Infrastructure investments in transport links and terminals directly provide additions to flow or throughput capacity in the form of new lanes and facilities, safer and speedier movement, and operational improvements. In turn, these improved infrastructure attributes get translated into freight services characteristics such as lower travel costs, reduced travel times and travel time variability. As Figure 11 indicates, transport infrastructure attributes (e.g. capacity, safety, access etc.) influence freight service characteristics such as travel costs, freight travel times and their variability, and other services. It must be clear that freight service characteristics and the service and process innovations mutually influence one another. The service and process innovations possible at a point in time are determined by the freight time and cost characteristics available; similarly, the available service and process innovations influence the new service attributes of the freight system.

Finally, these freight service attributes and technical innovations converge on the central activity in Figure 11, namely, the logistics process and its restructuring over time. Logistics refers to the integrated analysis and management of a firm's overall supply chain and embraces processes of transportation, warehousing, inventory maintenance, order processing and administration (Figure 12). Transport enterprises coordinate with other processes precisely in order to permit lower levels of inventory, warehousing, handling, errors, and waste. Taking advantage of the service and process innovations (noted above), and the substitutability of transport and inventory carriage, there has been reorganization of the logistics with an overall reduction of total logistics costs (estimated at 40% for an average American enterprise). This logistics reorganization appears in the form of:

a) process changes, such as better management systems (Improved vehicle utilization, handling systems, etc.) and product flow rescheduling (use of JIT, quick response system, etc.). These process changes reflect improving efficiency and, through changing load factors and carrying capacity, will influence the total level of goods transport, and
b) service change, such as realignment of supply chains (new patterns of sourcing, vertical disintegration of production value chains, changing markets), and refashioning of the logistical systems (the spatial concentration of inventories and production). These service changes underlie the growth in the number of elements in a supply chain and, given the increasing market areas and the spatial dispersion of locations, the growth in the distance over which the freight is carried ³.

Quarmby (1989) suggests that the benefits of this reorganization can exceed the benefits of time savings by 30-50%, while McKinnon (1995) argues that the benefits accrue less in the form of transport cost savings but more in the form of 'service opportunities' such as precise scheduling, market expansion and spatial agglomeration.

Figure 12. Worldwide Logistics Costs Exceed $1 Trillion, Of Which $610 Million Is Non-Transport Logistics Service Charges

![Logistics Costs Diagram]

Source: P.O. Roberts, SAIC, "Presentations on Supply Chain Management: New Directions for Developing Countries", page 6, no date.

The major consequences of the logistical improvements promoted by transport infrastructure investments occur in the various freight transport service-using sectors--primary,
manufacturing, and service sectors— which make up the larger economy. How do the cost reductions and service enhancements in the freight sector provide benefits to various industries producing goods and services? What are the mechanisms and interacting pathways by which the logistics improvements course through the different transport-using economic sectors and improve the overall performance of the economy?

We respond to these issues in greater detail Section III of this paper. However, a brief summary of the argument is in order. While the impacts will clearly vary by economic sector, lowered transport costs and shorter and predictable transit times would expand the size of different markets: first, of labor markets, broadening the access of firms to a larger pool of qualified labor; second, an expansion of market areas of goods and services, providing economies of scale in production. This leads to a better integration of markets over larger areas. As many transactions costs decline, 'peripheral' areas are incorporated in the national economy, and competition is enhanced from freer interregional trade. In these regions consumers gain from lower product prices, while payments to labor may rise in the integrated marketplace. In turn, regional specialization of production develops, leading to higher levels of intra-industry and interregional trade and goods movements over an expanded national production space. Under certain conditions there is likely formation of spatial/urban clusters of firms whose knowledge specializations can yield synergistic impacts. Overall these interactive sectoral and spatial/regional effects or general equilibrium effects of transport and logistical improvements yield productivity enhancements and improved economic performance.

How do we measure the full range of these economic effects of transport investments -- a task we turn to next.

**Different Approaches to Measuring the Economic Benefits of Transport**

Since Departments and Ministries of Transport fund the large transport infrastructure investments underlying the pervasive economic effects noted above, it is not surprising that they have made several efforts to measure these economic benefits in order to develop rational criteria for their investment programs. In his review essay on Infrastructure Investment, Gramlich (1994) identifies four analytical approaches in this regard: engineering assessments, political
measures based on voting outcomes, economic rates of return, and econometric estimates of productivity impacts. Others have used other categorizations.

For our purposes, we find the three analytical approaches identified in Figure 10 useful. The three approaches can be identified as:

* Macroeconomic models
* Microeconomic models of gains from logistics reorganization, and
* Models of General Equilibrium Effects.

The greatest proportion of analytical effort on the transport-economy linkages is represented by Macroeconomic modeling. The thrust of this approach is to relate the investments in transport infrastructure to GDP (Gross Domestic Product) in the economy. It views infrastructure as a direct injection to the economy and introduced typically as a factor of production additional to the traditional factors of capital and labor in a production function. In this form, it is possible to observe whether and to what degree infrastructure increases the level of economic output and enhances the productivity of private capital. Such positive economic relationships have been observed in most studies -- both in the U.S. and abroad over the last two decades -- though the magnitude of the relationships between infrastructure investments and economic output varies widely across studies. However, this analytical apparatus is a 'black box' variety where we have little inkling about the causal mechanisms and processes which translate infrastructure investments into output and productivity enhancements. Some observers question whether strong correlations between infrastructure and the economy clarify the direction of the cause and effect. However, recent rigorous work in the area offers a firmer basis to infer the magnitudes of the economic impacts of transport infrastructure. Section III of this paper reviews the extensive literature in this area and teases out the inferences that can be drawn from this literature.

