trend to represent overall technological change, Z is a vector of energy infrastructure and ε the standard i.i.d. residual.[12]

Thereafter, to account for country-specific effects and omitted variables, (1) is estimated by RE and FE:

$$MVApc_{it} = \beta' X_{it} + \lambda' Z_{it} + \eta_i + \varepsilon_{it}\ , \tag{2}$$

where the additional parameters η_i represent unobserved country-specific effects, fixed or random. Although it is well-known that the RE estimator may implausibly assume that the country-specific effects and explanatory variables are uncorrelated, the strength of the estimator is that it provides an estimate that weighs in cross-country variation. Therefore, it seems reasonable to apply both estimators.

The possibility that infrastructure Z_{it} is endogenous is acknowledged and addressed by way of IV versions of (2). The vector Z_{it} is, then, replaced with the fitted counterpart $\tilde{z}_{it}$

$$MVApc_{it} = \beta' X_{it} + \delta' \tilde{z}_{it} + \eta_i + \varepsilon_{it}\ . \tag{3}$$

[12] Geography is excluded because its effects are captured by the country-specific effects when applying panel-data techniques.

The instrument vector I_{it} includes variables suggested and found reasonable by Canning (1998), which are lags 1-3 of population and urban population density, as well as the growth of them. In addition, the other assumed exogenous explanatory variables are included in I_{it}. In the levels regression, lags 1-3 of energy infrastructure growth are included, whereas in the growth regression lags 1-3 of energy infrastructure level are used. The choice of lag length is arbitrary but kept low to preserve degrees of freedom, but also because it does not make much sense to use higher order.

Equations (1) to (3) are also estimated in growth form to answer whether growth of energy infrastructure helps explain industrial development. Although first differencing removes the need to account for state dependent factors, it does not necessarily follow that the FE estimator becomes redundant. The reason to continue using the estimator is the wish to account for the effect of initial conditions. For example, the initial income level differs across countries and could have an impact on subsequent growth performance.

How good are the instruments? As often is the case, it is possible to argue that some of the external instruments chosen are, indeed, correlated with manufacturing growth. For example, structural transformation often goes hand-in-hand with manufacturing growth *and* urbanization. However, the level of urbanization or population should not present such a problem in the FE estimation, since the country-specific effects should account for that. Population growth and rate of urbanization should, to a lesser extent, be correlated with the *level* of manufacturing, although one may conceive of a situation where relatively rich countries have a slower growing population as well as high manufacturing per capita.

Easterly (2009) argues that population size is not necessarily a bad instrument because there is a small-country bias in foreign aid such that smaller countries receive more aid on a per capita basis as well as more aid as a ratio to their income. Because aid is often used to fund large infrastructure projects in developing countries, at least for IV-regressions involving such countries, population size might actually work well. Easterly claims that the literature has been unable to show that population has any scale effect for economic growth—for which manufacturing ought to be significantly important—which gives some additional support for using population as an instrument.

The initial parsimonious instrument vector is too large to be valid and needs to be reduced. Therefore, the final instrument vector used is decided through a sequence of tests. In the first, all instruments and three lags of each are included. The error from this regression is included in a second regression, to test for its statistical significance using a simple t-test. Statistical significance at conventional levels suggests whether infrastructure is endogenous. If, in the first step, the residual is statistically insignificant and neither the t-test nor the f-test is statistically significant, the test process stops and infrastructure is deemed exogenous.

To decide whether an instrument is valid, each variable and lag is tested one by one, where statistical significance at a t-value of at least 3.30 is required. In addition, lags 1-3 of each variable are jointly tested (e.g., lags 1-3 of population), as are all lags of each variable (e.g., the first lag of each instrument). In this case, the f-value needs to exceed 10 (Hill, Griffith and Lim, 2008). In each step, the vector of instruments is tested using Sargan's over-identifying test. After each instrument reduction, the entire procedure is repeated. The final step is to ensure that, in the first stage regression, the instruments chosen are all statistically significant.

To reduce the scope for errors—after all there are strong priors that infrastructure is endogenous—a stronger condition as to whether energy infrastructure is exogenous is imposed. This is done by continuing the test procedure with those instruments that are statistically significant at conventional levels but have t-values below 3.30. In fact, there are only a few cases when the original test procedure erroneously leads to the conclusion of exogeneity. But when that occurs infrastructure is taken to be endogenous, although the standard test procedure suggests otherwise.

What may be missing from the empirical model is the role of dynamics. For example, past manufacturing production may be an important predictor of current output, the impact of infrastructure might only be felt after some time, or output may increase in anticipation of investments in infrastructure. To some extent, dynamics are captured in the instruments vector, where as many as three lags are allowed. However, no serious attempt to model the dynamics of the relation between manufacturing and energy infrastructure has been made. Having said that, the levels estimations seek to capture long-run behaviour, and as such, dynamics do not appear very important. Short-term behaviour is less certain, but it is unlikely that growth of infrastructure affects industrial development contemporaneously.

4. Data

Data on aggregate manufacturing value added in constant US$ 2000 are drawn from UNIDO's INSTAT3 Database (UNIDO, 2006). The time series had to be interpolated and smoothed before employed in statistical work. Energy infrastructure (ELGEN) is measured as electricity-generating capacity, or kilowatts per capita. There are at least two reasons why physical measures of infrastructure are to be preferred to monetary values. First, Pritchett (1996) argues that the monetary value of public investment may contain little information regarding efficiency in implementing investment projects, especially in developing countries. According to his estimates, only some little more than half of investment contributes to the stock of public capital. Consequently, public capital stocks are likely to be overestimated and, thus, may affect its estimated impact. Secondly, if the composition of the stock matters because the marginal productivity of one link depends on the capacity and configuration of all links in the network, it is unclear whether the average or marginal product of additional energy infrastructure today is being measured (Fernald, 1999).

However, there are reasons to adjust ELGEN for quality. Using a sample of 26 European and Central Asian countries, Iimi (2008), for example, shows that a one-hour reduction in electricitiy outages could generate savings for firms on operating costs of an average of 1.5 per cent. Furthermore, the World Bank (1994) claims that, on average, only 60 per cent of the power-generating capacity in developing countries is actually available for production. Consequently, ELGEN offers a version adjusted for "quality" (ELGENQ), measured as ELGEN * 1-percentage of power losses. While ELGEN is obtained from Canning (1998), the adjustment information sources from Calderón and Servén (2004). Human capital (H) is measured as the average attainment level for the population aged 15 and older (Barro and Lee, 2000). The institutions variable (INST), proxied by economic freedom, is supplied by Gwartney, Lawson and Emerick (2003), while agricultural labour productivity (AGR) and manufacturing exports (MEXP), both in constant US$ 2000, are from the World Development Indicators (World Bank, 2007).

These data cover 79 advanced and developing countries. When ELGEN is quality-adjusted for its quality, the number of countries decreases to 66. The data are annual spanning 1970 to 2000. The actual number of observations used in the estimations is a function of the combined data availability of all the right-hand side variables and instruments remaining in the final specification. The panel is unbalanced in the sense that some countries are observed for shorter time periods. Table 1 provides the list of countries in the dataset.

In order to analyze whether countries' stage of development matters for the role of infrastructure, meta-countries are created by grouping countries according to their year 2000 income levels—high, upper-mid, lower-mid and low—with a special group consisting of fast-growing Asian countries, tigers. The last is of particular interest for their ability to sustain considerable economic growth for an extended period.

Table 2 contains a collection of summary statistics for the entire sample. It is readily seen that the range of manufacturing value added per capita across countries is substantial, as is installed electricity-generating capacity. Although this does not necessarily imply a correlation between the two, it embodies the working hypothesis of this paper. The range of agricultural productivity and manufacturing exports is significant, while those of human capital and institutions appear to be less. The range of growth rates for nearly all variables starts from the negative and continues to fairly high levels, such as 10.1 per cent for manufacturing value added per capita. The highest average growth rates are those for energy infrastructure, which slightly exceed those for manufacturing. Not surprisingly, institutions register the least average change.

Ratios between stocks of infrastructure across meta-countries adds fuel to the notion of performance gaps between industrialized and non-industrialized countries (Table

3).[13] All groups significantly lag behind the high-income countries' manufacturing levels, with the upper-mid income countries coming closest, at 16 per cent. The worst case is the low-income group, which attains just more than one per cent. In the case of ELGEN, upper-mid income countries reach a little more than 23 per cent of the high-income group's score, while the other country groups range from 2.29 to 10.79 per cent. The figures for ELGENQ are essentially in the same range. As with manufacturing per capita, the quantity of energy infrastructure is much smaller in developing countries. However, Yepes, Pierce and Foster (2009) suggest that convergence in infrastructure could be underway.

Why is there such a massive infrastructure gap? Electricity supply is an increasing returns-to-scale industry because it is a natural monopoly. Productive efficiency is achieved only with large scale production. Setting up such production networks implies potentially large profits but also considerable costs. Only governments and large private companies can bear these costs. Moreover, energy infrastructure is partially a public good and carries natural monopoly characteristics, in that they facilitate many different economic activities. Since they are in large quantities, they are expensive and funded through taxation, or in the case of many developing countries, via official development assistance. Another common characteristic is that they are lumpy in the sense of technical indivisibilities. The implication is that energy infrastructure is strongly correlated with income levels. This further motivates an analysis that accounts for stages of development.

The Appendix contains two sets of two-way illustrations: the first for levels and the second for growth. A casual look at the level illustrations suggests that the steepest slopes, i.e., largest parameters, might be found for energy infrastructure, manufacturing exports and human capital, but that all the other ones are positively sloped too. The growth illustrations are more difficult to decipher. With the possible

[13] The story is reminiscent of those in UNCTAD's LDC report (2006) and World Bank's World Development Report (1994). The former adds that quality of infrastructure is remarkably lower in developing countries, in particular, in LDCs. For example, between 1999 and 2001, an average of 20 per cent of total electricity output in the LDCs was lost in transmission and distribution, compared with 13 per cent in other developing countries and six per cent in OECD.

exception of INST, they are, however, all positively sloped. The multivariate regression analysis that follows helps to sort out whether these two-way relations continue to hold or capture other features shared by other relations.

5. Regression analysis

There are two main sets of results to present. The first set focuses on cross-country differences in manufacturing per capita levels. In other words, why do some countries have higher manufacturing levels than others? In the second set of results, the enquiry concerns why some countries' industries grow faster than others'. Both sets of results start by analyzing pooled datasets, followed by results based on meta-countries.

5.1. Manufacturing per capita

5.1.1. All countries

Table 4 contains the results of three estimators, ordinary least squares (OLS), random-effects (RE) and fixed-effects (FE). OLS, which is based on pooling the data, is the benchmark estimation only. It is well known that if country-specific effects are omitted, OLS yields inconsistent estimates. On the other hand, the RE and FE estimators can control for omitted country-specific effects such as geographical features. While the latter estimator accounts for correlations between such effects and infrastructure as well as with other explanatory variables, the former assumes such correlations are zero. The two estimators can be expected, therefore, to produce differing results if such correlations are non-zero. In contrast to OLS, the focus of the FE estimator is on the within-effects, that is, the impact within, in this case, countries. Despite its obvious shortcomings regarding zero correlation between country-specific effects and right-hand side variables, the rationale for employing the RE in addition to the FE estimator is that it factors in the between-country variation, which is ignored by FE. Although the FE estimator can mitigate endogeneity bias, the obvious objection of infrastructure being endogenous is elaborated below.

The vector of control variables includes AGR, MEXP, INST, H and a trend variable (T), where the latter accounts for technological change common to all countries.[14] Because infrastructure is expected to have profound long-term effects on technological change (see, for example, Hulten and Isaksson, 2007), the trend variable enters in interaction with the two energy infrastructure variables, denoted (TINT). A simple interpretation of TINT would be to understand it as an indication of how the impact of energy infrastructure changes over time. A more interesting one is that infrastructure strengthens or weakens the effect of technological change on manufacturing. Alternatively, the incidence of technological change affects the impact of energy infrastructure on manufacturing. In any case, the expected sign of the coefficient is positive.

