CONTEXTUAL DETERMINANTS OF TRANSPORT INFRASTRUCTURE PRODUCTIVITY: THE CASE FOR A NEW MODELING STRATEGY

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I. INTRODUCTION AND OVERVIEW

Since the pioneering Japanese contribution of Koichi Mera (1973), there have been a variety of analytical explorations of the contributions of public infrastructure to economic productivity. In the first fifteen years, this line of inquiry was the province of transport and regional economists, economic geographers, and regional scientists. A number of production functions and cost functions -- initially the Cobb-Douglas variety but eventually with more flexible functional forms -- were applied to national and regional data on (aggregate or sectoral) output, private factor inputs and public capital stocks in the U.S., Sweden, and India (Ratner, 1983; Wigren, 1984; Elhance and Lakshmanan, 1988; Keeler and Ying, 1988; Deno, 1988). The cost function studies using flexible functional forms in particular produced robust estimates of positive and modest cost elasticities of transport infrastructure.

David Aschauer (1989) with his Journal of Monetary Economics paper burst on this scene with strong claims about the productivity contributions of public capital. He had a two-part story: first, his production function analysis of post-World War II economic growth experience, concluded that public capital made a major contribution to GDP growth, outranking that of private capital; and second, he identified, in the major OECD economies, a close positive relationship between the level of public investment an economy engaged in and its rate of growth of productivity --- an inference that drew the attention of mainstream economics and policy personnel. The resulting ferment (at a time of concern with productivity declines in the U.S. economy) in academic and public policy debates led to a host of claims and counterclaims about public capital, methodological attacks on and improvements of Aschauer’s model, and a variety of new sophisticated analyses of public infrastructure (e.g. Nadiri and Mamuneas, 1996). The outcome has been a growth industry in the last fifteen years in the modeling of the productivity contributions of infrastructure.

Two types of lessons emerge from this literature developed over the last three decades on the economic contributions of infrastructure: First, there is the traditional view that transport

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1 Aschauer appears to have been blissfully unaware of earlier macroeconomic modelling efforts which had addressed the statistical and conceptual weaknesses of his formulation.
infrastructure contributes to economic growth and productivity. This view, reflecting a great many studies, which use various specifications of production and cost functions over different time periods, in different countries, and with slightly different representations of several variables, is that this contribution is modest and variable by economic sector and type of infrastructure.

Second, some recent (methodologically sophisticated) studies, however, produce some seriously dissonant estimates of the productivity of transport infrastructure (e.g. output or cost elasticities and net rates of return of transport capital). As we detail below, these elasticities and rates of return differ sharply for the same country for one period and over time, for different countries at comparable stages of development, and for countries in different stages of development.

These conflicting and dissonant results cannot be attributed in these cases to the deficiencies of functional form or statistical methods. A legitimate question then is whether macroeconomic modeling of transport infrastructure is underspecified and is unable to incorporate key transport-economy linkage processes. A well-known major deficiency of the macroeconomic research is that it does not take into account the network character of roads or other transport modes. The productivity-enhancing impact of transport infrastructure depends on the spatial, temporal, and development stage of the network. The impact of a road investment depends very much on where in the network it is made. The impacts can be large if the investment completes a route or relieves a congested section. The impacts of a transport infrastructure investment on regional incomes depend on initial levels of income and degrees of economic integration. If it is made in a ‘peripheral’ region the economic impacts may be slight. Again, if the transport investment is made in the early years of a large transport network formation the effects can be significant. If the infrastructure investment is made in a declining or low growth period, the economic response will be minimal. Finally, the impact of transport infrastructure investments in a highly industrialized economy with already large stocks of infrastructure capital is likely to be less impressive than of a similar investment in a developing region, where it is likely to be a non-marginal addition to the extant limited stocks of public capital.

Another deficiency of macroeconomic modeling approach is its inability to account for threshold effects in transport development. As transport developments expand the geographical
scope of markets, above a critical density of the transport network, isolated markets fuse into a national market promoting increased specialization and an acceleration of economic growth (Kelly, 2000; Fujita, Krugman and Venables, 1995; Lakshmanan and Anderson, 2001). Further, the observed augmentation of impacts of transport investments by agglomeration factors and by innovation-led endogenous growth stimuli are not incorporated in the macroeconomic models.

The central idea of this paper is that the ‘context’ of transport improvements is critical to defining the types and forms of economic impacts generated by the improvements. The context or the environment in which transport improvements are made and in which economic actors respond to changing transport conditions can and does vary. Attributes that differentiate such contexts include: the state of the pre-existing transportation network; the state of economic development of regions undergoing transport improvements; the structure of markets (the degree and type of competition) functioning in regions; the presence of spatial agglomeration effects; and the potential for innovation-led endogenous growth. When transport investments are nonmarginal or large relative to a developing economy they are likely to alter the constellation of relative outputs and prices over the whole economy. Recent theoretical developments suggest that transport infrastructure has a major impact on the extent of the market and the ability of firms to exploit economies of scale and specialization and spatial agglomeration effects, or where infrastructure allows the greater dissemination of knowledge and technology. General equilibrium effects come into play affecting regional and interregional interactions and the resultant growth, which aggregate to the GDP as measured by macroeconomic models. The macroeconomic modeling approach, however, does not incorporate such processes yielding scale economies, agglomeration and innovation-induced effects.