Micro-economic analysis of the relationship between transport and the economy represents the second approach. The micro view is that transport improvements such as reduced and predictable travel times and the consequent lowered vehicle operating costs will lead to
lower transport costs. The eventual consequences of such dropping transport costs include lower product prices, increasing product demand, and a higher level of economies of scale, which in turn lead to further cost reductions and output growth. The microeconomic analysis and modeling approach focuses on the direct and indirect micro-level benefits arising from the consequent changes in the freight transport services sector. The further economic changes induced by these freight services sector improvements in the many transport-using economic sectors are no, however, the object of inquiry here. As noted above, these changes in the use of freight services derive from the reorganization and spatial concentration of distribution operations and lead to wide benefits in the guise of lower inventory costs. The argument is that transport improvements, by enabling the restructuring of logistical systems, have significant indirect effects on firm competitiveness (through lower overall costs and new value-adding services). There is significant and growing amount of theoretical and empirical work to formulate analytically these indirect effects and measure them (e.g. Mohring and Williamson, HLB, 2001; Quarmby, 1989; Mckinnon, 1998; Shirley and Winston, etc.). Section IV of this paper reviews the status of development and findings of this line of micro-economic assessment of logistical reorganization.

The third approach reviewed in this paper derives from recent theoretical developments in 'The New Economic Geography', which provide an analytical handle for measuring a variety of interacting sectoral/spatial/ regional effects of a general equilibrium type 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. Such impacts are often noted in the preamble of many studies (conducted over the last four decades) of economic impacts of transport, without any further influence on the scope of that study. Indeed, the usual maintained assumption of perfect competition in transport-using sectors has the implication that transport cost changes are passed through into prices the firms charge, so that the full value of transport investment is captured by the willingness to pay and transport user benefits captures the full economic value. 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. In a path-breaking paper
commissioned by SACTRA (Standing Advisory Committee on Trunk Road Assessment) of the U.K. Department of the Environment, Transport, and Regions (DETR), Venables and Gasiorek (1999) have shown the key role of the general equilibrium approach, which traces 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. Section V of this paper reviews this strand of analysis and its implications for future transport economic impact analysis.

The three approaches have a core of common elements; however, they interact and overlap, representing and measuring somewhat different classes of economic effects. Microeconomic analysis has a transparent causal structure and captures the direct effect of transport improvements and to some degree the indirect effects of the logistics process restructuring induced by transport improvements. Macroeconomic models have a more opaque structure, but capture the full network effects or the full multiplier effects in terms of increased productivity in the economy. The third approach offers potentially a richer transparent portrait of the various mechanisms which translate the improvements induced by transport infrastructure investments into impacts rippling through the economy.

II. TRANSPORT-ECONOMY LINKAGES—CONCEPTS AND DEFINITIONS

It is part of conventional wisdom that transport investments are a crucial factor in economic growth, and in the transformation of regions and cities. The contribution of transport investments to the growth and development of the U.S. economy in the last two centuries has
been noted extensively—first the canals, then the railroads stimulating the agricultural development of the Midwest, then the transcontinental railroad linking the two coasts and helping alter the distribution of population and economic activity by around 1900, and finally the auto and the Interstate System transforming the urban landscapes shaped earlier by the streetcar (e.g. Fishlow, 1965; BTS, 1995)⁴. Similarly, the World Bank, which has funded $50 Billion in a large number of transport projects in recent decades in developing countries, estimates an average annual rate of return of 22% (Table 4) for all transport projects—as compared to a 15% rate of return for projects in all sectors (Eno, 1997).

Table 4. Estimated Returns from World Bank Projects

<table>
<thead>
<tr>
<th>Type of Project</th>
<th>Number of Projects</th>
<th>Annual Rate of Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airports</td>
<td>8</td>
<td>21%</td>
</tr>
<tr>
<td>Highways</td>
<td>306</td>
<td>26%</td>
</tr>
<tr>
<td>Rail</td>
<td>72</td>
<td>14%</td>
</tr>
<tr>
<td>Ports</td>
<td>96</td>
<td>20%</td>
</tr>
<tr>
<td>All Transport Projects</td>
<td>482</td>
<td>22%</td>
</tr>
<tr>
<td>All Sectors</td>
<td>n.a.</td>
<td>15%</td>
</tr>
</tbody>
</table>

Source: Eno, 1997, p.24

In spite of these and other impressive inferences on transport’s impacts on overall economic performance from economic history and from project appraisals, there has been a continuing debate (among planners, policy types, and academics) between those who hold that transport investments are crucial to economic growth at the regional and national levels and those that maintain an opposite view, suggesting that there is limited evidence of a causal connection between transport improvements and economic performance. Part of the debate swirls around the magnitude or size of transport’s economic impact as well.

⁴ Fishlow, computing the social savings of railroads and their impact through backward and forward linkages on different economic sectors, concluded that railroads played a role in promoting agricultural growth and specialization, and in disseminating of industrial skills throughout the economy. The BTS study provides two case studies—in Midwest and upstate New York—of developmental effects of transport infrastructure in the 19th century.
This debate is complicated by the absence of a received analytical wisdom that can settle the issues. One major strand of analysis, focusing on the linkages between transport infrastructure investments and GDP growth, is a 'black box', offering no guidance as to how improved infrastructure translates into higher productivity for the firms and the larger economy. The second analytical approach (micro) is transparent and causal, describing not only the direct cost savings from transport improvements but also the indirect impacts of the cost and time savings in the form of gains from logistical reorganization. However, it is deficient in not treating the further ‘network’ or the general equilibrium effects on transport-using sectors in the broader economy. The third approach comprising of the delineation of the various economic processes and mechanisms involved in translating transport improvements (via labor, and product markets and technical and organizational changes) into the wide-ranging economic impacts in the larger economy remains poorly developed.