Starting with the OLS, the coefficient of ELGEN is positive and statistically significant. A 10 per cent increase in energy infrastructure is associated with a manufacturing per capita increase of four per cent. However, this impact decreases over time, as evidenced by the negatively signed coefficient of TINT, leading to a total effect of 3.56 per cent. Large positive effects on manufacturing are also obtained from AGR and INST, which display elasticities between 0.50 and 0.56. A 10 per cent increase in H is associated with a long-term increase of manufacturing of some three per cent, while the corresponding correlation between manufacturing and MEXP is approximately one per cent. Global technological change has a negative effect on industry. One reason for the negative sign is that agricultural labour productivity has already been accounted for, although its coefficient is not significant. The unexpected sign of the coefficient could also reflect the composition of the sample in that manufacturing grows fastest in middle- and upper-middle income economies. However, high- and low-income countries have slower growing industries. With technological change emanating mainly from the manufacturing sector, it is conceivable that, if other sectors grow faster, the overall association between global

[14] The trend variable might, more generally, include the impact of macroeconomic environment or factors that affect trend changes in this environment. However, since technological change is interpreted to be one of the main factors behind such change, the interpretation of technological change is maintained throughout the paper.

technological change and manufacturing could be negative. This issue will be revisited when the estimation results for income groups are analyzed.

Some of these results may confound the impact of country-specific effects and those of the explanatory variables. Controlling for such effects may change the impact of several of the determinants. This could be an indication that individual determinants are correlated with state-dependent factors, such as geography and initial conditions, such as high or low income. However, the RE and FE estimators deliver very similar results, suggesting that neither correlation between determinants and country effects, nor between effects, is a major issue.

With a coefficient of some 0.53 for both FE and RE, the impact of energy infrastructure is significantly greater than in the case of OLS. However, a smaller, rather than greater, point estimate could have been expected. This is based on the idea that ELGEN might capture country-specific effects with a positive impact on manufacturing and that the fixed- and random effects would now reduce that from the ELGEN coefficient. However, if those effects have a negative effect, the point estimate of ELGEN would increase, as it does now. One plausible explanation for the increase could be that ELGEN previously captured the effects of initial income, or the initial stock of energy infrastructure, which under assumptions of convergence, or catching up, should be negatively correlated with manufacturing per capita. So, conditional on the initial levels of income and energy infrastructure, a 10 per cent increase of ELGEN is associated with a 5.3 per cent increase in manufacturing per capita. This effect seems excessively large, but is mitigated by the negative impact of the interaction with technological change, leading to a total effect of 4.5 per cent.

Other important consequences of moving to panel-data estimators are registered. Except for AGR, all parameters are drastically reduced in size. Based on the fixed-effects estimator, the parameters of INST and H are approximately 0.19 and 0.13, respectively. The parameter for MEXP, on the other hand, becomes statistically insignificant. This suggests that, in the OLS estimation, MEXP may have captured the effect of an omitted variable such as geography. The link between industry and agriculture remains as strong as that between industry and energy infrastructure.

Based on panel-data estimators, adjusting ELGEN for quality (ELGENQ) does not seem to change the results in any important way. The impact of energy infrastructure on manufacturing is still considerable, albeit somewhat reduced. However, this might as well be an effect of a smaller sample, since 13 countries did not have information on ELGEN quality. It is reassuring that despite this reduction of observations, the previous results generally remain intact. Regarding the other determinants, the parameters are somewhat smaller, in particular in the case of INST, which could imply that countries with better institutions are less prone to uncertain electricity supply. In the random-effects estimation, MEXP has regained its statistical significance, at the 10 per cent level but with a parameter of 0.026, the impact is small.

So far, an economically meaningful, even substantial, impact of energy infrastructure on manufacturing has been recorded. To asses how much of effect reflects causality running from energy to manufacturing, ELGEN and ELGENQ are allowed to be endogenous. Two panel-data estimators are employed, the instrumental-variables estimators of RE and FE.

Table 5 contains the results of the IV estimators. The estimated coefficients for ELGEN and ELGENQ, as predicted, are lower, but not much, than previously. In the case of the former, the decrease amounts to approximately 0.07 percentage points (from 0.53 to 0.46), while, in the latter, it is somewhat less, at 0.03 percentage points (from 0.51 to 0.48). Accounting for the negative contribution of TINT reduces the total effect further to 0.43 in both cases. These estimates, at least, seem to be approaching more reasonable magnitudes. Thus, ignoring endogeneity of energy infrastructure tends to bias upward the estimates to some extent, but not as much as a priori believed. Other notable changes are that MEXP, again, enters significantly, at between 0.034 and 0.053, depending on estimator and measure of energy infrastructure used. Moreover, in the ELGENQ fixed-effects specification, the coefficient of H is no longer statistically significant. Finally, according to the t-test, ELGEN might actually be an exogenous variable. Even if not, the Sargan-test accepts the instruments, and the first-stage regression results appear to support strongly the final set of instruments.

5.1.2. Meta-countries

How do these average results hold up across different stages of development? Recall that the marginal effect of an investment in a low-income country is expected to exceed that in a high-income one. Whether or not statistically significantly different from zero, the point estimates are evaluated. The reason for also accepting insignificant parameters for this purpose is that significance only measures whether there is enough variation within each group to measure infrastructural impact. Although of interest, there is an additional purpose to compare impacts across stages of development. The obvious drawback of the approach adopted in terms of making such inferences is that the parameter is statistically indistinguishable from zero. Therefore, insignificant parameters are treated with caution, but fortunately this turns out not to be a major concern because the parameters tend to be statistically significant.

Table 6, which has one panel each for ELGEN and ELGENQ, provides the results for all the five different estimators discussed above. Due to space limitations, only the coefficients relevant for energy infrastructure are presented. Empty slots mean that ELGEN/ELGENQ is not endogenous.

It is striking that energy infrastructure is positively signed and statistically significant for all income groups. Focusing on the FE estimator, for reasons of comparability, and total impacts the largest impact occurs for the fast-growing tigers and low-income countries, followed by upper-mid income countries. Unexpectedly, the smallest coefficient is for lower-mid economies, rather than the high-income ones. For countries with high underlying productivity growth—the high-income ones and the tigers—the parameters for the interaction terms imply that the impact increases over time. For the other income groups, impact decreases over time. Comparing with the results for the pooled samples, it appears that the negative impact of technological change comes from developing countries, which overwhelms the positive one registered for the other two income groups.

The economic significance of energy infrastructure differs across meta-countries but not entirely in the way predicted. Instead of being inversely related to income levels in a smooth fashion, impact varies fairly erratically. The FE estimator suggests that energy infrastructure, with a total effect of ELGEN and TINT at about 0.65, has the largest impact in the fast-growing tiger economies. For low-Income countries, the total effect is 0.45, falling to 0.25 for upper-mid, about 0.11 for high-income countries and, lastly, a mere 0.05 for lower-mid income countries. An interpretation is that low-mid income countries have reached a sort of development plateau, where adding more energy infrastructure is not the answer to how to resolve this issue.

Turning to ELGENQ, the low-income countries record an impact of 0.34, which is 0.1 percentage point smaller than for ELGEN, while for lower-mid income countries the impact is 100 per cent greater (0.085). For other income groups, there is little difference. In those cases where energy infrastructure is deemed endogenous (tigers and low), the point estimates seem to be excessively large. Nonetheless, the conclusion that energy infrastructure heterogeneously impacts on manufacturing, as well as, on the size ranking, remains.

One interesting aspect of impact plateaus such as that detected here is that the impact of energy infrastructure could be non-linear. Furthermore, this characteristic could depend on complementarities not in place. For instance, for energy infrastructure to support fully production, its distribution might require strong institutions. Hence, bottlenecks could impair on its efficient functioning. Once the necessary institutions are in place, the large impact of energy infrastructure might be restored.

Another possible explanation is that infrastructure investments tend to be lumpy, occurring in infrequent spurts. Moreover, due to adjustment lags, the full response from the rest of the economy is likely to take place with delay. Again, the implication is a smaller measured marginal impact but probably a much larger total impact. Against this, one could question why low income countries should experience a large impact. In a situation where there is little or no infrastructure, installing a grid of energy infrastructure is akin to releasing the economy of a binding bottleneck and, thus, can have a significant effect. Based on the notion of decreasing marginal returns, additional energy grid is unlikely to deliver the same impact. Hence, the impact in high-income countries is expected to be less than that in poor ones.

5.2. Growth of Manufacturing per capita

5.2.1. All countries

Although the industrial development regressions are carried out as first differences, a trend and an interaction term are included. Technological change might have an impact on how rapidly manufacturing grows as well as on the interaction between technological change and growth of energy infrastructure. While the trend variable is not statistically significant in any of the regressions, the interaction term is. As was the case of the level regressions, there are no important differences between the RE and FE estimators.

Table 7 presents the OLS, RE and FE results for ΔELGEN and ΔELGENQ. The rate of industrialization is positive related to the growth of energy infrastructure. An increase of mean ΔELGEN by one percentage point—from 2.3 per cent to 3.3 per cent, which amounts to a 50 per cent increase—is associated with a 0.12 to 0.134 percentage point increase in the speed at which manufacturing grows, from 3.6 to some 3.73 per cent, depending on the estimator. This does not seem excessive, especially since it includes effects of network externalities and spillovers. The results for ΔELGENQ are in line with this, albeit somewhat smaller.

Because the interaction term is close to zero in the case of OLS, the initial effect remains unchanged. In terms of total impact, both panel-data estimators deliver fairly sizeable interaction terms, essentially reducing the total growth impact to nil. The conclusion is that increasing the growth rate of energy infrastructure does not have any sizeable impact on the pace of industrial development, once country-specific factors such as initial income and geography are controlled for. This also illustrates the important difference between statistical and economic significance.

Turning to the other determinants of ELGEN, the dominating one appears to be growth of human capital (ΔH). Focusing on the RE and FE estimates, at 0.29 and 0.24 respectively, both impacts are of significant magnitude. Change in agricultural labour productivity is positively related to industrial development, where a one percentage point increase is associated with a 0.13 to 0.155 percentage point increase in manufacturing growth, depending on the estimator. The point estimate is somewhat smaller in the case of ΔELGENQ. Neither ΔMEXP nor ΔINST are statistically significant.

These conclusions are considerably altered when the endogeneity of ΔELGEN/ ΔELGENQ is addressed. Table 8 shows that faster growth of energy infrastructure sharply increases the pace of industrial development. In the case of RE-IV, the point estimate suggests that a one percentage point increase in the growth of energy infrastructure increases the rate of industrialization from 3.6 to 4.43 per cent, accounting for the interaction term. Ignoring the between effects (FE-IV) further increases the impact to 4.8 per cent. Beginning with a mean growth rate of 2.5 per cent, the corresponding figures, for ΔELGENQ are 3.28 and 3.44 per cent for RE-IV and FE-IV respectively. These are serious growth effects and suggest that the rate at which investment in energy infrastructure occurs spurs the rate at which industry grows.

Alterations occur for many of the other determinants as well. In the case of ΔELGEN, the previously significant effect of human capital is wiped out in terms of statistical significance, although it enters with a less than negligible parameter. It is replaced by the significant impact of ΔINST on manufacturing growth. A percentage point increase of institutions raises manufacturing growth from 2.3 to some 2.6 per cent. The disappearance of human capital in the entrance of institutions in the regression may indicate some correlation among the explanatory variables. Agricultural labour productivity growth retains its statistical association with industrial development, while manufacturing exports remain insignificant. A new feature, however, is a positive and significant trend parameter, suggesting that global technological change has a positive impact on manufacturing growth.

Using the RE-IV estimator, in the ΔELGENQ specification, human capital and institutions as well as agricultural labour productivity, enter with statistically significant parameters of 0.25, 0.19 and 0.10 respectively. However, in the case of FE-IV, human capital drops out.