Part II of the paper offers a review of recent research on the productivity contributions of transport infrastructure and the analytical issues they raise for the macroeconomic modeling approach. Part III discusses the issues of the context of transport development and analytical frameworks which can incorporate this context and enrich our understanding of the economic contributions of transport infrastructure. Part IV concludes the paper.
II. STATUS OF PRODUCTIVITY ANALYSES OF TRANSPORT CAPITAL: ANALYTICAL ISSUES

As widely known, analyses of the economic contributions of transport infrastructure take two forms: microeconomic and macroeconomic models. The microeconomic perspective tries to identify the link between specific infrastructure improvements and the productivity of specific production units. The traditional economic tool of the microeconomic perspective is cost benefit analysis (CBA), which tries to capture the benefits of time and cost savings, as well as further gains from logistical improvements and, facilities consolidation. CBA is an inherently ex ante tool which seeks to predict economic benefits to both households and firms and contrast them with project, operational, external and other costs.

By contrast, the macroeconomic models offer ex post econometric analyses of the contributions that transport infrastructure investments offer an economy in terms of cost reductions and output expansion -- such effects typically captured by cost functions and production functions. The idea of the macroeconomic models is that there are externalities to investments in transport infrastructure which are not captured in microeconomic CBA studies. The incorporation of these externalities allows the macroeconomic models potentially to identify social rates of return to transport infrastructure. However, models which represent aggregate output by GDP, can capture the value of time savings from infrastructure only to the extent that time saved is applied to production -- missing time savings devoted to leisure (which can be picked up by CBA). Further, analyses focusing on aggregate output may ignore relative price effects of transport facility construction, which can yield a sizeable welfare effect (Haughwout, 1998).

Such macroeconomic analyses of productivity of transport infrastructure have been carried out over the last three decades in Japan, U.S., Sweden, U.K., France, Germany, India, Mexico, and elsewhere. These different studies vary along many dimensions:

* in the functional specification of those models, (Cobb-Douglas, CES, or flexible functional forms);
* in the types of measures they apply to different model variables such as output (e.g. GDP, personal income, Gross state Product, etc.), or public capital (Value of capital stock or other measures of physical infrastructure);

* in the level of disaggregation of economic sectors [e.g. from aggregate output in the Aschauer model to outputs by 35 sectors in the Nadiri-Mamaneus model]

* in the size of the geographic areas used (nation, region, state, metro area, or county), and

  - in the temporal level of analysis (time-series, cross section, or pooled)

**Agreements and Sharp Disagreements in the Literature**

The major agreement that can be gleaned from these macroeconomic analyses of transport-economy linkages is the broad support for the view that transport infrastructure contributes to economic growth and productivity. However, this contribution is modest and variable over time. This inference about the economic impact of infrastructure is robust, as it reflects a great many studies which use various specifications of production and cost functions over different time periods, in different countries, and with slightly different representations of several variables (See Table 1).

**Table 1. Summary of Output and Cost Elasticities of Highway and Other Public Capital in Various Countries**

<table>
<thead>
<tr>
<th>Country</th>
<th>Sample</th>
<th>Infrastructure Measure</th>
<th>Elasticity Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>aggregate (ts) states (xs) states (ts/xs) regions, trucking industry (ts/xs)</td>
<td>public capital public capital highway capital highway capital</td>
<td>output: 0.05 to 0.39 output: 0.19 to 0.26 output: 0.04 to 0.15 cost: 0.044 to -0.07</td>
</tr>
<tr>
<td>Japan</td>
<td>regions (ts/xs)</td>
<td>transportation &amp; communication infrastructure</td>
<td>Output: 0.35 to 0.42</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>aggregate (ts)</td>
<td>public capital</td>
<td>cost: negative, statistically significant</td>
</tr>
<tr>
<td>France</td>
<td>regions (xs)</td>
<td>public capital</td>
<td>output: positive, statistically significant</td>
</tr>
<tr>
<td>Germany</td>
<td>industry (ts/xs)</td>
<td>public capital, highway capital</td>
<td>cost: negative, statistically significant</td>
</tr>
<tr>
<td>India</td>
<td>aggregate (ts), states (xs)</td>
<td>economic infrastructure: roads, rail, electric capacity</td>
<td>cost: -0.01 to -0.47</td>
</tr>
<tr>
<td>Mexico</td>
<td>national, 26 industries</td>
<td>transportation, communication &amp; electricity, public capital</td>
<td>returns to public capital: 5.4% - 7.3%</td>
</tr>
</tbody>
</table>

*Note: ts=time-series; xs= cross-section*
However, this inference of a modest positive contribution of infrastructure investments masks some sharp differences and conflicts in the results of recent studies. If one compares the different measures of economic contribution of infrastructure (e.g. output elasticities, cost elasticities or rates of return of transport infrastructure), there appear to be sharply different results among the recent studies:

* for the same country overall, and at different periods of time,
* for different countries at comparable stages of development,
* for countries at different stages of development and,
* where threshold effects and accelerated growth are evident.