Transport is basically an activity shrinking space and time. The economic analysis of a world involving (the noncovexities of) space and time, and where the usual convenient assumption of perfect competition is not often valid, is clearly complex and presents difficulties. While much has been learnt in the last two decades about the presence and size of the positive impacts of transport improvements on economic growth and productivity, much remains to be known about the market and technological mechanisms and pathways linking transport improvements and regional and national economic growth and evolution. While a number of studies of transport’s role in economic development in Developing countries and in the lagging regions in the U.S. in the 1960s (e.g. Appalachia) describe and clarify such market and structural processes of economic transformation (e.g. Heyman, 1965; Owen, 1965; CRA, 1968) they make little use of formal and modern economic analysis of these transport-economy linkages. Recent research on the formal representation of these transport-economy linkages, taking advantage of new theoretical developments in the 'New Economic Geography' in U.K. (SACTRA, 1999; Venables and Gasiorek, 1999) has given a boost to this research area. This work relaxes the simplifying assumption of perfect competition, introduces notions of imperfect competition and increasing returns to scale, thereby offering new and powerful lines of inquiry.
This work is highly relevant to this White Paper surveying the state-of-the-art of analysis of linkages between transport and the economy.

At this juncture, it is necessary to define and clarify a number of concepts and terms that figure in the discussion in the rest of the paper on the transport-economy linkages.

A Definitional Digression

The demand for freight services sector is essentially a *derived demand* deriving from the requirements of transport-using sectors. The latter requirements encompass the conveyance of various inputs to the production center and the distribution of the products to the final points of consumption. An improvement in the supply of transportation infrastructure (in a variety of modes) lowers the costs and the eventual price charged to the user of freight transport services. The actual cost of transport to the user is usually formulated as *generalized cost*, that includes operating costs, tolls, other incidental costs and the significant time costs of travel. Since economic sectors differ in their demand for transport, in the spatial patterns of their input sources and locations of sales, in their sensitivity to transport prices, and their demand for external and urbanization economies, the level of transport costs can impact the spatial location and agglomeration of economic activities in regions and urban areas.

Infrastructure services and improvements arrive in several forms:

* improved quality of the stock—new highways, airports, commuter rail lines, etc, (this is more common in developing countries and occasionally as in the in early years of building the Interstate Highway System network) in the U.S., where most capacity additions today are often marginal increases to an already large infrastructure stock
* repair and maintenance of existing infrastructure stock
* squeezing more capacity from existing infrastructure—via intelligent transportation systems, better management of traffic flows and breakdowns, etc.,
* changing user costs – fuel taxes, tolls, etc.
These different types of changes in infrastructure stock and use patterns will influence the generalized costs of transport users and thus their economic impacts.

From an economic perspective, infrastructure has been traditionally viewed loosely as "large and costly installations", "provide services basic to any production capacity", etc. Youngson (1967) rescued the concept of infrastructure from this wooly thinking by suggesting that *infrastructure is not a set of things but a set of attributes*. To the degree any capital stock possesses two attributes, they can be regarded as infrastructure. First, capital can be viewed as infrastructure to the extent it is a source of external economies⁵. Second, it must be provided in large units, "ahead of demand". Both imply the desirability of a certain amount of public investment (since the pattern of investment in a private enterprise economy, given the external effects, tends not to be socially optimal). The second criterion of provision ahead of demand is truly an expost argument (satisfactory when the outcome is known). The argument for such infrastructure is particularly strong in the case of those investments that may be thought of as somewhat *non-specific* in character—that is, those that can be utilized in the production of a wide variety of economic sectors such as transport or education infrastructure (Lakshmanan, 1989).

Economic Growth is a *quantitative* change in economic performance, measured typically by the Gross Domestic Product (GDP), defined as the total value added in the economy. Economic Development is, however, a *qualitative* or transformational change in the economy. Development implies the emergence of a new technical environment or a new set of economic opportunities and a changed pattern of behavioral relationships between the environment and the economic actors.

When a major transport infrastructure investment is made in a country with limited stocks of such public capital, as in a developing country, there is transformational or developmental economic impact. Not only is the transport service associated with existing production and consumption activities made cheaper, faster, and more reliable, but a variety of new transport

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⁵ The concept of external economies was introduced by Alfred Marshall (1920) to refer to the shared advantages that firms in a spatial agglomeration (e.g. The Sheffield Cutlery District) possess.
services which did not exist before are made possible. The latter effect derives from the pervasive consequences of the new lower transport costs and enhanced market accessibility that producers and consumers in the central and 'peripheral' regions (vis-à-vis the new transport link) experience now, and are able to find new and larger markets for their products—leading potentially to a virtuous cycle of economic effects and growth. Examples are legion in the transformation of largely agricultural societies with a limited level of manufacturing and low per capita incomes in the newly industrializing countries. The oft-noted role of the canals and railroads in opening up the American West in the 19th century is another case. These transport infrastructures contributed to the westward migration, accelerating its pace, influencing its path, and affecting the rate of economic development opportunities—thereby determining the nation’s spatial organization (Heyman, 1965; Pred, 1966).

In contemporary U.S., where marginal additions are typically made to the extant high levels of infrastructure stocks, economic growth effects are the targets of inquiry. It is tenable, however, to argue that when a transport infrastructure is both a major program and a new technology even in an affluent industrialized country like the U.S. (e.g. The Interstate System, a new technology with limited access, high speed, improved design and improved safety introduced in the late 1950s) the economic impacts can be very large. See for example Section III of this paper, where Nadiri and Mamuneas (1996) arrive at a net return of 35% for Highway Capital for the 1950s and 1960s, when the Interstate was being built and the effects of a transport network completion were becoming cumulative!

Productivity is a notion representing the efficiency with which economic resources are used. It is measured as a ratio of the value of output produced over some period to a measure of inputs used in the same period. Since productivity is a ratio of output to input, productivity growth implies that the level of output in a firm, sector, or the economy is growing faster than the levels of inputs -- thereby making a contribution to economic growth. The early focus of productivity measurement -- measured since the late 19th Century in the U.S. (Kendrick, 1977) -- was on labor productivity (Output per unit of labor input). Recently, there is more emphasis on a better measure of overall efficiency, namely, total factor productivity (TFP), where the labor input is replaced by an index of the level of two or more factor inputs, in order to capture factor
substitution effects. The growth of TFP reflects technological progress, increasing efficiency in the use of resources, and economies of scale. Policymakers value and seek higher levels of productivity, which enhance the economy's competitiveness.