5.2.2. Meta-countries

Starting with a focus on non-IV estimation results, it is only for countries in the lower-mid income category for which energy infrastructure is statistically significant. This is significant in light of the level results, where this income group displayed the weakest statistical association. However, at some 0.05, the total impact for ΔELGEN is not very strong, while it is somewhat stronger in the case of ΔELGENQ. Considering also statistically insignificant parameters, the total effect for several of them is actually negative. However, they are all close to zero and near the impact obtained for the lower-mid economies. Rather than there being no difference across meta-countries, the conclusion drawn is that lower- and upper-mid income countries experience similar positive effects, while increasing the rate of investment for the other groups of countries does not pay. In terms of manufacturing growth rates, another conclusion is that energy infrastructure might play a role in terms of convergence due to the need for complementary investments. Relieving one bottleneck is not enough to increase the growth rate. Furthermore, there are limits as to how quickly economies can grow owing to adjustment costs and learning. Although the parameters in all other cases are insignificant, the parameter sign in the cases of upper-mid and low-income countries is negative. This may be interpreted as providing support for the notion of overprovision in those countries (e.g., Devarajan, Swaroop and Zhou, 1996; Canning and Pedroni, 2004).

As in the case of the full sample, IV-estimates generate much stronger associations between manufacturing growth and change in energy infrastructure. However, the difference compared with non-IV estimators is so large that it is difficult to explain. For example, the largest impact is now found for upper-mid income countries for whom the total impact is greater than 0.62. These are followed by the high-income countries, with a total impact ranging from 0.44 to 0.53 for ΔELGEN and 0.42 to 0.58 for ΔELGENQ. lower-mid income countries come third, with 0.31, while for the other income groups the IV estimates are not statistically significant. Hence, controlling for endogeneity is important, but the IV estimates are not entirely reliable.

Generally, the IV estimates appear too large, even if accounting for externalities. A one percentage point increase in the growth of energy infrastructure implies a very large increase in public and private spending, but even to hope for a one-to-one relation does not seem realistic. One alternative is that the causal relation running from manufacturing to energy infrastructure is negative, so controlling that effect increases the estimate of the causal relation from energy infrastructure to manufacturing. This could happen, for example, if there is overprovision of infrastructure in poor countries, where, for example, the channel could be foreign aid. It is also possible that poorer countries devote more of their resources to infrastructure than rich countries do.

However, the weighted impact of energy infrastructure is likely to be underestimated because manufacturing has important linkages to other sectors of the economy. If investment in energy infrastructure improves manufacturing, it means that such investment contains spillovers for the rest of the economy. Those effects are not fully accounted for in the above regression analysis, which they would be if, for example, GDP per capita were the dependent variable. For that reason, the weighted estimates should be seen to constitute a lower bound.

The overall conclusion remains that energy infrastructure is positively related to industrial development. The economic effect is important, but probably not as important as the IV estimates seem to suggest.

6. Conclusions

The purpose of this paper has been to estimate the impact of energy infrastructure on cross-country differences in manufacturing levels as well as differing pace of industrialization. A serious attempt has been made to address statistical issues such as reverse causality, endogeneity bias and omitted state-dependent variables. Whereas the starting point for the econometric work was to treat all countries as homogenous, it was recognized early on that such an assumption might be difficult to defend. Furthermore, it was believed that the impact of energy infrastructure could be higher if the initial infrastructure stock was small. Following this, the sample of countries was divided into four groups based on income levels, to proxy for different stages of development. In addition, a group of Asian fast-growing countries—tigers—was created.

Apart from regressing manufacturing on energy infrastructure, the regression models employed have drawn from the so called deep determinants literature, as well as from the structural change literature. These literatures ought to be as relevant for manufacturing as for total economy aggregates. From the former, human capital, institutions, manufacturing exports and geography are obtained, while from the latter, the strong linkage between agriculture and manufacturing is proxied with agricultural labour productivity. Geography is only controlled for by way of country-specific effects, with no estimated explicit effect. To address the econometric issues mentioned above, random- and fixed-effects instrumental variables estimators were used.

The first conclusion drawn is that energy infrastructure in an economically meaningful sense helps to explain why some countries have managed to industrialize while others have not. In other words, energy infrastructure holds one part of the key that brings development and prosperity. With the intrinsic role of energy in production and, indirectly, in education and health, it would be surprising if such infrastructure was not important.

Secondly, energy infrastructure is positive and significant across all income groups, but there are differences. The impact seems to be largest for the poorest economies and for the fast-growing Asian tigers. The lowest estimate is for lower-mid income countries, suggesting there might be important threshold effects, or non-linearities, on which to focus future research. Non-linearities may arise because infrastructure investment tends to be lumpy, which breaks the link between capital stocks and its service flows. At low incomes, infrastructure may be complementary and have higher pay-offs, while at high incomes, substitution effects dominate and pay-off, therefore, are lower.

Adjustment for the quality of energy infrastructure has no significant effect on the results. However, use of panel-data methods has significant effects on the estimates showing the importance of accounting for omitted variables and state-dependent country-specific effects. To some extent, instrumental variables techniques are important but appear less urgent than country-specific effects. At least the overall conclusions appear rather unaffected.

Thirdly, energy infrastructure provides an explanation for differing industrial growth rates. However, once the interaction effect between energy infrastructure and technological change is accounted for, the impact significantly decreases. Contrary to the level case, endogeneity of energy infrastructure is important. The estimated parameter inflates considerably suggesting that energy infrastructure has a significant effect on the pace of industrialization. Compared with the level or long-term cases, where the endogeneity of energy infrastructure is not very pronounced, for growth or the short-term case, there is feedback to address.

Fourthly, growth of infrastructure is not positively related to industrial development for all groups of countries—only for lower-mid income ones. This is interpreted as a sign of convergence in the sense that energy infrastructure is important for catching-up. However, this is probably one of several possible explanations. There are also some signs that energy infrastructure might be overprovided in the case of low and upper-mid income countries, at least judged by the negative estimate obtained. Using instrumental-variables estimation leads to much larger parameters, with lower-mid, upper-mid and high-income economies, displaying positive effects of energy infrastructure.

While most empirical work on the impact of infrastructure uses public capital as a proxy and focuses on some total economy aggregate, such as GDP, this paper has contributed by focusing directly on energy infrastructure and its role in furthering industrial development, although it is far from the final word on energy infrastructure. For example, the empirical model used here lacks dynamic components. If the parameter of energy infrastructure captures some of that dynamics, the marginal impact is overestimated, although the total effect over time may not. In terms of the conditions under investment in energy infrastructure leads to contemporaneous growth, little is known of the lag time involved from investment to the inception effects of industrialization, as well as of the length of time the effect occurs. This is likely to be a larger issue in the growth than level regressions, since the latter is about describing long-term industrial development. Tackling the question whether governments should build energy capacity in advance of needs, it is possible that such investment has little or no effect on growth if complementary investments are not undertaken or there is no real demand for it. Simply, investment in infrastructure leads to contemporaneous growth only if the country is poised for growth.

As investment in energy infrastructure may only prepare for growth, there may be better investments with higher rates of return in the short term. This implies that governments should make such investments in order to relieve the economy from infrastructural bottlenecks. The policy decision of governments needs to asses demand before deciding on investing in infrastructure, especially in developing countries where resources are relatively scarce and trade-offs plentiful.

This paper has alluded to the possibility of threshold effects. Development stage has been proxied by income levels, but those levels are chosen in rather arbitrary fashion. Methods such as those developed by Hansen (1999) and Caner and Hansen (2004) might better illuminate how and at what stage of development energy infrastructure impacts on manufacturing and its growth. Although an attempt to account for the quality of energy infrastructure has been made—without any significant difference in the result—such data are actually sparse and may not adequately proxy for actual quality. Hulten (1996) has shown how quality might trump the quantity of infrastructure. [15] Although crowding-out effects, financing or ownership of infrastructure have not been addressed, they may be important for understanding when and under what circumstances the effect of energy infrastructure is maximized.

Data quality across countries is likely to differ significantly, which means that the stages of development analysis may be biased.[16] Furthermore, although the income groups have been ranked according to their point estimates and rates of return, formal statistical tests have yet to be carried out to determine if differences are actually statistically different. For these reasons, the results are indicative rather absolute.

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[15] The *World Development Report 1994* (World Bank, 1994) goes beyond quantity of energy infrastructure to consider quality of infrastructure services as well as the role of maintenance.

[16] That issues of data quality and accurate coverage not only apply to developing countries, although problems ought to be more severe in those countries, is exemplified by the proposal for a new architecture for the United States national accounts (Jorgenson and Landefeld, 2009).

This paper has made a considerable case for energy infrastructure in explaining cross-country differences in manufacturing levels and rates of industrialization, which should prove useful for policymaking. Future research needs to address in depth the exact dynamics of investment in energy infrastructure, identify threshold effects and collect information on quality and maintenance.

References

Acemoglu, Daron, Simon Johnson and James A. Robinson (2005), "Institutions as the Fundamental Cause of Long-Run Growth," in Philippe Aghion and Stephen Durlauf (Eds.), *Handbook of Economic Growth*, Amsterdam: Elsevier, North-Holland.

Adenikinju, Adeola (2005), "Analysis of the Cost of Infrastructure Failures in a Developing Economy: The Case of the Electricity Sector in Nigeria," *AERC Research Paper 148*, Nairobi: AERC.

Agénor, Pierre-Richard and Blanca Moreno-Dodson (2006), "Public Infrastructure and Growth: New Channels and Policy Implications," *Policy Research Working Paper No. 4064*, Washington, D.C.: World Bank.

Agénor, Pierre-Richard (2009), "Public Capital, Health Persistence and Poverty Traps," Discussion Paper Series, No. 115, Manchester: Centre for Growth and Business Cycle Research, Economic Studies, University of Manchester.

Alvarez-Cuadrado, Francisco and Markus Poschke (2009), "Structural Change out of Agriculture: Labor Push versus Labor Pull," *IZA Discussion Paper*, No. 4247, Bonn: Institute for the Study of Labor.

Andres, Luis A., J. Luis Guasch, Thomas Haven and Vivien Foster (2008), *The Impact of Private Sector Participation in Infrastructure: Lights, Shadows and the Road Ahead*, Washington, DC: World Bank.

Aschauer, David A. (1989), "Is Public Expenditure Productive?" *Journal of Monetary Economics*, Vol. 23, pp. 177-200.

Aschauer, David A. (2000), "Public Capital and Economic Growth: Issues of Quantity, Finance, and Efficiency," *Economic Development and Cultural Change*, Vol. 48(2), pp. 391-406.

Aschauer, David A. and Lachler, U. (1998), "Public Investment and Economic Growth in Mexico," *Policy Research Working Paper No. 1964*, Washington, DC: The World Bank.

Auriol, Emmanuelle and Aymeric Blanc (2009), "Capture and Corruption in Public Utilities: The Cases of Water and Electricity in Sub-Saharan Africa," *Utilities Policy*, Vol. 17, pp. 203-16.

Awokuse, Titus O. (2009), "Does Agriculture Really Matter for Economic Growth in Developing Countries?" *mimeograph*, Department of Food and Resource Economics, University of Delaware.

Barro, Robert J. (1990), "Government Spending in a Simple Model of Endogenous Growth," *Journal of Political Economy*, Vol. 98(5), pp. 103-25.

Barro, Robert J. and Jong-Wha Lee (2000), "International Data on Educational Attainment: Updates and Implications," *NBER Working Paper No. 7911*, Cambridge, MA: NBER.

Blundell, Richard and Stephen Bond (1998), "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models," *Journal of Econometrics*, Vol. 87(1), pp. 115-43.

Botta, Alberto (2009), "*Structural Change and Economic Dynamics*," Vol. 20, pp. 61-73.

Calderón, César (2009), "Infrastructure and Growth in Africa," *Policy Research Working Paper No. 4914*, Washington, D.C.: World Bank.

Calderón, César and Luis Servén (2004a), "The Effects of Infrastructure Development on Growth and Income Distribution," *Policy Research Working Paper No. 3400*, Washington, D.C.: World Bank.

Calderón, César and Luis Servén (2004b), "Trends in Infrastructure in Latin America, 1980-2001," *Policy Research Working Paper No. 3401*, Washington, D.C.: World Bank.

Caner, Mehmet and Bruce Hansen (2004), "Instrumental Variable Estimation of a Threshold Model," *Econometric Theory*, Vol. 20, pp. 813-43

Canning, David. (1998), "A Database of World Stocks of Infrastructure, 1950-1995," *The World Bank Economic Review*, Vol. 12(3), pp. 529-47.

Canning, David and Peter Pedroni (2004), "The Effect of Infrastructure on Long Run Economic Growth," *mimeograph*, Harvard University.