This large variety of conflicting results can not be attributed to methodological deficiencies as many of them are associated with recent studies employing sophisticated functional forms and statistical methods.

*Differential Results for the Same Country or Countries at Similar Stages of Development*

Table 2 illustrates one aspect of this dissonance among the studies about the impact of public capital. Pereira (2001) and Demetriades and Mamuneas (D-M 2000) apply sophisticated production functions to analyze the relationships between public capital and output in 12 OECD countries for approximately the same period, using respectively a Vector Auto Regressive/ Error Correction Mechanism (VAR / ECM) framework and a flexible functional form for the profit function.

First, the D-M (2000) study estimates output elasticities of public capital for the U.S. (and for Sweden and Germany) four times as large as the Pereira (2001) study does. For U.K. and Japan, the estimates are twice as large. Why do the studies offer such different results?

Further, the five OECD countries in Table 2 are affluent industrialized countries with comparable levels of technological evolution, industrial composition and income and consumption. As the various transport-using firms respond to transport infrastructure and service improvements in an economy, the many market mechanisms and structural processes interact and generate the economic effects rippling through the economy and culminating in the growth
in GDP. Such effects in these 5 economies can be expected to be of comparable magnitude. Yet, D-M (2000) study’s estimates of the output elasticities, however, range from 1.03 (U.S.) to 0.358 (U.K.); Pereira’s estimates range from 0.2573 (U.S.) to 0.143 (U.K.).

Such sharp differences in parameters for the same country and for countries in comparable levels of development need an explanation.

Table 2. Productivity Effects of Public Capital: Sharply Dissonant Results

<table>
<thead>
<tr>
<th></th>
<th>U.S</th>
<th>Japan</th>
<th>U.K.</th>
<th>Sweden</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pereira (2001) Vector Auto Regressive/Error Correction. Mechanism - data early 1960s to later 1980s</td>
<td>L.R. (10 yr) 0.2573</td>
<td>0.2525</td>
<td>0.1430</td>
<td>0.2270</td>
<td>0.1905</td>
</tr>
<tr>
<td>Demetriades and Mamuneas (2000), Flexible functional form for profit function (data for 1972-1991)</td>
<td>1.03</td>
<td>0.499</td>
<td>0.358</td>
<td>1.217</td>
<td>0.768</td>
</tr>
</tbody>
</table>

Figure 1 traces the variation of infrastructure productivity over time in the U.S. The Nadiri-Mamuneas (1996) identify net rates of return of Highway capital (which makes up a major part of public capital):

* Between 30% to 45% for years 1951-67,
* from 15% to 30% for years 1968-78 and,
* Below 15% for 1979 to 1987

The net rate of return of public capital was higher than that of private capital from 1951 to 1978. In subsequent years, private capital had higher rates of return than highway capital.
Fernald’s (1999) analysis of public capital’s contribution to U.S. industry productivity between 1953 and 1989 suggests a similar time pattern of effects. He suggests that the massive road-building of the 1950s and 1960s (the interstate system) offered ‘a one-time’ increase in the level of productivity (in the pre-1973 period).

Demetriades and Mamuneas (2000), on the other hand, arrive at a time pattern of productivity effects in the U.S., different from that espoused by Nadiri-Mamuneas and Fernald. They identify net rates of return of public capital, which exceed consistently private net rates of return of private capital in the U.S. all the way from 1972 to 1991. Indeed, the estimated long-run net rates of return to public capital in the U.S. (and Canada, Japan, Germany, France, Italy and U.K.) remained above those of private capital. In other words, an extra dollar of investment in the early 1990s (according to Demetriades and Mamuneas) would have been socially more productive in the long-run if it were invested as public capital.

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2 Fernald (1999) argues that the aggregate correlation between productivity and public capital primarily reflects causation from public capital to productivity, and the slowdown in productivity growth after 1973 may reflect the public investment patterns in that period.
Thus, for the period of the mid 1970s to early 1990s, two different patterns of productivity performance of public capital are offered by the Nadiri - Mamuneas and Fernald studies on the one hand and by Demetriades and Mamuneas on the other.

*Countries at Different Stages of Development and Threshold Effects*

Figure 2 presents (and Table 3 summarizes) the estimates of the elasticities of output with respect to public capital for a panel of countries in different stages of development (Canning and Bennathan, 2000). There is an inverted U shape, with higher elasticities in middle income countries and somewhat lower in the low and the high ends of the income distribution.