The Macroeconomic Approach

Economic theory suggests that investment and productivity growth underlie long run economic growth. If infrastructure investments are to have an impact on the long run growth, as has been claimed by economists since Rosenstein-Rodan (1943) and Hirschman (1958), they must operate directly and indirectly through these two pathways as reflected by the decisions of firms and households. Transport can contribute to the economy directly through additions to capital stocks via increases in transport infrastructure capital. This is the argument used by a variety of analysts using the macroeconomic perspective. Figure 13 depicts this argument as initially proposed by Koichi Mera (1973) for Japan, later dramatized by Aschauer (1989), and used by many others including Nadiri and Mamuneas (1996).

Figure 13. Infrastructure and Economic Growth
(a la Mera, Aschauer, Nadiri, et al)

Transport can also contribute to economic growth indirectly. Improved transport services induce greater efficiency in input use by transport-using firms, and from the gains in accessibility, market expansion, and restructuring of activities as the transport improvements course through the broader economy. We return to this aspect at the end of this section.

Returning to the growth effect of transport infrastructure capital, it is worth noting that the neo-classical growth theory of Solow (1956) and Swann (1956) postulates that capital accumulations are subject to diminishing returns, so that the effect of high transport capital
investments tend to peter out over time. According to this theory, the long run growth in GDP per capita, will depend on TFP growth, which reflects technological progress (which is exogenous in the Solow model). Consequently, the transport effects are on the level of GDP per capita rather than on the increase in its growth rate of the economy.

Recent work in Endogenous Growth Theory (Romer, 1987, 1990; Lucas, 1988; Aghion and Howitt, 1992) has demonstrated, however, that under some circumstances the diminishing returns effect can be postponed or kept in abeyance, so that the growth rates in the economy can be affected by investments in the long run. This new theory (unlike Solow and Swann) endogenizes technical change and expands the scope of capital stocks to include human capital, and other forms of knowledge-rich capital. It endogenizes technology in a dynamic general equilibrium framework, using the monopolistic competition or the product variety model of Dixit and Stiglitz (1977) with increasing returns to scale. With continuing growth of knowledge-rich capital, the growth dynamics with self-reinforcing circular and cumulative causation mechanisms can pave the way to a virtuous cycle of growth (Ray, Lakshmanan, and Anderson, 2001).

For our purposes, the interesting question is the role of transport infrastructure capital in such a model where innovation is endogenous and a notion of broad capital is operative. Transport capital-induced improvements promote access and thus contribute to improved human capital in the region or nation. Further, to the degree that transport infrastructure improvements (and the consequent greater accessibility) a) promote efficiency through economies of scale in larger markets and by economic restructuring through the entry and exit of firms exposed to competition and b) influence innovation or the mechanisms and the creation of spatial clusters of economic sectors affecting innovation, those transport improvements can promote more total factor productivity (TFP) growth -- thereby contributing to increasing growth rates in the economy. Thus the effects of transport investments on national or regional endogenous growth become positive and strong. This indeed is the perspective of 'the New Economic Geography' analysts (e.g. Fujita, Krugman, and Venables, 1999; Venables and Gasiorek, 1999; Johansson, 1998) who examine the interactions between transport improvements, increasing returns to scale, and spatial agglomeration of economic activities, and tease out the spatial/ regional effects of
transport improvements. The last part of Section II, dealing with the general equilibrium aspects of transport-economy linkages, elaborates this conceptual approach further.

The Microeconomic Perspective

In contrast to the macroeconomic approach linking aggregate infrastructure formation to aggregate productivity growth, the microeconomic perspective tries to identify the link between specific infrastructure improvements and the productivity of specific production units. In this sense, microeconomic analysis is the key to *unbundling* the macroeconomic effects observed in econometric studies. The traditional economic tool of the microeconomic perspective is cost benefit analysis (CBA). Unlike the *ex post* econometric analyses of the macroeconomic perspective, 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.

Figure 14 illustrates the microeconomic perspective of the economic impacts of transportation infrastructure improvements. Infrastructure improvements either reduce distances between origins and destinations or reduce congestion (and thereby travel time) by adding links to a network or enhancing the capacity of existing links. Either way, they make it possible to offer freight transportation services that are either cheaper of more reliable, or both. This has the effect of reducing the cost of assembling inputs at the production site and delivering goods to customers, yielding direct efficiency gains. Further gains, however, can arise through a number of mechanisms.

One such mechanism is the reorganization of logistical systems in order to economize on inventory carrying costs. Transportation services that are cheaper and more reliable provide an incentive for firms to institute changes in their operations that reduce the average inventory levels of both intermediate and finished goods. This is the essence of the just-in-time (JIT) system in which firms reduce carrying costs but may increase their demand for transportation services both in terms of quantity and quality (McCann, 1998). Lower costs and more reliable services also make it feasible for firms to consolidate production and distribution centers into fewer units, thus taking advantage of scale economies. Since consolidation implies longer

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1 At the same time, they name positive or negative effects on externalities other than congestion.
average lengths of shipments, again firms may increase their demand for transportation services. In both cases, fundamental changes in logistical design result in shifts in the firm's transportation demand schedule (Lewis, 1991).

Other benefits accrue from shifts in location in response to improved infrastructure. For example, firms may relocate to take advantage of enhanced accessibility in certain places. Such movements do not yield benefits in and of themselves, as they may represent a shift of income from one place to another. In some cases, however, location shifts yield productivity benefits, as in the case where expanded infrastructure capacity permits agglomeration, which can have efficiency implications (Ciccone and Hall, 1996). Ultimately there are various mechanisms through which infrastructure improvements help firms not only to cut costs, but also to add value – both in the provision of transportation services and in the production of freight-using goods and services.