Dethier, Jean-Jacques, Maximilian Hirn and Stéphane Straub (2008), "Explaining Enterprise Performance in Developing Countries with Business Climate Survey Data," *Policy Research Working Paper 4792*, Washington, DC: World Bank.

Devarajan, Shantayanan, Vinaya Swaroop and Heng-fu. Zou (1996), "The Composition of Public Expenditure and Economic Growth," *Journal of Monetary Economics*, Vol. 37, pp. 313-44.

Dollar, David, Mary Hallward-Driemeier and Taye Mengistae (2005), "Business Climate and Firm Performance in Developing Countries," *Economic Development and Cultural Change*, Vol. 54(1), pp. 1-31.

Easterly, William (2009), "Can the West Save Africa?" *Journal of Economic Literature*, Vol, XLVII(2), pp. 373-447

Escribano, Alvaro, J. Luis Guasch and Jorge Pena (2008), "Impact of Infrastructure Constraints on Firm Productivity in Africa," *Africa Infrastructure Country Diagnostic Working Paper*, No. 9, Washington, DC: World Bank.

Esfahani, Hadi Salehi and María Teresa Ramírez (2003), "Institutions, Infrastructure and Economic Growth," *Journal of Development Economics*, Vol. 70(??), pp. 443-77.

Estache, Antonio (2006), "Infrastructure: A survey of recent and upcoming issues," *paper presented at the Annual Bank Conference on Development Economics*, Tokyo, Japan, May 29-30, 2006.

Fedderke, J.W. and Z. Bogetic (2009), "Infrastructure and Growth in South Africa: Direct and Indirect Productivity Impacts of 19 Infrastructure Measures," *World Development*, Vol. 37(9), pp. 1522-39.

Fernald, John. G. (1999), "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity," *American Economic Review*, Vol. 89, pp. 619-38.

Fernandes, Ana M. and Ariel Pakes (2008), "Factor Utilization in Indian Manufacturing: A Look at the World Bank Investment Climate Surveys Data," *NBER Working Paper*, No. 14178, Cambridge, MA: NBER.

Foster, Vivien (2008), *Overhauling the Engine of Growth: Infrastructure in Africa*, Executive Summary (draft), African Infrastructure Country Diagnostic, Washington, DC: World Bank.

Foster, Vivien and Jevgenijs Steinbuks (2009), "Paying the Price for Unreliable Power Supplies," *Policy Research Working Paper*, No. 4913, Washington, DC: World Bank.

Frankel, Jeffrey and David Romer (1999), "Does Trade Cause Growth?" *American Economic Review*, Vol. 89(3), pp. 379-99.

Glaeser, Edward L., Rafael LaPorta, Florencio López de Silanes and Andrei Schleifer (2004), "Do Institutions Cause Growth?" *Journal of Economic Growth*, Vol. 9(3), pp. 271-303.

Gramlich, Edward M. (1994), "Infrastructure Investment: A Review Essay," *Journal of Economic Literature*, Vol. 32(September), pp. 1176-96.

Gwartney, James and Robert Lawson, with Neil Emerick (2003), *Economic Freedom of the World: 2003 Annual Report*, Vancouver: The Fraser Institute. Data retrieved from www.freetheworld.com.

Hansen, Bruce (1999), "Threshold effects in non-dynamic panels: Estimation, testing and inference," *Journal of Econometrics*, Vol. 93, pp. 345-68.

Hill, R. Carter, William E. Griffiths and Guay C. Lim (2008), *Principles of Econometrics, 3rd edition*, Hoboken: John Wiley & Sons, Inc.

Hirschman, Albert O. (1958), *The Strategy of Economic Development*, New Haven: Yale University Press.

Holtz-Eakin, Douglas (1994), "Public Sector Capital and the Productivity Puzzle," *Review of Economics and Statistics*, Vol. 76(??), pp. 12-21.

Hulten, Charles. R. and Robert M. Schwab (1991), "Public Capital Formation and the Growth of Regional Manufacturing Industries," *National Tax Journal*, Vol. 44(4), pp. 121-34.

Hulten, Charles R. (1996), "Infrastructure Capital and Economic Growth: How Well You Use It May Be More Important That How Much You Have," *NBER Working Paper No. 5847*, Cambridge, MA: NBER.

Hulten, Charles, R., Esra Bennathan and Sylaja Srinivasan (2005), "Infrastructure, Externalities, and Economic Development: A Study of Indian Manufacturing Industry," *report to the World Bank research project 'Growth and Productivity Effects of Infrastructure: Regional Study in India'*, Washington, D.C.: World Bank.

Hulten, Charles R. and Anders Isaksson (2007), "Why Development Levels Differ: Differential Growth in a Panel of High and Low Income Countries," *NBER Working Paper No. 13469*, Cambridge, MA: NBER.

Iimi, Atsushi (2008), “Effects of Improving Infrastructure Quality on Business Costs: Evidence from Firm-Level Data,” *Policy Research Working Paper*, WPS 4581, Washington, D.C.: World Bank.

Jorgenson, Dale W. and J. Steven Landefeld (2009), “Implementation of a New Architecture for the U.S. National Accounts,” *American Economic Review: Papers and Proceedings*, Vol. 99(2), pp. 64-68.

Jorgenson, Dale W. (1961), ”The Development of a Dual Economy,” *Economic Journal*, Vol. 71(??), pp. 309-34.

Kessides, Christine (1993), “The Contributions of Infrastructure to Economic Development: A Review of Experience and Policy Implications,” *World Bank Discussion Paper*, No. 231, Washington, DC: World Bank.

Lee, K.S. and A. Anas (1992) (1992), “Impacts of Infrastructure Deficiencies on Nigerian Manufacturing: Private Alternatives and Policy Options,” *Infrastructure and Urban Development Department Report No. 98*, Washington, D.C.: World Bank.

Munnell, Alicia.H. (1992), “Policy Watch: Infrastructure Investment and Economic Growth,” *Journal of Economic Perspectives*, Vol. 6, pp. 189-98.

Noriega, Antonio and Matias Fontenla (2005), “Public Infrastructure and Economic Growth in Mexico,” *mimeograph*, Universidad de Guanajuato.

Pinstrup-Andersen, Per and Satoru Shimokawa (2006), “Rural Infrastructure and Agricultural Development,” *paper presented at the ‘Annual Bank Conference on Development Economics’*, Tokyo, Japan May 29-30, 2009.

Pritchett, Lant (1996), “Mind your P’s and Q’s,” *World Bank Policy Research Paper*, No. 1660, Washington, D.C.: World Bank.

Reinikka, Ritva and Jakob Svensson (2002), “Coping With Poor Public Capital,” *Journal of Development Economics*, Vol. 69(1), pp. 51-69.

Sachs, Jeffrey D. (2008), *Common Wealth: Economics for a Crowded Planet*, New York: Penguin Group.

Sachs, Jeffrey D. (2003), “Institutions Don’t Rule: Direct Effects of Geography on Per Capita Income,” *NBER Working Paper No. 9490*, Cambridge, MA: NBER.

Straub, Stéphane (2008), “Infrastructure and Growth in Developing Countries: Recent Advances and Research Challenges,” *Policy Research Working Paper No. 4460*, Washington, DC: World Bank.

UNCTAD (2006), *The Least Developed Countries Report, 2006*, New York and Geneva: United Nations.

World Bank (1994), *World Development Report 1994: Infrastructure for Development*, Washington, D.C.: World Bank.

World Bank (2007), *World Development Indicators 2007 CD-Rom*, Washington, D.C.: World Bank.

Yepes, Tito, Justin Pierce and Vivien Foster (2009), “Making Sense of Africa’s Infrastructure Endowment: A Benchmarking Approach,” *Policy Research Working Paper*, No. 4912, Washington, DC: World Bank.

Table 1. List of countries

HIGH INCOME	UPPER-MID	LOW-MID	LOW INCOME	TIGERS
	Income per capita = 6,001 and above in year 2000, excluding OECD + Israel	*Income per capita = 3,001-6,000 in year 2000*	*Income per capita = up to 3,000 in year 2000*	
Australia	Argentina	Algeria	Bangladesh	China
Austria	Barbados *	Colombia	Benin *	India
Belgium	Chile	Costa Rica	Bolivia	Indonesia
Canada	Mauritius *	Dominican Republic	Cameroon	Korea, Republic of
Denmark	Mexico	Ecuador	Central African Rep. *	Malaysia
Finland	Panama	Egypt	Congo	Singapore
France	South Africa	El Salvador	Ghana	Thailand
Greece	Syria	Fiji *	Guinea Bissau *****	
Italy	Trinidad and Tobago	Guatemala	Honduras	
Japan	Tunisia	Guyana	Kenya	
New Zealand	Turkey	Iran	Malawi *	
Norway	Uruguay	Jamaica	Mali *****	
Portugal	Venezuela	Jordan	Nepal	
Spain		Pakistan	Nicaragua	
Sweden		Paraguay	Niger *	
Switzerland		Peru	Papua New Guinea *	
UK		Philippines	Rwanda *	
USA		Sri Lanka	Senegal	
			Tanzania, U. Rep. of	
			Togo	
			Uganda *	
			Zambia	
			Zimbabwe	

79 countries in the ELGEN dataset, 66 countries in the ELGENQ dataset.

* Not included in the ELGENQ dataset.

Table 2. **Descriptive statistics (in logs)**

Variable	Mean	Stand. Dev.	Min	Max
*Levels of**				
MVA per capita	5.837	1.763	2.237	8.736
ELGEN	-1.343	1.591	-5.065	1.670
ELGENQ	-1.279	1.486	-4.707	1.589
AGR	7.646	1.519	5.131	9.992
MEXP	3.182	1.163	0.488	4.554
INST	1.755	0.158	1.342	2.079
H	1.605	0.158	-0.338	2.439
*Growth of***				
MVA per capita	0.023	0.028	-0.094	0.101
ELGEN	0.029	0.025	-0.045	0.093
ELGENQ	0.029	0.025	-0.033	0.088
AGR	0.025	0.017	-0.028	0.068
MEXP	0.027	0.049	-0.239	0.272
INST	0.007	0.009	-0.022	0.067
H	0.016	0.010	0.001	0.051

* Year is 2000.

** Average, 1970-2000.

Table 3. Comparison of infrastructure stocks across meta-countries, relative to high-income, per cent, year = 2000

	MVA	ELGEN	ELGENQ
High	100.00	100.00	100.00
Low	1.30	2.29	2.86
Lower-mid	8.03	10.79	10.35
Upper-mid	16.20	23.06	22.09
Tigers	9.55	9.99	9.98

Table 4. Energy and Manufacturing per capita, OLS, Random and Fixed effects

	OLS	RE	FE	OLS	RE	FE
Constant	0.790***	1.969***	2.436***	0.621***	1.969***	2.933***
	(3.58)	(4.99)	(4.82)	(2.74)	(4.99)	(5.14)
ELGEN	0.404***	0.528***	0.531***			
	(16.22)	(12.18)	(10.46)			
ELGENQ				0.355***	0.507***	0.507***
				(13.83)	(11.16)	(9.73)
AGR	0.564***	0.538***	0.499***	0.588***	0.538***	0.454***
	(23.82)	(12.60)	(8.54)	(23.06)	(12.60)	(7.12)
MEXP	0.106***	0.022	0.012	0.114***	0.026*	0.012
	(10.05)	(1.57)	(0.84)	(10.45)	(1.77)	(0.75)
INST	0.500***	0.207***	0.187***	0.419***	0.171***	0.134**
	(4.28)	(3.78)	(3.47)	(3.43)	(3.01)	(2.43)
H	0.296***	0.155***	0.129**	0.360***	0.166***	0.110*
	(7.01)	(2.59)	(2.11)	(7.52)	(2.63)	(1.69)
T	-0.024***	-0.019***	-0.017***	-0.024***	-0.019***	-0.015***
	(13.98)	(15.27)	(8.06)	(13.77)	(13.11)	(6.44)
TINT	-0.003***	-0.005***	-0.005***	-0.002**	-0.005***	-0.004***
	(3.53)	(7.18)	(6.50)	(2.56)	(6.59)	(5.93)
N	1685	1685	1685	1536	1536	1536
R^2	0.93	0.92	0.60	0.93	0.92	0.60
F [a]	3604.83***	1652.36***	135.82***	3048.50***	1398.37***	131.08***
	(7,1677)	(7)	(7,1599)	(7,1528)	(7)	(7,1463)

Note: All variables are in logs and absolute t-values in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 per cent, respectively, small-sample correction carried out for FE, robust standard errors and N = number of observations.