Table 4 reports the rates of return to paved roads obtained from a translog production function (Canning and Bennathan, 2000) in a set of countries which span the world income distribution. High rates of return to paved roads are evident in some middle income developing countries (Chile, Columbia, South Korea, and the Philippines). By contrast, low rates of return accrue to paved roads in affluent developed countries and in some developing countries.

**Table 3. Transport Infrastructure Productivity in Countries at Different Stages of Development**

<table>
<thead>
<tr>
<th></th>
<th>Countries in Lower Quartile of Incomes</th>
<th>Countries in Middle Quartile of Incomes</th>
<th>Countries in Upper Quartile of Incomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Elasticity of Paved Roads</td>
<td>0.05</td>
<td>0.09</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*Source: Canning and Besanthan, 2000.*
Table 4. Net Rates of Return for Paved Roads and Private Capital around the World

<table>
<thead>
<tr>
<th></th>
<th>Rate of Return to Paved Roads</th>
<th>Rate of Return to Private Capital</th>
<th>ROR Paved Roads/ROR Private Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>3.85</td>
<td>0.29</td>
<td>13.33</td>
</tr>
<tr>
<td>Australia</td>
<td>-0.01</td>
<td>0.30</td>
<td>-0.02</td>
</tr>
<tr>
<td>Bolivia</td>
<td>7.9</td>
<td>0.21</td>
<td>37.09</td>
</tr>
<tr>
<td>Botswana</td>
<td>0.20</td>
<td>0.58</td>
<td>0.34</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.61</td>
<td>0.57</td>
<td>1.07</td>
</tr>
<tr>
<td>Cameroon</td>
<td>1.88</td>
<td>0.35</td>
<td>5.31</td>
</tr>
<tr>
<td>Chile</td>
<td>5.24</td>
<td>0.73</td>
<td>7.15</td>
</tr>
<tr>
<td>Columbia</td>
<td>9.47</td>
<td>0.54</td>
<td>17.53</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>1.96</td>
<td>0.37</td>
<td>5.24</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.12</td>
<td>0.30</td>
<td>0.40</td>
</tr>
<tr>
<td>Ecuador</td>
<td>1.97</td>
<td>0.51</td>
<td>3.85</td>
</tr>
<tr>
<td>El Salvador</td>
<td>1.11</td>
<td>0.47</td>
<td>2.38</td>
</tr>
<tr>
<td>Germany, West</td>
<td>0.16</td>
<td>0.29</td>
<td>0.55</td>
</tr>
<tr>
<td>Honduras</td>
<td>0.39</td>
<td>0.34</td>
<td>1.15</td>
</tr>
<tr>
<td>India</td>
<td>0.74</td>
<td>0.78</td>
<td>0.96</td>
</tr>
<tr>
<td>Indonesia</td>
<td>2.03</td>
<td>0.83</td>
<td>2.45</td>
</tr>
<tr>
<td>Italy</td>
<td>0.26</td>
<td>0.34</td>
<td>0.76</td>
</tr>
<tr>
<td>Japan</td>
<td>0.62</td>
<td>0.20</td>
<td>3.05</td>
</tr>
<tr>
<td>Kenya</td>
<td>0.53</td>
<td>0.35</td>
<td>1.51</td>
</tr>
<tr>
<td>Korea, Rep.</td>
<td>15.76</td>
<td>0.43</td>
<td>36.95</td>
</tr>
<tr>
<td>Liberia</td>
<td>1.04</td>
<td>0.15</td>
<td>6.82</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.15</td>
<td>0.32</td>
<td>0.46</td>
</tr>
<tr>
<td>Pakistan</td>
<td>0.52</td>
<td>1.17</td>
<td>0.45</td>
</tr>
<tr>
<td>Panama</td>
<td>2.18</td>
<td>0.38</td>
<td>5.76</td>
</tr>
<tr>
<td>Philippines</td>
<td>7.19</td>
<td>0.40</td>
<td>17.99</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.06</td>
<td>0.29</td>
<td>0.21</td>
</tr>
<tr>
<td>Turkey</td>
<td>1.58</td>
<td>0.78</td>
<td>2.03</td>
</tr>
<tr>
<td>U.K.</td>
<td>0.13</td>
<td>0.39</td>
<td>0.32</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>0.07</td>
<td>0.29</td>
<td>0.26</td>
</tr>
<tr>
<td>Zambia</td>
<td>0.65</td>
<td>0.24</td>
<td>2.69</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>0.15</td>
<td>0.45</td>
<td>0.33</td>
</tr>
</tbody>
</table>

To contrast the attractiveness of transport infrastructure capital, column 3 of Table 4 lists the rates of return to private capital. Again, the highest rate of return is observed in middle income countries (with the top returns associated with the top half of the middle income countries). Further, the ratio (column 4) of the rate of return of paved roads to that of private...
capital is less than one in all affluent developed countries and in the poorer developing countries, but several multiples of one in a group of middle income countries.