Given the variety of channels through which infrastructure can confer efficiency benefits on individual firms, a critical question is whether the full value of benefits is likely to be captured by CBA. This issue is further complicated by the fact that CBA relies on assumptions of perfect competition, and may undercount benefits in the face of imperfect competition (Venables and Gasiorek, 1999). At least from the partial equilibrium perspective, considerable progress can be made in expanding the scope of CBA, while at the same time guarding against double counting. But this requires both theoretical extensions and a number of challenges for empirical implementation (HLB, 2001).
The Spatial/Regional General Equilibrium Effects Perspective

The basic 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. As noted above in the discussion of the microeconomic perspective, freight transport services firms respond to the lowered transport costs and increased interaction possibilities by realizing additional economic gains from reorganizing the logistical function. We appear to have an analytical handle on this process and its outcomes.

Our understanding of, and the formal representation of the complex and multi-level responses of transport-using firms to transport infrastructure and service improvements is, however, more sketchy. Figure 15 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.
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, both via the restructuring of the economy (as firms enter and exit) and by promoting leaner production processes, which lower costs of production and raise productivity. 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 15 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'. While we present formally the nature of these mechanisms in Section V, we briefly highlight here the underlying concepts and their potential in helping specify the full range of transport-economy linkages in their general equilibrium richness.
Transport improvements can have an endogenous growth effect to the degree they impact the rate of innovation and transfer of technology, thereby promoting Total Factor Productivity (TFP) growth. 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 15); and the benefits accruing to various economic actors from the likely parallel increase in information flows, especially in locations where industries are spatially agglomerated -- see below. 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 (Harris, 1954; Pred, 1966) and Development Economics (Myrdal, 1957; Hirschman, 1958). 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 Marshall (1920) sense. Different firms clustered in a location experience positive externalities in the form of diversity of labor supply, training, business services, etc. in that location. 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 highend 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 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.

Section V will describe more formally these general equilibrium effects and the dynamic changes.

III. TRANSPORT-ECONOMY LINKAGES: THE MACROECONOMIC VIEW

The argument is that investments in transport infrastructure will increase the efficiency and reduce the prices of production inputs. Not only do costs such as those of skilled labor and material assembly become lower, but increases in the capacity of transport infrastructure lead to an increased quality of service. A six lane limited access highway not only has greater capacity than a two lane road, it is also faster and safer-thereby generating new demands.
Figure 16 shows how these effects could be conceptualized for a market economy with perfect competition.

**Figure 16. Infrastructure and the Efficiency of Production**

![Diagram showing cost and output with MC1 and MC2 curves]

- **MC₁** = marginal cost with infrastructure deficiencies
- **MC₂** = marginal cost with improved infrastructure

Where infrastructure is inadequate, the firms are confronted by high marginal costs (MC₁) at every level of production, and given the market price of their output, produce Q₁ units of output. As infrastructure services are improved, the marginal cost curve shifts to a lower level (MC₂). The result is twofold. There is a total cost savings of *abcd* for the earlier level of output Q₁, and an output expansion effect *bce* as Q₂ - Q₁ additional units are produced.

These cost reduction and output expansion effects of transport infrastructure are captured in the macroeconomic approach empirically by the formulation and estimation of production functions and cost functions.
Production and Cost Functions: A Brief Primer

Some readers may wish to skip this section, which introduces and defines a few concepts and definitions relating to production and cost functions.

The production function approach aims at estimating the contribution that transport and other forms of public capital make to private production. Since such infrastructure capital is available to all firms in an area, it is viewed as entering the production function of all area's firms as a factor additional to private factors. The aggregate production function is of the form:

$$Y = Y(\bar{X}, PK)$$  \hspace{1cm} (1)

Where $Y$ represents the aggregate output of the economy, $\bar{X}$ represents a vector of private factors of production [usually labor (L), capital (K), and sometimes expanded to include Energy (E), and Materials (M)], and $PK$ is a vector of public capital (e.g. transport infrastructure, sewer, water, etc.) services.

Production functions are familiar to most analysts and are easy to interpret. If the relationship between increases in infrastructure capital and the economy's output is positive and significant, one can argue that infrastructure investment is an important determinant of economic output. A typical measure estimated from the production function (1) to shed light on the role of public capital on economic output and productivity improvements is the output elasticity of transport infrastructure. The output elasticity is the percentage change in output for a 1% change in public (transport) capital stock.

$$e_{PK} = \frac{PK}{Y} \cdot \frac{\partial Y}{\partial PK}$$  \hspace{1cm} (2)

where $e_{PK}$ is the output elasticity of infrastructure capital.
Duality theory suggests that we can derive the underlying production function parameters from the cost functions\(^6\). The same rationale can be used to insert transport capital stock as an unpaid input into a production function or cost function. The costs of output in a firm are determined by: the cost of different input factors such as labor, capital, etc., the level of the firm’s output, and the stock of infrastructure capital. In a cost function, firms choose the quantities of private inputs (e.g. labor, capital, etc.) so as to minimize the private costs of producing output \(Y\).

\[
C = C(Y, \bar{P}_x, PK)
\]  

(3)

Where \(C\) is the total cost of producing output \(Y\), the vector \(\bar{P}_x\) are the prices for the various private factor inputs such as labor and capital, and \(PK\) is publicly financed capital services. The conditional input demands {applying Shepard’s lemma to (3)} are:

\[
X_i(Y, \overline{P}_x, PK) = \frac{\partial C}{\partial P_i} \quad \forall_i
\]  

(4)

