Transportation Infrastructure, Freight Services Sector and Economic Growth

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A White Paper prepared
for
The U.S. Department of Transportation
Federal Highway Administration

January, 2002

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FIGURE AND TABLE LEGEND

The U. S. Department of Transportation, Federal Highway Administration (FHWA) has had a long interest in gaining a clear understanding of the nature of linkages between transport infrastructure investments and economic growth and performance.

Several factors underlie this continuing interest of FHWA. First, FHWA directly and indirectly invests significant amounts in highway infrastructure each year, and needs to know that these investments are justified by rational decision criteria. Second, FHWA is committed by the Department's Strategic Plan to promote the nation's economic growth and economic competitiveness in the way it conducts its investment and non-investment activities. To accomplish this strategic mission, FHWA clearly needs knowledge on the nature and scope of the relationships between the provision of highway investments and economic growth and performance. An important dimension of these economic impacts relates to the impacts of transport investments on the performance of the rapidly evolving freight services sector, whose improved productivity in turn enhances the productivity of the overall economy.

Research aimed at improving our understanding of these linkages between transport infrastructure, the freight services sector, and economic performance can potentially address a range of issues:

- What is the nature and magnitude of the relationship between transport investments and the performance of the freight services sector, of other economic sectors, and indeed of the overall economy? What effects does transport public capital have on the productivity of labor and capital? What is the willingness to pay on the part of a private sector firm or industry for an additional increase in transport public capital? How robust are these relationships when the transport infrastructure investments are made in different contexts—say a link completion in a core region vs. a road in a peripheral region, or an investment in a growth period vs. in a declining era, etc.? To what degree does transport investment influence economic growth and to what extent is it in turn an outcome of economic growth?

  Since the convergence of transport policy reforms (particularly the new economic incentives and competition created by transport deregulation and liberalization in recent years) and novel transport and information technologies have promoted major productivity-enhancing service and process innovations in the freight services sector, a further question arises: what is the role played by transport public investments in promoting such structural changes as the reorganization of the logistical processes, which may augment productivity both in the transport service sectors and in the many transport-using sectors in the economy? In other words, what are the multiple and complex linkages between public investments in transport, the freight services sector and economic performance?

  Yet, our current understanding of these transport-economy linkages derives largely from models of aggregate relationships between transport and the economy. How should we open such 'black box' models? How do we characterize and analyze the economic mechanisms by which improvements in transport infrastructure and freight services course through the national and regional economies? As freight transport cost-service improvements promote market expansion and integration, what interactive changes occur in labor, land, and product markets within and between various economic sectors? How do these interactions turn out in the world of 'The New Economic

> Geography' with its increasing returns and imperfectly competitive markets? How can we trace the general equilibrium responses rippling through the economy, integrating under the stimulus of transport infrastructure improvements? What implications follow from this analysis for assessing transport's role in the nation's economic competitiveness?

This White Paper surveys and assesses current knowledge on these multiple and complex linkages among transport infrastructure investments, the freight services sector, and economic performance, as viewed from the perspective of the issues raised above.

I. THE FREIGHT SERVICES SECTOR: TECHNICAL CHANGE, EVOLUTION, AND CONTRIBUTION TO ECONOMIC GROWTH

The growth of the freight transport services sector in the last four to five decades has made possible and in turn has been made possible by the growth of the American economy. In this period, the U.S. economy has undergone deep structural changes: an increasing shift from goods production to a service economy; towards a less material-intensive and energy-intensive production system; from an emphasis (in the early decades after 1950) on the fuller integration of national markets -- incorporating the Southern and Western regions into the national network of production—towards becoming part of a globally organized and distributed production system.

In the last two decades there has been a parallel evolution of the freight services sector, enabled and motivated by driving forces such as technical change in transport and information technologies, transport infrastructure investments, the reforms in the policies of transport governance, and the globalization process. In the environment of new economic incentives and competitive regimes created by these drivers, the freight services sector has witnessed considerable technical change, organizational innovations and restructuring of the logistical process. The consequence is a broad *qualitative* change in the scope of services offered to transport-using economic sectors. The freight services sector is offering to its customers a variety of service and process innovations -- greater speed and reliability at lower overall costs, time-definite global delivery of goods, sourcing and distribution functions, flexibility in destinations, etc..