It is generally observed that private returns to capital are quite low in the poorer developing countries, and that diminishing returns to capital set in slowly in affluent industrialized countries --- because they can keep up their marginal productivity up by accumulating large amounts of human capital (Canning and Bennathan, 2000). The higher returns to private capital are also understandable in the middle income newly industrializing countries (NICs), which have received in recent years considerable flows of foreign direct investment (and associated technologies) from developed countries and participate in the global production system. If one assumes that NICs have invested in transport infrastructure to facilitate participation in global production and trade, a legitimate question arises: whether the high rates of return to paved roads observed in such countries reflect an expansion of transport networks to a critical density at which interregional economic integration occurs, thereby promoting regional specialization and accelerated growth in those economies.

Indeed, such an evolutionary path for a developing economy to a stage of accelerating growth initiated by expansion of transport networks is the result of a dynamic growth model elaborated by Kelly (1997) --- an outcome that cannot be detected in the macroeconomic models reviewed above. Kelly analyzes the evolution of an economy whose growth is driven by increased specialization caused by geographic expansion of markets. Below a critical density of transport linkages, the economy is split into isolated local markets with limited specialization. With transport investments, a geographical expansion of markets occurs. Above a threshold density, these isolated markets begin to fuse into a large economy-wide market promoting increased specialization, reallocation of labor into more efficient production and growth acceleration.

Kelly (1997) demonstrates this threshold effect in a dynamic model of Smithian growth first parametrically and later as holding in general. He proceeds to use this model to provide a formal evaluation of the role of transport-induced market expansion in the economic transformation of the Sung Dynasty China. Between the 8th and the 12th centuries Sung China built a 30,000 mile national network of canals and navigable rivers, and changed from a simple subsistence economy to a level of commercial and industrial development not matched anywhere
until the end of the 18th century. Kelly assembles historical data on real money supply (a proxy for real output growth) to capture the patterns of market expansion and economic growth.

Figure 3 is a plot of the log of real money supply series (a proxy for real output growth) from 805 A.D. to 1075 A.D. Around 1000 A.D., when the waterway network was completed linking the more important parts of China, there is a marked acceleration of growth.

**Figure 3. Real Money Supply in China, 805-1075 A.D.**

Spatially Variant Effects of Transport Infrastructure

While transport cost reductions lead to beneficial impacts in the aggregate (as measured by macroeconomic models), they can also have spatially variable impacts, being unfavorable in some places which are ‘peripheral’ and have a poor degree of economic integration.

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3 By 1075 A.D., manufacturing enterprises in mining, metallurgy, and shipbuilding operated on a large scale, employing hundreds and often thousands of workers serving large geographic markets via a national waterway network. Key innovations were: use of coal in iron smelting, a Bessemer process for steel production, a water-powered spinning wheel, printing and gunpowder; universal use of money, negotiable instruments facilitating large transactions over large distances. There was also a complex set of articulated markets from periodic village markets to large urban markets (Kelly, 1997).
Alternatively, a major transport investment made in a situation of poorly developed prior transport networks can yield large non-marginal developmental impacts.

Recent theoretical developments provide an analytical handle for measuring a variety of such interacting sectoral/spatial/regional effects, which derive from improvements in transport infrastructure and freight services. These effects trace the various mechanisms by which transport and logistical improvements course through the economy. The freight industry’s cost-service improvements impact in an interactive fashion on labor markets, product markets, and land markets. The new insight of ‘the new economic geography’ literature is that imperfect competition is relevant to both the transport service sectors and transport-using sectors. As contrasted with the macromodelling approach, the advantage of this general equilibrium approach is its ability to trace the linkages (and transmission mechanisms) within and between various economic sectors. If different sectors display different degrees of competition, different transmission mechanisms will operate interactively through labor and product markets to yield variable consequences -- with understatements sometimes and overstatements other times of economic impacts, as compared to the usual assumption of perfect competition. From this perspective, it is possible to incorporate increasing returns to scale and potentially virtuous and vicious circles of economic impacts. The implications of such general equilibrium responses — the way firms respond to logistical changes, the way labor and product markets respond to transport changes -- are changes in the geographic distribution of economic activity and in the differential growth of regions summing up to national growth. This approach offers potentially a richer transparent portrait of the various mechanisms which translate the improvements induced by transport infrastructure investments into broad economic impacts rippling through the economy.

More generally, the variety of dissonant results from the macroeconomic models, the occurrence of threshold effects and, the spatially variant effects noted above make a key point at the heart of this paper. That is, that the type and magnitude of the economic benefits that derive from a transport infrastructure investment depend on the context in which the transport investment is made. As we detail in the next section, this context can be defined partly in terms of where, when, and at what stage of development of the network the transport investment is made. This context is the environment in which producers and consumers respond to changing
conditions and initiate the interactive market forces and structural processes which lead to wider economic impacts.

In reality, we view the contexts of transport investments in more differentiated forms than can be handled in macroeconomic analysis in the next section.