The relevant cost elasticity computed from (3) for our purposes is the percent reduction in output costs for a percent increase in infrastructure stocks. While the results will depend on the functional forms chosen for equations (1) and (3), the cost function approach has advantages and offers potentially a richer framework to address a variety of additional questions pertaining to transport-economy linkages raised in this report and elsewhere (see Nadiri, 1993; Lakshmanan, Anderson, and Jourabchi, 1982).\(^7\)

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\(^6\) Under certain regularity conditions, there is unique correspondence between production and cost functions, and both functions contain all the information about the underlying technology (Shepard 1970, Diewert 1974)

\(^7\) In a production function, factor inputs are exogenous variables which determine the endogenous variable of output. From equation (4) above, in a cost equation the factor inputs are endogenous and depend on private factor prices and the stock of publicly-funded infrastructure. Thus, the estimation of a production function like (1) \(Y=Y(X, PK)\) suffers from simultaneous equation bias and the OLS estimation will be biased. Other advantages noted by Nadiri (1993) for the cost functions include a) the ability to get direct estimates of Allen elasticities of substitution, which indicate the level and pattern of complementarity and substitution between factors of production b) the direct estimation of the effect of public infrastructure capital on demand for inputs (the second partial derivative of the cost function) c) since the joint estimation of the cost function and the derived demand for inputs increases the degrees of freedom, the statistical precision of the estimates is improved; and d) From the ability to compute easily the marginal benefit of infrastructure capital (the first derivative of cost with respect to public capital), as well as the optimal level of infrastructure, a richer analytical framework can be developed to address questions such as the
In practice, the quality of estimates of such elasticities and other parameters estimated in these studies depends on the functional form chosen for representing the production or cost functions. Most production function studies of transport infrastructure assume a Cobb-Douglas specification (e.g. Aschauer, 1989; Munnel, 1990). The Cobb-Douglas formulation imposes \textit{a priori} restrictions on the substitutability of factor inputs. More recent studies adopt flexible functional forms for specifying the models to be estimated. Such flexible functional forms do not impose restrictions such as constant returns to scale on the parameters of the cost functions, and indeed allow testing of hypotheses of relationships among the production factors. Examples are the translog and the Generalized Quadratic (Elhance and Lakshmanan, 1988; Keeler and Ying, 1988; Seitz, 1993; Lynde and Richmond, 1992, 1993; Nadiri and Mameneus, 1996)

\textbf{Selective Review of Macroeconomic Studies of Transport-Economy Linkages}

Since the pioneering application of macroeconomic modeling to an estimation of transport-economy linkages by Koichi Mera (1973) in Japan, there has emerged a significant body of empirical work in the field as applied to U.S., Japan, India, Sweden, U. K., Germany, France, and Mexico. Despite a broad agreement among the studies in the U. S. and abroad on the positive contribution of transport infrastructure to the overall economy, there has been debate about the \textit{magnitude} of this contribution. Some studies make dramatic claims about transport’s contribution to American economic growth (Aschauer, 1989; Munnel, 1990), while most studies in the U.S. and elsewhere infer more modest but variable contributions of transport infrastructure to economic productivity.

The consequent debate in the early 1990s about the magnitude of the economic impact of transport has had two salutory effects. First, a careful inspection and analysis of the differences among the empirical studies in this field -- in terms of their model structures, in the statistical methods used, in their variable measurement concepts, and in their data -- has led to broad acceptance of a positive and modest economic impact of transport infrastructure.

\begin{footnote}
\textit{willingness of the private sector to pay for additional increases in infrastructure and the optimality of provided public capital for the private industries.}
\end{footnote}
Second, a recent sophisticated study, that has addressed the methodological deficiencies of some earlier studies, has provided results on disaggregate impacts of transport infrastructure, which are widely well received (Nadiri and Mamuneas, 1996). In addition, this study has developed a rich framework for posing a variety of related policy issues we note below, such as the marginal benefit and optimality of transport infrastructure. The following review offers a brief tour of this body of research, noting its strengths and weaknesses and highlighting some analytical issues which need further research.

Koichi Mera (1973) carried out the first study which found that public infrastructure--including transport and communications infrastructure -- contributes to aggregate private production in ways similar to that of privately supplied inputs and that its impact on productivity could be assessed through the use of the production function framework. He divided Japan into eight regions, and concluded that from 1954 to 1963 (a period of intense reconstruction of the Japanese economy), investments in transport and communication substantially contributed to private production in the manufacturing and service sectors. The output elasticities of 0.35 for the manufacturing sector and about 0.40 for the service sector implied that a 1 percent increase in infrastructure stocks led respectively to 0.35 percent and 0.40 percent increases in the outputs of Japanese manufacturing and service sectors.

For over a decade and a half, there were limited additions to this line of research with which to compare these results on the economic contributions of infrastructure. The few studies that emerged in this period (Ratner, 1983; Wigren, 1984; Elhance and Lakshmanan, 1988), while noted in the fields of regional economics and development economics, failed to attract the attention of mainstream macroeconomic analysts. The latter group did not come on board till one of them entered the field in a dramatic fashion (Aschauer, 1989). In the dozen years since, however, there has been a virtual explosion of analytical studies on the economic contributions of public infrastructure within the framework of production and cost functions.

Relying on aggregate national data from 1949 to 1973, Ratner (1983) in the first such study in the United States, used a Cobb-Douglas production function and found a statistically significant output elasticity of nonmilitary public capital of 0.05--0.06. This figure raised no
controversy: since it was small, implying that while public capital was productive, the largest contributions were from privately supplied labor (0.72) and capital (0.22).

Ratner's study was followed in the late 1980s by a large number of production or cost function studies of highway productivity, but the striking findings of David Aschauer, in particular, about the U.S. experience from 1949 to 1985, raised their profile. Before discussing Aschauer's work, however, two earlier studies are noteworthy. One of these (Costa, Ellison, and Martin, 1987) employed a flexible production function (translog) and 48-state-level data to develop output elasticities for the state and local public capital. He obtained output elasticity values of 0.19 for manufacturing, 0.26 for non-agriculture sector, and 0.2 for all sectors.