ELGEN = electricity-generating capacity, ELGENQ = quality of electricity-generating capacity, AGR = agricultural value added per worker, MEXP = manufacturing exports in manufacturing value added, INST = economic freedom, H = educational attainment level for population aged 15+, T = linear time trend and TINT = interaction term between trend and ELGEN/ELGENQ.

[a] For OLS: F-test for joint significance of parameters, F[k, N-k-1].
[a] For RE: Wald-test for joint significance of parameters, F[k].
[a] For FE: F-test for joint significance of parameters, F[k+i, N-(k+i)].

Table 5. Energy Infrastructure and Manufacturing per capita, FE-IV

	RE-IV	FE-IV		RE-IV	FE-IV
Constant	1.814***	2.390***		2.042***	2.984***
	(3.76)	(6.30)		(3.88)	(6.99)
ELGEN	0.462***	0.463***			
	(5.21)	(5.46)			
ELGENQ				0.467***	0.476***
				(5.17)	(5.55)
AGR	0.531***	0.477***		0.511***	0.423***
	(15.54)	(13.55)		(14.02)	(11.40)
MEXP	0.045***	0.034**		0.053***	0.035***
	(2.59)	(2.17)		(2.77)	(2.01)
INST	0.159***	0.137**		0.175***	0.141**
	(2.75)	(2.30)		(2.97)	(2.32)
H	0.232***	0.208**		0.211*	0.147
	(2.08)	(2.16)		(1.81)	(1.46)
T	-0.017***	-0.015***		-0.017***	-0.013***
	(12.60)	(7.21)		(12.30)	(6.42)
TINT	-0.003***	-0.003***		-0.003***	-0.003***
	(3.99)	(3.90)		(3.84)	(3.83)
N	1494	1494		1339	1339
Endogenous	ELGEN	ELGEN		ELGENQ	ELGENQ
R^2	0.93	0.60		0.93	0.76
F [a]	341.67***	210.05***		305.53***	192.10***
	(7,1487)	(86,1408)		(7,1332)	(73,1266)
F [b]		117.41***			117.96***
		(78,1408)			(65.1266)
First t-test [c]	0.311***	0.270		0.322***	0.226
Final t-test [d]	-0.103	-0.106		0.083	0.067
First stage [e]			First stage [e]		
$\Delta ELGEN_{t-1}$	6.19***	6.46***	$\Delta ELGENQ_{t-1}$	6.11***	6.43***
$\Delta ELGEN_{t-2}$	5.36***	5.81***	$\Delta ELGENQ_{t-2}$	5.04***	5.43***
$\Delta ELGEN_{t-3}$	5.52***	6.12***	$\Delta ELGENQ_{t-3}$	5.48***	5.97***
Sargan [f]		0.246			1.383

Note: All variables are in logs and absolute t-values in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 per cent, respectively, small-sample correction carried out for FE-IV, robust standard errors. N = number of observations, Endogenous = endogenous explanatory variable, Δ = first difference operator.

ELGEN = electricity-generating capacity, ELGENQ = quality of electricity-generating capacity, AGR = agricultural value added per worker, MEXP = manufacturing exports in manufacturing value added, INST = economic freedom, H = educational attainment level for population aged 15+, T = linear time trend and TINT = interaction term between trend and ELGEN/ELGENQ.

[a] For RE-IV: Wald-test for joint significance of parameters, F[k, N-k]. [a] For FE-IV: F-test for joint significance of parameters, F[k+i, N-(k+i)]. [b] For FE-IV: F-test for whether the fixed effects are statistically significant F[i-1, N-(k+i]. [c] T-test for whether ELGEN/ELGENQ is endogenous in the first test round [d] T-test for whether ELGEN/ELGENQ is endogenous in the last test round [e] First stage t-values for instruments [f] χ^2-test for validity of instruments, χ^2 (instr.-1).

Table 6. **Energy Infrastructure and Manufacturing per capita, OLS, Random-effects RE), Fixed-effects (FE), and RE and FE instrumental variables, Meta-countries**

		High	Upper-Mid	Lower-Mid	Low	Tigers
OLS	ELGEN	0.125*** (2.84)	0.507*** (5.99)	0.485*** (6.11)	0.352*** (4.05)	0.722*** (9.94)
	TINT	0.003 (1.44)	-0.000 (0.09)	-0.015*** (4.99)	-0.007** (2.12)	0.005** (2.42)
RE	ELGEN	0.113*** (2.69)	0.499*** (10.02)	0.168*** (3.20)	0.508*** (9.53)	0.722*** (9.94)
	TINT	0.001 (0.79)	-0.015*** (6.54)	-0.007*** (3.91)	-0.008*** (4.35)	0.005** (2.42)
FE	ELGEN	0.106** (2.31)	0.494*** (10.17)	0.160*** (3.09)	0.557*** (9.93)	0.570*** (8.27)
	TINT	0.000 (0.36)	-0.015*** (6.96)	-0.007*** (3.67)	-0.007*** (3.67)	0.005** (2.36)
RE-IV	ELGEN				0.875*** (6.15)	0.445** (2.06)
	TINT				-0.008*** (4.99)	0.009** (2.32)
FE-IV	ELGEN				0.500*** (5.37)	1.428*** (4.15)
	TINT				-0.008*** (5.29)	-0.010 (1.53)
OLS	ELGENQ	0.123*** (2.76)	0.482*** (6.57)	0.563*** (6.62)	0.579*** (8.54)	0.723*** (10.69)
	TINT	0.003 (1.55)	-0.002 (0.38)	-0.018*** (5.99)	-0.019*** (6.27)	0.005*** (2.74)
RE	ELGENQ	0.106*** (2.58)	0.499*** (8.11)	0.227*** (3.20)	0.521*** (9.22)	0.723*** (10.69)
	TINT	0.001 (0.91)	-0.006** (2.54)	-0.009*** (3.91)	-0.012*** (7.09)	0.005** (2.74)
FE	ELGENQ	0.099** (2.20)	0.483*** (9.71)	0.213*** (4.22)	0.533*** (9.69)	0.531*** (8.16)
	TINT	0.001 (0.48)	-0.014*** (5.98)	-0.008*** (4.63)	-0.012*** (6.86)	0.006*** (2.80)
RE-IV	ELGENQ		-0.583 (1.60)		0.845*** (8.15)	0.645*** (3.06)
	TINT		0.019** (2.12)		-0.015*** (7.94)	0.006 (1.64)
FE-IV	ELGENQ		0.836*** (5.80)		0.472*** (6.63)	0.910** (2.47)
	TINT		-0.020*** (5.67)		-0.012*** (7.65)	-0.001 (0.20)

Note: All variables are in logs and absolute t-values in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 per cent, respectively.
Blank implies that ELGEN/ELGENQ was not endogenous
ELGEN = electricity-generating capacity, ELGENQ = quality of electricity-generating capacity, TINT = interaction term between trend and ELGEN/ELGENQ.

Table 7. **Energy and Industrial development, OLS and Fixed effects**

Table 7 Energy and Industrial development, OLS and Fixed effects

	OLS	RE	FE	OLS	RE	FE
Constant	0.012**	0.015**	0.017***	0.013***	0.017***	0.020***
	(2.526)	(2.53)	(3.39)	(2.61)	(2.95)	(3.81)
ΔELGEN	0.118**	0.129***	0.134***			
	(2.14)	(2.60)	(2.65)			
ΔELGENQ				0.095*	0.101*	0.104*
				(1.69)	(1.91)	(1.92)
ΔAGR	0.155***	0.141***	0.134***	0.133***	0.121***	0.114***
	(6.14)	(5.78)	(5.45)	(5.10)	(4.82)	(4.54)
ΔMEXP	0.011	0.004	0.002	0.002	-0.003	-0.006
	(1.06)	(0.44)	(0.18)	(0.20)	(0.29)	(0.62)
ΔINST	0.099	0.114	0.106	0.079	0.107	0.119
	(1.27)	(1.50)	(1.36)	(0.97)	(1.31)	(1.44)
ΔH	0.401***	0.285***	0.244**	0.401***	0.310***	0.236**
	(4.57)	(3.08)	(2.56)	(4.38)	(3.19)	(2.35)
T	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.82)	(0.83)	(0.65)	(0.80)	(1.02)	(1.18)
TINT	-0.001	-0.007**	-0.008***	0.000	-0.004	-0.006*
	(0.36)	(2.16)	(2.67)	(0.09)	(1.17)	(1.77)
N	1510	1510	1510	1395	1395	1395
R^2	0.07	0.06	0.04	0.08	0.03	0.04
F [a]	13.18***	63.01***	7.68***	10.70***	50.73***	5.92***
	(7,1502)	(7)	(7,1427)	(7,1387)	(7)	(7,1322)

Note: All variables are in logs and absolute t-values in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 per cent, respectively, small-sample correction carried out for FE-IV. N = number of observations, Groups = number of countries, Δ = first difference operator.

ELGEN = electricity-generating capacity, ELGENQ = quality of electricity-generating capacity, AGR = agricultural value added per worker, MEXP = manufacturing exports in manufacturing value added, INST = economic freedom, H = educational attainment level for population aged 15+, T = linear time trend and TINT = interaction term between trend and ELGEN/ELGENQ.

[a] For OLS: F-test for joint significance of parameters, F[k, N-k-1].
[a] For RE: Wald-test for joint significance of parameters, F[k].
[a] For FE: F-test for joint significance of parameters, F[k+i, N-(k+i)].

Table 8. **Energy Infrastructure and Industrial development, FE-IV**

	RE-IV	FE-IV		RE-IV	FE-IV
Constant	-0.034**	-0.057***		-0.026**	-0.029*
	(2.16)	(2.69)		(2.28)	(1.73)
ΔELGEN	0.848***	1.218***			
	(3.25)	(3.70)			
ΔELGENQ				0.683***	0.941***
				(3.89)	(3.55)
ΔAGR	0.134***	0.117***		0.102***	0.079**
	(4.42)	(3.08)		(3.33)	(2.24)
ΔMEXP	0.002	0.001		-0.008	-0.003
	(0.18)	(0.05)		(0.70)	(0.25)
ΔINST	0.230**	0.268**		0.193**	0.191*
	(2.41)	(2.14)		(2.15)	(1.77)
ΔH	0.170	0.133		0.247**	0.097
	(1.17)	(0.71)		(2.00)	(0.60)
T	0.001**	0.002***		0.001**	0.009*
	(2.30)	(2.69)		(2.47)	(1.83)
TINT	-0.001*	-0.000		-0.000*	-0.000
	(1.69)	(1.34)		(1.74)	(0.62)
N	1451	1451		1232	1395
Endogenous	ΔELGEN	ΔELGEN		ΔELGENQ	ΔELGENQ
R^2	0.03	0.00		0.03	0.00
F [a]	7.38***	4.89***		7.82***	4.58***
	(7,1444)	(83,1368)		(7,1325)	(73,1322)
F [f]		1.01			1.18
		(75,1368)			(65,1322)
First t-test [c]	0.499***	0.319**		0.565***	0.326***
Final t-test [d]	0.975***	1.202***		0.556***	0.941***
First stage [e]			First stage [e]		
$ELGEN_{t-3}$	4.58***	4.53***	$ELGENQ_{t-1}$		4.63***
			$ELGENQ_{t-3}$	5.84***	
Sargan [f]					

Note: All variables are in logs and absolute t-values in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 per cent, respectively, small-sample correction carried out for FE, robust standard errors, Endogenous = endogenous explanatory variable, Δ = first difference operator and N = number of observations.

ELGEN = electricity-generating capacity, ELGENQ = quality of electricity-generating capacity, AGR = agricultural value added per worker, MEXP = manufacturing exports in manufacturing value added, INST = economic freedom, H = educational attainment level for population aged 15+, T = linear time trend and TINT = interaction term between trend and ELGEN/ELGENQ.