III. CONTEXTUAL DETERMINANTS OF TRANSPORT PRODUCTIVITY

This paper argues that the types and magnitudes of economic impacts depend critically on the ‘context’ in which the transport infrastructure investment is made. The context or the environment within which transport improvements are made define the conditions which confront the various producers and consumers in the economy and which affect their behavior. Given the ubiquity of transport investments around the world, the conditions under which these investments are made, vary significantly. As transport improvements occur in richly differentiated contexts, the underlying constellation of economic forces in each context are likely to vary. Corresponding to these forces of change in each context, the scale and scope of responses of regional firms and individuals to transport improvements are likely to be different -- with the consequent socioeconomic impacts of different magnitude and manifest at different temporal and spatial scales.

We recognize here five such contextual determinants of productivity of transport development:

* The network context, defined in terms of spatial, temporal and developmental stage of the network,
* The level of economic development --- the threshold effect,
* Structure of markets functioning in the regions,
* Potentials for agglomeration effects and,
* Innovation-led endogenous growth effects.
The Network Context

One drawback of the macroeconomic modeling approach is that it does not take into account the network character of transport (as in roads or rail), which is an important determinant of economic impacts. Three dimensions of the network are relevant here. The type and magnitude of the economic impact of transport infrastructure depends on where, when, and at what stage in the evolution of the network the improvement is made.

The type and magnitude of the impact of a road investment depends very much on what part of the network it is made. The impacts can be large if the investment completes a route or relieves a congested segment of the network. If the transport improvement is implemented in a poorly integrated ‘peripheral’ region the economic impacts may be small. Sometimes, a large region with considerable quantity of infrastructure may register minimal regional economic benefits from transport infrastructure. As BTS (1995) notes, such a case may reflect the bridge nature of that region in the national road network --- as rural states that lie between major manufacturing regions. A Chicago firm selling goods in Seattle will truck them there by way of inter-state highways across South Dakota, Wyoming, Montana, and Idaho. While the infrastructure in those states contributes to income reported as produced in Illinois, the rural states present a picture of a very high ratio of highway infrastructure to the size of the labor force.

Again, if the transport investment is made in the early years of a large transport network formation the effects can be significant. If the infrastructure investment is made in a declining or low growth period, the economic response will be minimal. Finally, the impact of transport infrastructure investments in an affluent industrialized economy (e.g. U.S., Germany, U.K., etc.) with already large stocks of infrastructure capital is likely to be less impressive than in a similar investment in a developing region. In the latter country, a new divided highway linking an industrial city and a port is likely to be a non-marginal addition to the extant limited stocks of public capital. In such cases in developing countries, there can be large developmental impacts of transport improvements.  

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4 One potential approach to incorporating the network effects in macroeconomic models is to use a measure of accessibility to infrastructure services (to major export nodes) as an argument in the production function, as exemplified in Johansson (1993), and Forslund and Johansson (1995). The Forslund-Johansson approach offers the
Developmental Context

There have been occasions in history when transport improvements have led to dramatic economic impacts. At a particular stage in the economic development of a country or region, transport investments not only augment growth, but also initiate radical changes in the structure of production thereby accelerating the growth process. For example, the development first of canals and later of railroads in the 19th century U.S. made it possible for huge areas of the Midwest of the U.S. to be developed for specialized agriculture serving a national market. Before the development of railroads, only areas adjacent to navigable rivers and canals could ship goods economically. When railroad mileage increased dramatically after 1848, the markets in mid-Atlantic and the Midwest were integrated. Not only were areas cleared for agricultural specialization (Figure 4) but also specialized processing industries (Figure 5) sprang up. Thus at this stage of development, transport improvement made changes in the structure of production possible. In a shift from autarky to specialization this process involved the creation of new economic regions whose growth was driven from an early stage primarily by export commodities. Furthermore, it involved a fundamental transformation of production technologies, achieving much higher productivities through specialization and large-scale production. It can be argued that a host of improvements in agricultural technology were induced, at least in part, by the expanded market opportunities made possible by freight improvements.

Kelly’s model of dynamic Smithian growth and its illustration in the economic transformation in Sung China induced by network expansion to a critical level provides another example of development stage as a contextual factor in economic impacts of infrastructure.

Markets, Agglomeration, and Innovation

Transport improvements shrink space and time. The economic function of transport infrastructure networks is enabling -- connecting and integrating economic activities in space. When infrastructure networks are improved, an important analytical question relates to the way
in which the transport-providing firms and transport-using firms respond to the lower costs, time savings, and the accessibility-enhancing improvements.

Figure 6 provides an outline of the way transport improvements initiate interactive economic effects which ripple through the broader economy. It identifies and links the many market mechanisms and technical and structural processes, which interact with one another and generate what may be termed as general equilibrium effects of transport improvements. The upshot of these full effects is the TFP growth in the economy.