Keeler and Ying (1988) formulated the issue of highway productivity as a retrospective cost-benefit problem. They raise the issue of whether the interstate highway system lowered production costs for the trucking industry enough to cover a significant part of the highway investment. They use a translog cost function, time series / cross section data for 9 regions in the U.S. (1950-73) and obtain, for the trucking industry, a cost elasticity of -0.07 and an overall savings of 2 cents ($1973) per ton-mile. However, by focusing on the Class I trucking industry, the researchers knew they would capture only a portion of total benefits to the system, and that benefits to final consumers (such as households and the government) would be excluded. The study found that the reduction in costs due to highways was statistically significant; and that, when calculated annually, benefits to the trucking industry alone would have repaid between one-third and nearly three-quarters of the total highway investment (depending on assumptions on price elasticity and social discount rate).

Other studies (Deno 1988, Duffy-Deno and Eberts (1991) use metropolitan data to estimate output elasticity of infrastructure capital (smaller than at larger spatial level) and suggest that the causation appears to mostly run from infrastructure to output growth.

The profile of these U.S. studies and others carried out outside the U.S. was suddenly raised by the dramatic findings of Aschauer (1989) on the U.S. growth experience in the 1949-
The Aschauer Story: Claims and Counter Claims

Aschauer (1989) used an aggregate Cobb-Douglas production function with time series data, and obtained an output elasticity for all nonmilitary public capital of 0.39 and for "core" public capital (highways, airports, utilities, mass transit, and water and sewer systems) of 0.24. Since the output elasticities sum to 1 in this Cobb-Douglas, the relative contributions of privately supplied labor and capital were correspondingly smaller than those estimated by previous studies. The annual percentage changes in total factor productivity due to public capital estimated from the coefficients of his production function turn about to be large.

Alicia Munnell (1990) used a similar procedure, but different data, on aggregate private capital stock for a longer time period (1948-87). Her output elasticities were comparable (0.31 to 0.39 for core-public capital) to Aschauer’s.

Aschauer also showed that highway stock (per unit of state land area) and pavement quality made positive, statistically significant, effects on the average annual growth of state income between 1960 and 1985. However, since the analyses did not use a production function framework, the estimated magnitudes of these effects cannot be easily compared to previous production function analyses. A similar study by Munnel retained the production function framework and obtained statistically significant output elasticities of about 0.15 for core public capital and 0.04 for highway capital stock alone.

The Aschauer-Munnel studies were carried out at a time when many observers were concerned about factors that were behind the slowdown in U.S. productivity since 1973. Aschauer and Munnel suggested that their production function findings suggested that much of

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8 Using one type of production function, the estimated output elasticities for labor and private capital assumed quite satisfactory values (0.59 for labor and 0.31 for private capital), that were close to the fractions of overall national income going to those two categories of inputs.
the productivity decline since the early 1970s was due to under-investment in public infrastructure. This inference has acted as a lightening rod, drawing extensive critiques from other U.S. economists, who appeared to have largely neglected previous studies of infrastructure productivity in the United States as well as in Europe and Asia.

Critics noted two types of statistical problems associated with the use of aggregate time series data in the Aschauer study. The data may create a spurious relationship between production inputs and output because they both tend to grow over time. Further, there might be time lags between the construction of public infrastructure and producers' use of it, which could make estimates about productivity obtained from time series data unreliable. A smaller group of critics suggest that public infrastructure makes little, if any, contribution to the overall economy. Responses to both of these criticisms have led to sophisticated analytical reforms and reinterpretations of earlier findings.

Lynde and Richmond (1992), responding to these statistical deficiencies, conducted two studies, applying a more sophisticated analysis to the time series data--cointegration analysis or error-correction models. They used aggregate national time series—one annually for the United States from 1958 to 1989, the other quarterly for the United Kingdom from 1966:1 through 1990:2—and found a statistically significant, cost-reducing effect of aggregate public capital on private production. The U.K. study attributed about 17 percent of productivity growth in manufacturing to changes in public capital expenditures per employee; this is about the same contribution made by changes in private capital expenditures.

Another line of critique is exemplified by two studies in the past decade by Hulten and Schwab, who suggest that public capital has some limited value in accounting for regional differences in economic performances. One study found that most of the variation in total factor productivity growth among nine U.S. census regions between 1951 and 1976 can be accounted for by regional differences in the private capital-labor ratio, attributing nothing to differences in public infrastructure. However, the study is open to the criticism that it does not apply any measure of public capital, the variable (not included in the analysis but) about which conclusions were drawn.
Hulten and Schwab's second analysis of the role of infrastructure in economic growth provides results whose interjection is unclear. This study concluded that public capital made no contributions to productivity growth in manufacturing aside from those already captured in the growth of intermediate inputs, which include transport. However, the statistical results from this study were that private capital has an effect when public capital has none, and the interpretation of this result is unclear (BTS, 1995)

As indicated in the synopsis of the studies in Table 6, many studies about the effects of transportation and other public infrastructure on regional or national economic growth have been carried out in European and Asian countries (Sweden, United Kingdom, France, Germany, India, and Japan). These different studies vary along many dimensions:

* they vary not only in models they use but also in the functional specification of those models, (Cobb-Douglas, CES, or flexible functional forms);
* they also differ 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 measures of physical infrastructure);
* they differ in the level of disaggregation of economic sectors [e.g. from aggregate output in the Aschaeur model to outputs by 35 sectors in the Nadiri-Mamaneus model]
* they vary in the size of the geographic areas used (nation, region, state, metro area, or county), and
* they differ in the temporal level of analysis (time-series, cross section, or pooled)

These studies invariably found statistically significant output elasticities for aggregate public capital and highway capital, when measured separately. The size of the estimated highway elasticities varied within an acceptable range between 0.03 and 0.08; the ranges of output elasticities for labor and private capital were more varied.
Some of these studies consider certain analytical aspects not explored in American studies. For example, two analyses address the time lag in the private sector in responding to investments in public capital. Elhance and Lakshmanan used normalized restricted (translog) cost function, flexible accelerator formulations, and developed multi-equation econometric models, which distinguish between market (variable -- K,L, E, and M) and infrastructure (quasi-fixed) inputs. They explicitly incorporate costs of adjustment to publicly supplied infrastructure capital in a study of India (and six component states) from 1950-51 to 1978-79. They found that it took firms a little over 5 years to adjust completely their production activities to changes in public infrastructure. In a Swedish study, the period was found to be 14 to 26 years for complete adjustment to changes in highway infrastructure, depending on the industry.