[a] For RE-IV: Wald-test for joint significance of parameters, F[k, N-k]. [a] For FE-IV: F-test for joint significance of parameters, F[k+i, N-(k+i)]. [b] For FE-IV: F-test for whether the fixed effects are statistically significant F[i-1, N-(k+i]. [c] T-test for whether ELGEN/ELGENQ is endogenous in the first test round [d] T-test for whether ELGEN/ELGENQ is endogenous in the last test round [e] First stage t-values for instruments [f] χ^2-test for validity of instruments, χ^2 (instr.-1).

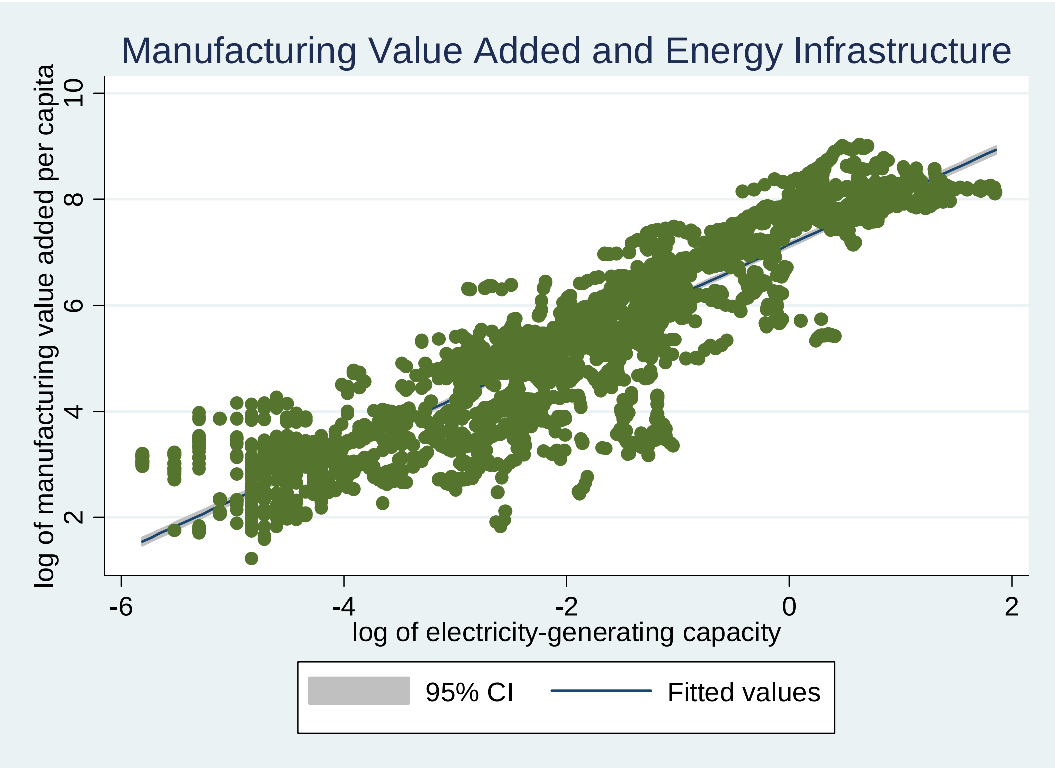
Table 9. **Energy Infrastructure and Industrial Development, OLS, Random-effects RE), Fixed-effects (FE), and RE and FE instrumental variables, Meta-countries**

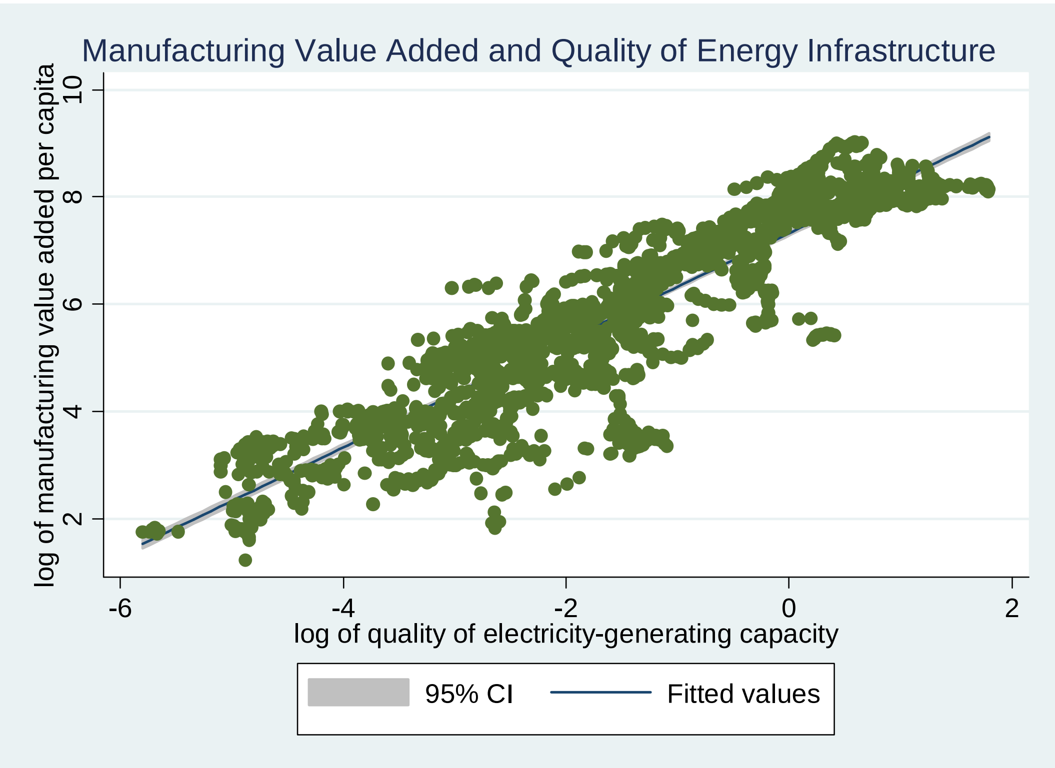
		High	Upper-Mid	Lower-Mid	Low	Tigers
OLS	ΔELGEN	0.194 (1.42)	-0.012 (0.08)	0.198** (2.40)	-0.194 (1.01)	0.075 (0.76)
	TINT	-0.011 (1.46)	0.006 (0.71)	0.082** (2.17)	0.005 (0.48)	-0.001 (0.18)
RE	ΔELGEN	0.186 (1.35)	-0.012 (0.08)	0.229** (2.87)	-0.184 (0.91)	0.075 (0.76)
	TINT	-0.011 (1.43)	0.006 (0.71)	-0.011** (2.35)	0.004 (0.32)	-0.001 (0.18)
FE	ΔELGEN	0.167 (1.19)	-0.040 (0.29)	0.228** (2.63)	-0.188 (0.88)	0.100 (1.09)
	TINT	-0.011 (1.36)	0.006 (0.72)	-0.012** (2.30)	0.004 (0.34)	-0.007 (1.05)
RE-IV	ΔELGEN	0.527** (2.56)	0.821*** (2.82)			
	TINT	0.000* (1.72)	-0.011** (2.28)			
FE-IV	ΔELGEN	0.424** (2.45)		0.341** (2.22)		
	TINT	0.001** (2.44)		-0.002*** (3.60)		
OLS	ΔELGENQ	0.192 (1.38)	-0.059 (0.44)	0.189** (2.35)	-0.251 (1.28)	-0.040 (0.11)
	TINT	-0.011 (1.45)	0.008 (0.92)	-0.006 (1.23)	0.012 (1.18)	0.003 (0.46)
RE	ΔELGENQ	0.184 (1.31)	-0.059 (0.44)	0.222*** (2.73)	-0.251 (1.28)	-0.040 (0.35)
	TINT	-0.011 (1.42)	0.008 (0.92)	-0.009* (1.88)	0.012 (1.18)	0.003 (0.46)
FE	ΔELGENQ	0.166 (1.17)	-0.090 (0.72)	0.223*** (2.59)	-0.242 (1.24)	0.002 (0.02)
	TINT	-0.011 (1.37)	0.008 (1.01)	-0.010* (1.97)	0.009 (0.90)	-0.003 (0.43)
RE-IV	ΔELGENQ	0.515** (2.38)	0.641** (2.31)			
	TINT	0.004* (1.76)	-0.001 (1.52)			
FE-IV	ΔELGENQ	0.403** (2.43)				
	TINT	0.001** (2.46)				

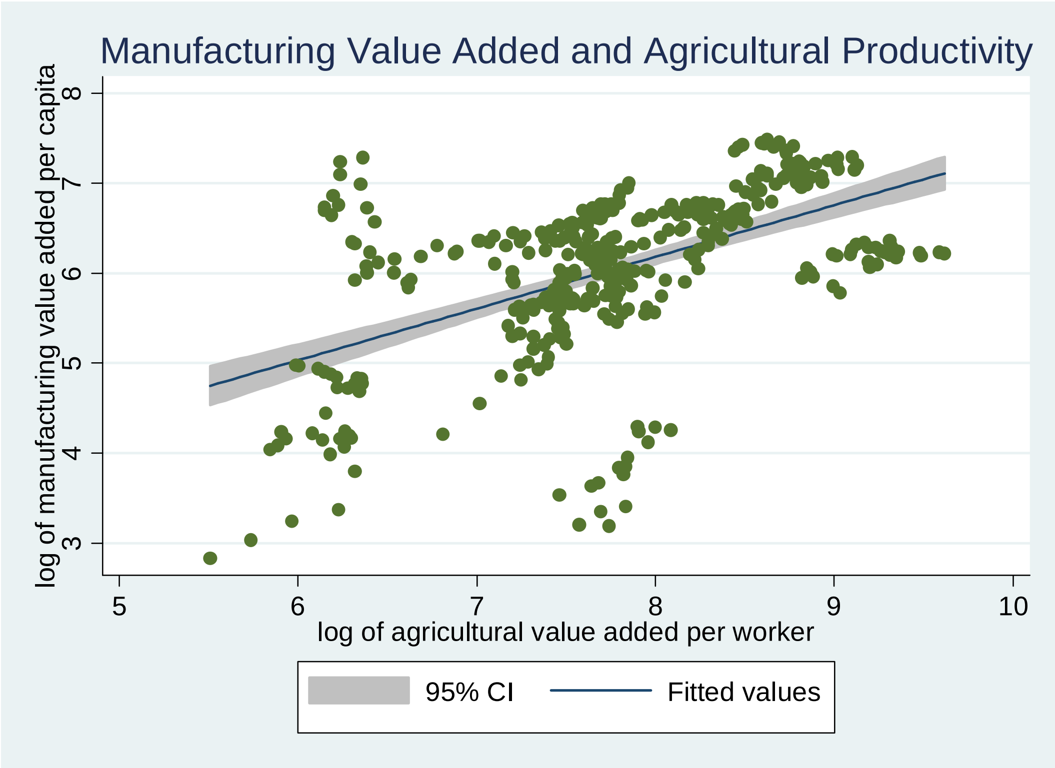
Note: All variables are in logs and absolute t-values in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 per cent, respectively.
Blank implies that ELGEN/ELGENQ was not endogenous
ELGEN = electricity-generating capacity, ELGENQ = quality of electricity-generating capacity, TINT = interaction term between trend and ELGEN/ELGENQ.