**Figure 4. Acres of Improved Land in the Midwest: 1810 – 1860**

Figure 5. Value of Manufactured Products in the Midwest: 1840 - 1860

Figure 6. Transport Infrastructure Supply Freight Services Sector and Full Economic Effects

Transport Infrastructure Investments

Improved Freight/Service Attributes: (lower costs, time-savings, more reliability, new services)

Increase Accessibility and Market Expansion (Gains from Trade)

Improved Labor Supply

Export & Import Expansion & Competitive Pressures

Expanded Production

Economic Restructuring Exit/entry of firms

TFP (Total Factor Productivity) & GDP Growth

Increasing Returns to Scale & Spatial Agglomeration Effects

Innovation & Technical Diffusion
As transport infrastructure and service improvements lower costs and increase accessibility to various market actors -- input suppliers, labor, and customers -- *market expansion and integration* will ensue. Opportunities for exporting and importing goods are enhanced, in turn opening up several channels of economic effects, both in product markets and in factor markets -- in a manner analogous to the results from tariff reduction and trade area expansion.

First, export expansion will lead to higher levels of output, which allow higher sales to cover fixed costs of operation, yielding efficiencies; Second, increasing imports put competitive pressures on local prices. Such pressures lead not only to the removal of monopoly rents but also to improved efficiency. Schumpeterian dynamics come into play — firms entry, exit, expansion, contraction. As firms promote leaner production processes, which lower costs of production and raise productivity, further restructuring of the economy occurs. Third, lower transport costs and increased accessibility enlarge the markets for labor and other factor inputs. Firms will likely draw labor from a broader area and with a greater range of attributes improving labor supply and with lower costs. Similar effects in land and other factor markets are likely as transport improvements open up new land for economic activities.

However, in an integrated market, there are likely some feedback effects associated with expanded production, which may dampen the initial strong positive impacts of transport improvements noted above. Since production expansion deriving from market expansion will raise the demand for labor and land, wages and rents will go up offsetting part of the initial lowering of costs and gains in competitiveness. The wage rises, if persistent, will have migration consequences. Finally, higher production may induce congestion in the networks and a rise in transport costs. The point to be made here is that transport improvements initiate a sequence of economic effects and feedback effects in a number of interacting markets.

Finally, Figure 6 suggests that the two mechanisms in the oval boxes, one dealing with innovation and the other with spatial arrangements in the economy. These two mechanisms create, *in the context of transport infrastructure improvements*, conditions which enhance economic performance, and promote total factor productivity and endogenous growth. As noted earlier, our understanding of these two mechanisms of innovation and spatial arrangements derive from recent research in Endogenous Growth theory and the ‘New Economic Geography’.

Transport improvements can have an endogenous growth effect to the degree they impact the rate of growth of the economy through the transfer of technology, thereby promoting Total
Factor Productivity (CTFP) growth, and the *rate of growth* of the economy. Such impacts of transport improvements can derive from the following sources: industrial restructuring resulting from the entry and exit of firms and the opening of larger markets (noted above in Figure 6); and the benefits accruing to various economic actors from the likely parallel increase in information and knowledge flows, especially in locations where industries are spatially agglomerated. The key notion in this case of spatial proximity is that innovation derives from the Jacobs’ (1969) *economies of variety* (as contrasted with the Marshallian economies noted below) be. Impacts from both these sources can impact the pace of technology transfer and innovation, thereby increasing TFP growth.

The core idea of the ‘new economic geography’ is the notion of increasing returns, an idea that has earlier transformed both trade theory and growth theory (Fujita, Krugman, and Venables, 1999). Taking advantage of Dixit and Stiglitz’s (1977) formalization of monopolistic competition, tractable models of competition in the presence of increasing returns have been developed in the fields of industrial organization, international trade, economic growth and location theory.

A key belief in this line of argument pertains to assumptions on the market structure of transport-producing firms and transport-using firms. It may be useful to consider the competitive structure of transport in the partial equilibrium case. As contrasted with the typical assumption in the microeconomic models of perfectly competitive markets, the belief here is that both types of transport firms are inherently *imperfectly competitive*.

Research on imperfect competition and the increasing returns to scale extends to locational analysis emphasizes the importance of the interactions between transport costs on the one hand and market size and economies of scale on the other. With dropping transport costs and economies of scale, a firm in a location gains a larger market area and dominance, which in turn promotes the concentration of other firms in the same location. This idea of a location with good access to markets and suppliers for one firm improves market and supply access for other producers there, and the process of *cumulative causation* (where a location becomes more attractive to successive firms as more firms locate) derives from earlier ideas in Economic Geography. The central feature of this theory of agglomeration (as has been noted for a long time in economic geography and regional science) is the presence of external economies of scale in the Marshallian sense. Different firms clustered in a location experience positive externalities in
the form of agglomeration economies, industrial complexes and social networks engaged in untraded interdependencies. In short order, regional specialization develops. Indeed, without increasing returns to scale in the context of transport improvements, it is impossible to account for the observed spatial concentration of firms and regional specialization in regional and national economies.