Anwar Shaw (1992) used a restricted cost function with capital and infrastructure as quasi-fixed inputs using Mexican data on 26 manufacturing industries. Returns to infrastructure ranges from 5.4% to 7.3%, while returns to private capital are higher—from 14.3% to 18.6%. Using different models, two Swedish studies (Anderson, Anderstig, and Harsman, 1990, Johansson, 1993), one in France (Prud'homme, 1993), and in Germany (Conrad and Seitz, 1994) found that the level of public capital and accessibility of public capital to the populations they serviced contributed to their productivity. In still another study, Moomaw and Williams used U.S. data from the state level and found statistically significant contributions of highway density to total factor productivity growth.

**Nadiri and Mamaneus Contribution**

The Nadiri and Mamaneus (1996) approach incorporates explicitly demand and supply factors, including the contribution of highway capital, which affect the productivity performance of 35 industries. A cost function specified in a flexible functional form explores the interaction among highway capital, private sector inputs and outputs in the U.S. Economy for the period 1947-1989. For each industry, cost and demand functions are estimated separately and the parameter estimates of the model utilized to decompose Total Factor Productivity (TFP) growth. While the cost elasticities vary by sector, the overall aggregate cost elasticity is –0.044, and the overall output elasticity is 0.051.
The rate of return of highway capital (the ratio of the sum of industry marginal benefits to cost minus the depreciation rate of highway capital) varies over the period. It is high initially at around 37% until 1968 -- well above the rate of return to private capital -- during a period of introduction of the new technology of high speed, safe, divided highways of the Interstate System and a period of rapid network expansions with its nonlinear effects (Figure 17). In the latter years, the rates of return to highway capital drops to levels closer to that of private capital, as the interstate highway system gets completed and a significant and increasing proportion of annual highway investments is intended for maintenance. As noted above, this study provides a variety of additional information pertaining to optimality of highway capital, and the contribution of highway capital to total factor productivity growth, so that questions relating to crowding out effects of transport infrastructure can be posed.

![Figure 17. Net Rates of Return of Highway Capital, Private Capital, and Private Interest Rate, 1951-1989, computed by Nadiri and Mamuneas (1996)](image)

Table 5 provides a summary of the output and cost elasticities of highway and other public capital in the various country and regional studies which are highlighted in Table 6.
Table 5. 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

Lessons Learned from Macroeconomic Analysis of Transport-Economy Linkages

First, there is widespread support for the view that transport infrastructure contributes to economic growth and productivity. The emerging consensus is that 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 5). Since the industries vary in the benefits they receive from different types of infrastructure, the transport-economy linkages need to be clarified for disaggregated sets of both output sectors and transport infrastructure type. The carefully specified model of Nadiri-Mameneus has powerfully reinforced this view of robust, modest contribution of different types of road infrastructure to a disaggregated set of national economic sectors. Additionally, it provides a rich information base, which can address other issues relating to optimality of infrastructure investment, the crowding effect on private investment, etc.
Second, the difference in the magnitude of output elasticities for infrastructure estimated from aggregate, national data and from state data reflects transport's spill-over characteristics. However, the size of the difference may point to a more serious technical problem which arises when estimating the productivity effects of transport at the state level. For example, when output, labor, and private capital inputs are reported at the state level, they describe the input quantities deployed by firms within the state and the value of income they produce. As BTS (1995) notes, such reporting does not consider the unique characteristics of transport. A Chicago firm selling goods in Seattle will truck them there by way of inter-state highways across South Dakota, Wyoming, Montana, and Idaho. Although the infrastructure in those states contributes to income reported as produced in Illinois, the method of analyzing state-level transport productivity attributes the interstate mileage (or capital value) in those states against their own production, which does not include the Chicago-based firm's output. Thus, the data present a very high ratio of highway infrastructure to the size of the labor force in the rural states that lie between major manufacturing regions -- this discrepancy between the economic theory of the production function and the accounting system that generates highway infrastructure data used in the production function studies poses problems for the output elasticity estimates of public capital calculated in state level studies (Jones, et. al., 1993).

Third, it is necessary to analyze explicitly the demand from firms for infrastructure services, which will vary with technology changes and changes in the structure of the economy. How does the private sector demand for infrastructure change as factors exogenous to the firm change? More attempts in this direction (Elhance and Lakshmanan, 1988; Shah, 1992) are called for.

Fourth, a 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. 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 in 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. 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 potential to link the overlapping but different approaches of production function and the microeconomic C-B approach.

Finally, the specification of impacts of transport infrastructure on production factors (labor, capital, and other factors) in macroeconomic models is too aggregate to be more than a 'black box'. This black box needs to be unbundled. Transport infrastructure improvements, as noted in the Section II and detailed in Section V below, impact on labor and other factor markets and on product markets in complex ways with positive and negative feedback loops--in the context of spatial agglomeration and potential innovation stimuli (see Figure 14). The net outcomes of these complex mechanisms are *uncertain and contextual*. The general equilibrium effects approach are described in Section V. Further research from the macroeconomic perspective must be complemented by an analysis from the general equilibrium view as noted in section V.