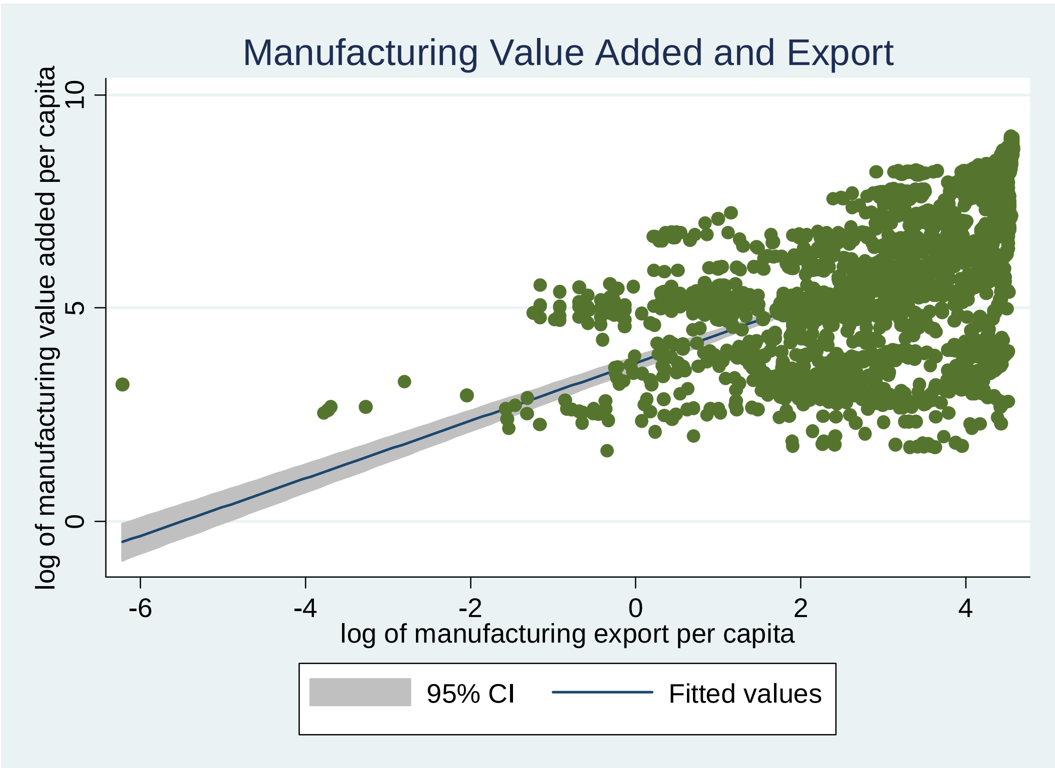
Appendix I:

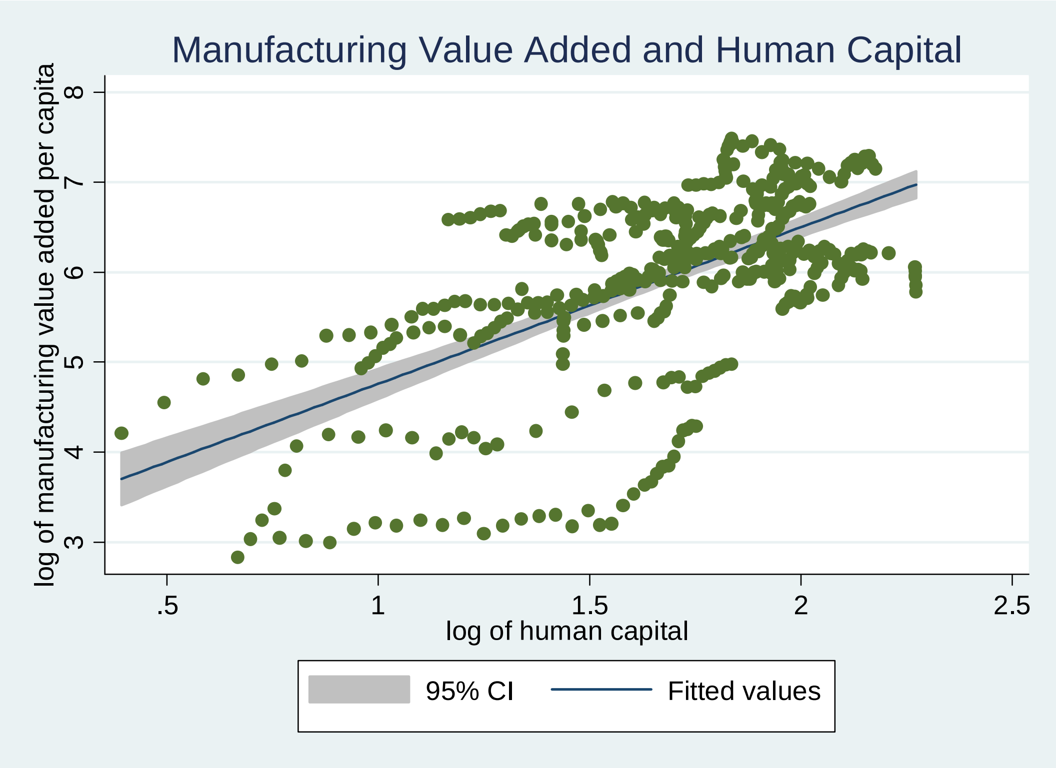
Two-way illustrations of manufacturing per capita and selection of RHS variables

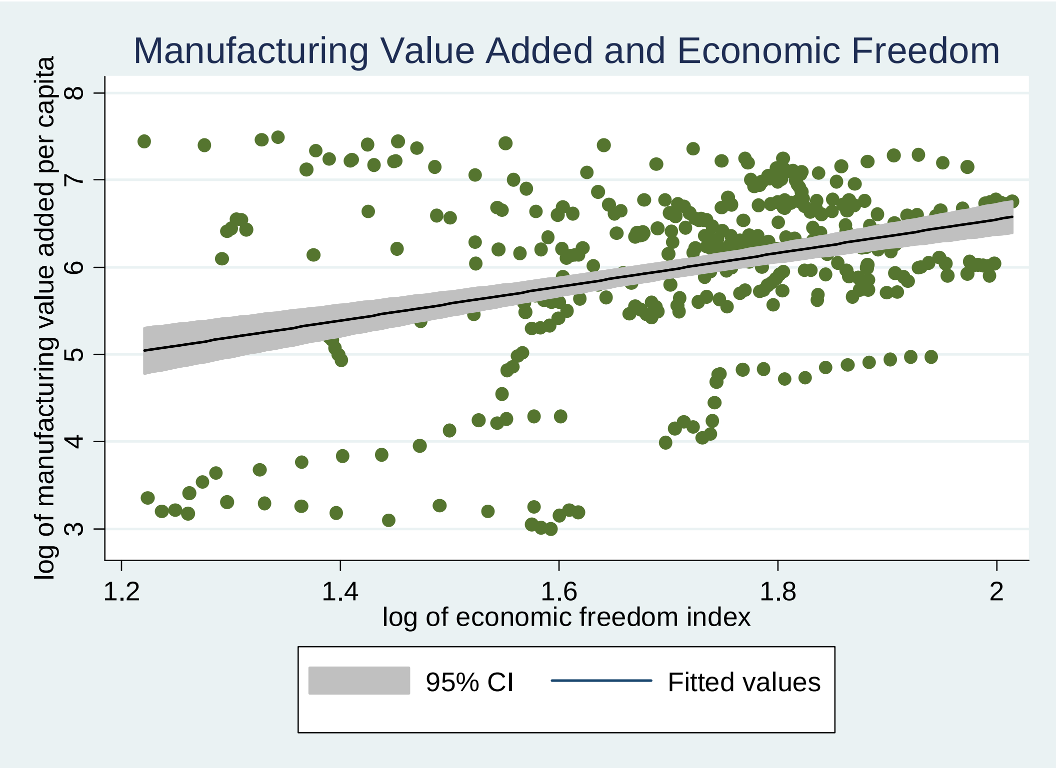





Manufacturing Value Added and Agricultural Productivity
log of manufacturing value added per capita
3
4
5
6
7
8
5
6
7
8
9
10
log of agricultural value added per worker
95% CI
Fitted values

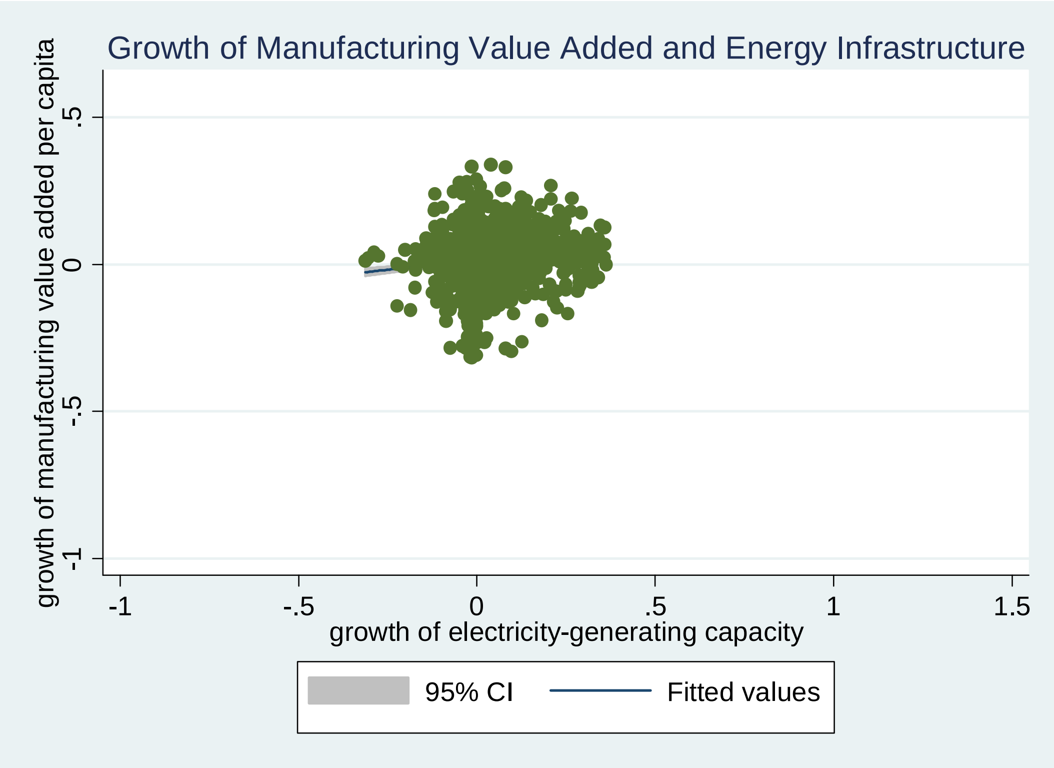

Manufacturing Value Added and Export
log of manufacturing value added per capita
0
5
10
-6
-4
-2
0
2
4
log of manufacturing export per capita
95% CI
Fitted values

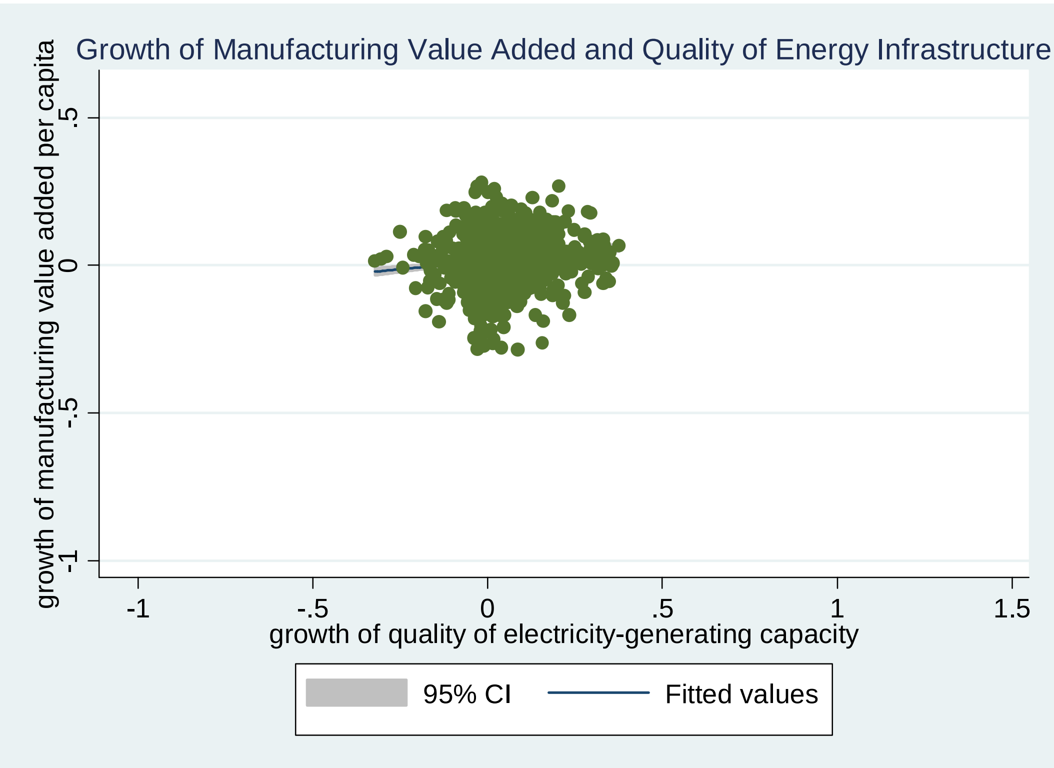

Manufacturing Value Added and Human Capital
log of manufacturing value added per capita
3
4
5
6
7
8
.5
1
1.5
2
2.5
log of human capital
95% CI
Fitted values