In contemporary spatial agglomerations of economic activity — where there are frequent transactions between suppliers and customers and where high-end business services often accompany goods delivery -- the cost of transactions are likely to be lower inside such centers than outside them. Further, some interregional links gain advantages from the existence of increasing returns to transportation and transactions, which may help form transportation and transaction hubs as noted by Krugman (1999) Johansson (1998) uses the notion of density (of economic activities, social opportunities and transaction options) and economic milieu in such locations as leading to self-reinforcing and cumulative causation effects. Density is a positive factor to the degree it enhances accessibility to all economic actors. Ciccone and Hall (1996) also show that productivity differentials between regions derive from differences in economic density.

The purpose of our discussion is to show how transport infrastructure and transport improvements open up markets and create conditions, in the context of spatial agglomerations and technical change and diffusion, which influence economic structure and performance. A broad variety of interactions take place within firms and between firms, within sectors and between sectors and more broadly within and between households and organizations. Hence the first inference we draw is the importance of general equilibrium analysis of transport-economy linkages. The implication is that the impacts of transport improvements must be examined in a general equilibrium fashion, dealing with linkages between sectors and within sectors, where sectors exhibit different transport requirements, varying competitive strengths, and diverse spatial markets. These effects are realized through the operation of product markets and factor (labor, land, etc.) markets and technological and structural changes. Since these interactions are not only numerous and multiple and complex but may also operate to enhance or dampen the initial economic impacts of transport improvements, a more disaggregate analysis than is currently the case is called for in future analyses of transport-economy linkages. The second
inference that can be drawn is the importance of the role of imperfect competition in the analysis of transport-economy linkages.

The third inference from the general equilibrium perspective of transport-economy linkages analysis is that there is no general analytical solution. The analytical results are contextual. The complexity and the multiplicity of the linkage mechanisms involved militate against predictions of outcomes on a priori basis. The Venables-Gasiorek (1999) work suggests that the results are case specific.

The case made here is that the current crop of transport productivity models are unable to incorporate some key transport-economy linkage processes. Such processes deriving from market expansion, agglomeration and innovation-induced effects generate general equilibrium effects at the regional and interregional levels and aggregate to national effects.

CONCLUDING COMMENTS

Models for assessing the economic contributions of transport infrastructure have been around for some time and take two forms: microeconomic (cost benefit analysis (CBA), and macroeconomic models. The macroeconomic models offer ex post econometric analyses of the contributions that transport infrastructure investments offer an economy in terms of cost reductions and output expansion --- such effects typically captured by cost functions and production functions. The idea of the macroeconomic models is that there are externalities to investments in transport infrastructure which are not captured in microeconomic CBA studies. The incorporation of these externalities allows the macroeconomic models potentially to identify social rates of return to transport infrastructure.

The sizeable literature developed over the last three decades on macroeconomic modeling of the economic impacts of transport infrastructure yields two broad conclusions. The traditional view is that transport infrastructure makes a positive but modest contribution to economic growth and productivity. However, this broad ‘consensus’ is subject to serious questioning from two developments. First, there are sharp differences and conflicts on the magnitudes and direction of these economic impacts of infrastructure --- with the measures sharply different for the same country overall, and at different periods of time, for different countries at comparable
stages of development, and for countries at different stages of development. Further, the macroeconomic models are unable to account for recently observed economic impacts of infrastructure---such as market expansion-induced threshold effects and accelerated growth in some contexts, and for growth engendered by agglomeration effects and endogenous growth effects in other contexts.

This paper advances the notion that the ‘context’ of transport improvements is critical to defining the types and forms of economic impacts generated by the improvements. The context or the environment in which transport improvements are made and in which economic actors respond to changing transport conditions can and does vary. Given the ubiquity of transport investments around the world, the conditions under which these investments are made, vary significantly. As transport improvements occur in richly differentiated contexts, the underlying constellation of economic forces in each context are likely to vary. Corresponding to these forces of change in each context, the scale and scope of responses of regional firms and individuals to transport improvements are likely to be different -- with the consequent socioeconomic impacts of different magnitude and manifest at different temporal and spatial scales.

We recognize five such contextual determinants of productivity of transport development, and discuss them in some detail:

* The network context, defined in terms of spatial, temporal and developmental stage of the network,
* The level of economic development --- the threshold effect,
* Structure of markets functioning in the regions,
* Potentials for agglomeration effects and,
* Innovation-led endogenous growth effects.

A case is developed for the need for reformulation of the transport productivity models to take into account the variety of transport-economy linkage processes that are currently ignored. Such processes deriving from market expansion, agglomeration and innovation-induced effects generate general equilibrium effects at the regional and interregional levels and aggregate to national effects.
REFERENCES


Growth and Regional Development: The Case of Highly Industrialized Developed Countries,” Jönköping, Sweden, June.


SACTRA (Standing Advisory Committee on Truck Road Assessment), 1999. *Transport and the Economy*, United Kingdom, DETR (Department of Environment, Transport and Regions) London.