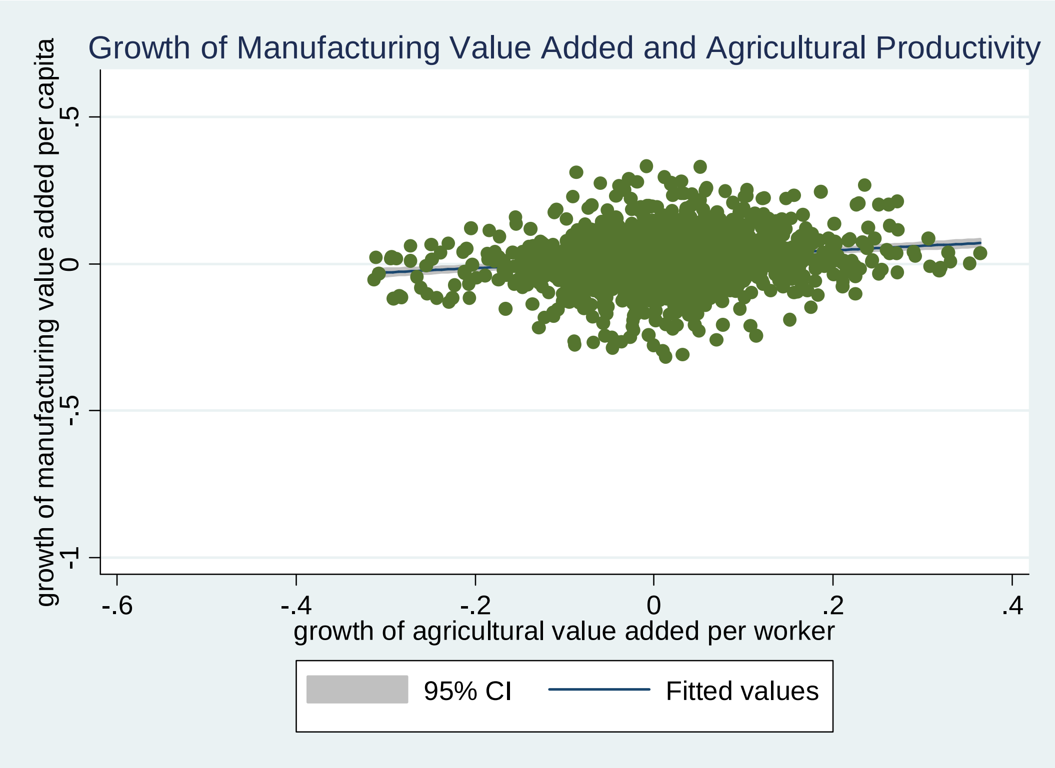

Manufacturing Value Added and Economic Freedom
log of manufacturing value added per capita
3
4
5
6
7
8
1.2
1.4
1.6
1.8
2
log of economic freedom index
95% CI
Fitted values

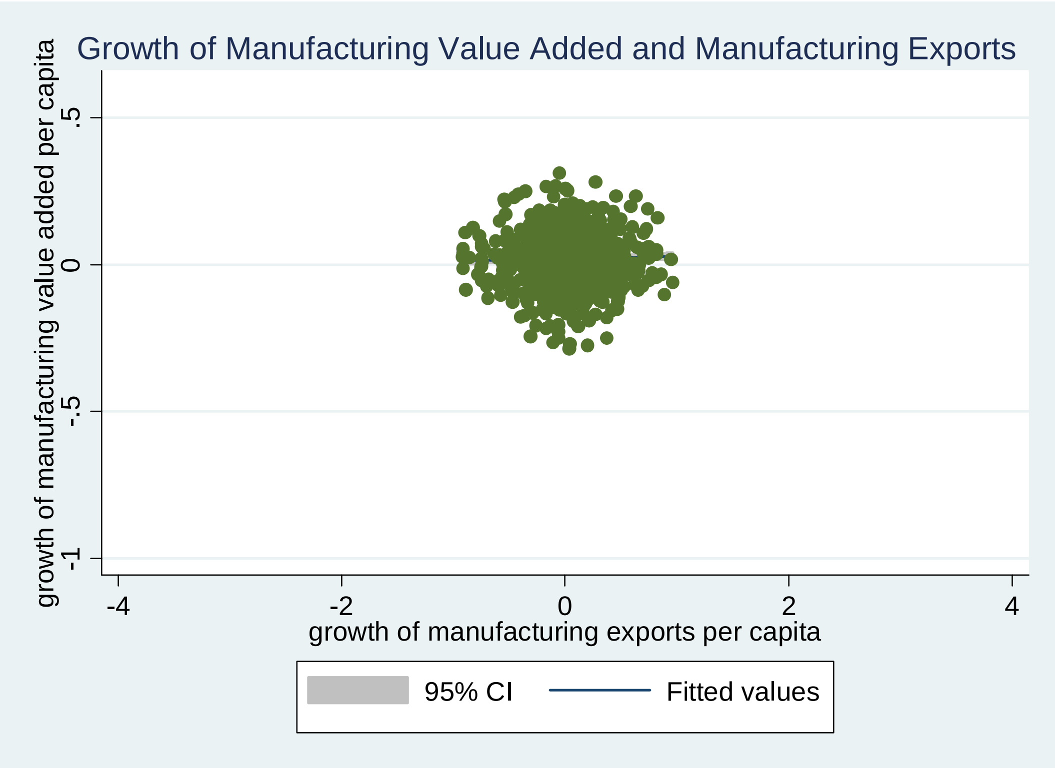
Appendix II:

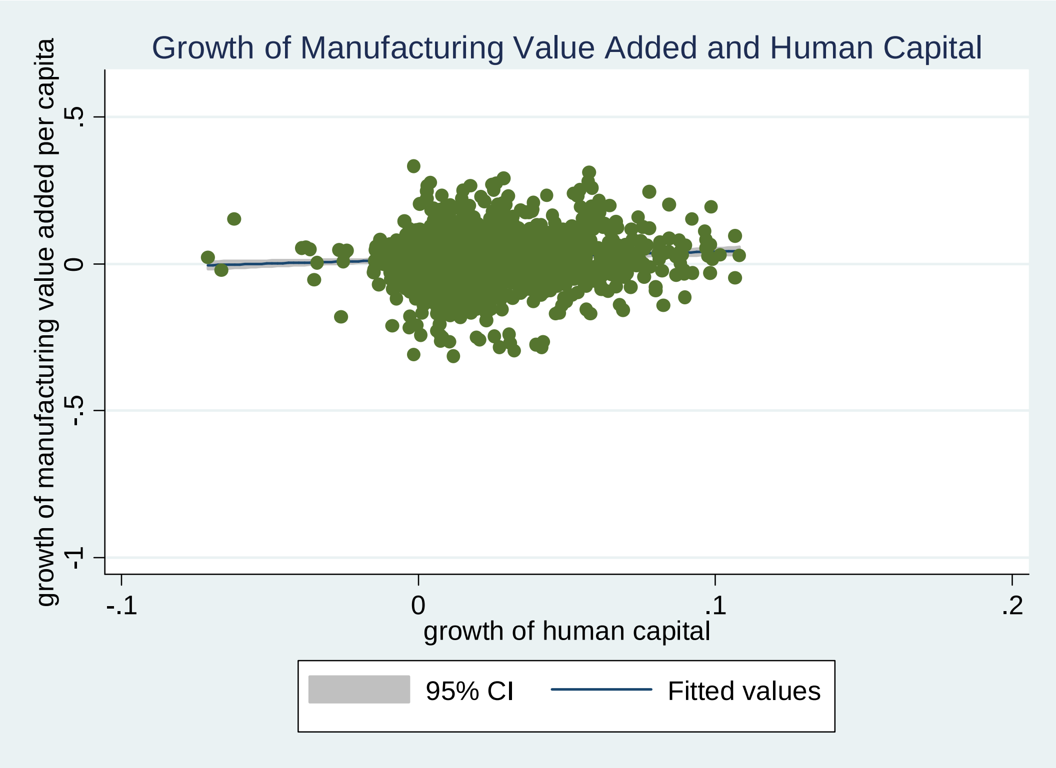
Two-way illustrations of change in manufacturing per capita and selection of RHS variables

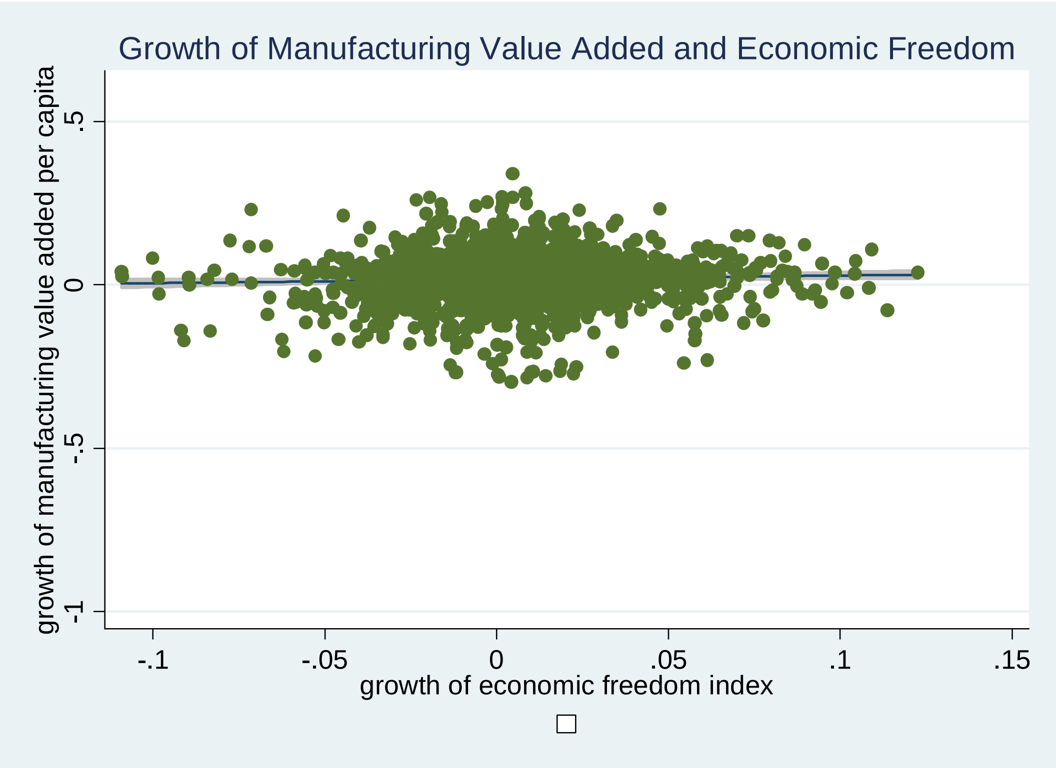





Growth of Manufacturing Value Added and Agricultural Productivity
growth of manufacturing value added per capita
-1
-.5
0
.5
-.6
-.4
-.2
0
.2
.4
growth of agricultural value added per worker
95% CI
Fitted values


Growth of Manufacturing Value Added and Manufacturing Exports
growth of manufacturing value added per capita
-1
-.5
0
.5
-4
-2
0
2
4
growth of manufacturing exports per capita
95% CI
Fitted values


Growth of Manufacturing Value Added and Human Capital
growth of manufacturing value added per capita
-1
-.5
0
.5
-.1
0
.1
.2
growth of human capital
95% CI
Fitted values


Growth of Manufacturing Value Added and Economic Freedom
growth of manufacturing value added per capita
-1
-.5
0
.5
-.1
-.05
0
.05
.1
.15
growth of economic freedom index

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Telephone: (+43-1) 26026-0, Fax: (+43-1) 26926-69
E-mail: unido@unido.org, Internet: www.unido.org