The role of transport infrastructure investments in the evolution of the freight services sector, and its subsequent economic impacts -- as the changed freight cost-service mix courses through the larger economy promoting integration of labor and product markets and economies of scale and scope -- are of considerable interest to decision makers concerned with transport infrastructure investments.

This section of the White Paper briefly outlines a) the processes which are transforming the freight services sector, and b) the mechanisms which translate improvements in freight services into a range of economic impacts in the broader economy. It opens with a statistical profile of the U.S. freight services sector in recent decades, charting its quantitative growth, its changing composition and spatial organization, and providing a comparison to its counterparts in selected affluent industrialized countries. It proceeds to a brief description of the changing context and scope of the freight services sector, as well as the forces underlying these changes. Next, it identifies and discusses the linkages between transport investments, freight services sector, and overall economic performance. This sets the stage for identifying and briefly characterizing the three analytical approaches currently available for measuring the impacts of transport infrastructure investments on the freight services sector and on the performance of the larger economy.

A Statistical Profile of the U.S. Freight Services Sector

Two attributes capture the crux of the progress of the U.S. freight services sector in recent decades. The first characteristic evident in the last four decades is *the quantitative change***,** namely the continuous growth of the volume of freight moved and the distance over which the merchandise has been moved at ever lower prices. Between 1965 and 1998 total tonnage moved in the U.S. rose from 4.54 billion tons to 6.21 billion tons (an increase of 37%), while ton-miles rose more sharply from 1854 billion ton-miles to 3710 billion ton-miles (an increase of 100%). As noted below, these aggregate changes reflect the interacting effects in this period of several broad economic processes—increasing spatial integration and robust growth of the American economy, increasing shift to less material-intensive service sectors, and a variety of technological and organizational changes in the economy.

The second attribute is a broad *qualitative* change in the last two decades in the scope of the freight services being offered to transport-using firms—in the form of greater speed and reliability, time-definite global delivery of goods, flexibility in destinations, etc.. These freight services, made possible by recent technical innovations in transport, information, and financial services, by transport policy reforms and by the consequent structural changes in the freight services sectors, not only reduce costs but also add to the production value of transport user firms.

Over the last four decades, the growth of freight and passenger movements has broadly paralleled the growth of Gross Domestic Product indicating high levels of freight and passenger mobility (Figure 1). Passenger-miles have kept pace with GDP particularly in the 1960-90 period with an income elasticity over the entire period of close to one (0.94). Ton-miles of freight exhibit a slower relative growth (income elasticity of 0.50). In the decades of 1960s and 1970s, however, freight traffic growth kept pace with GDP growth, but has subsequently slackened.

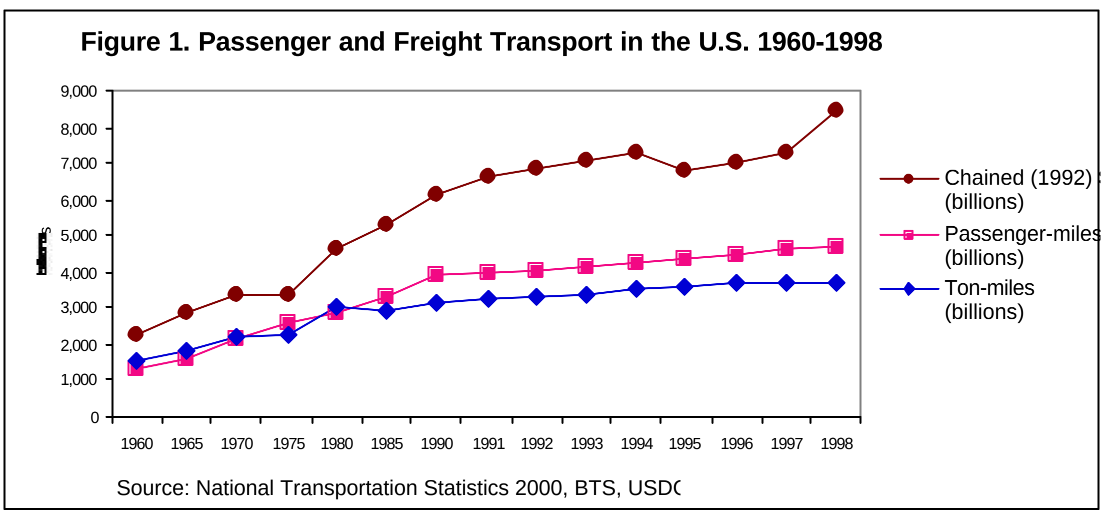
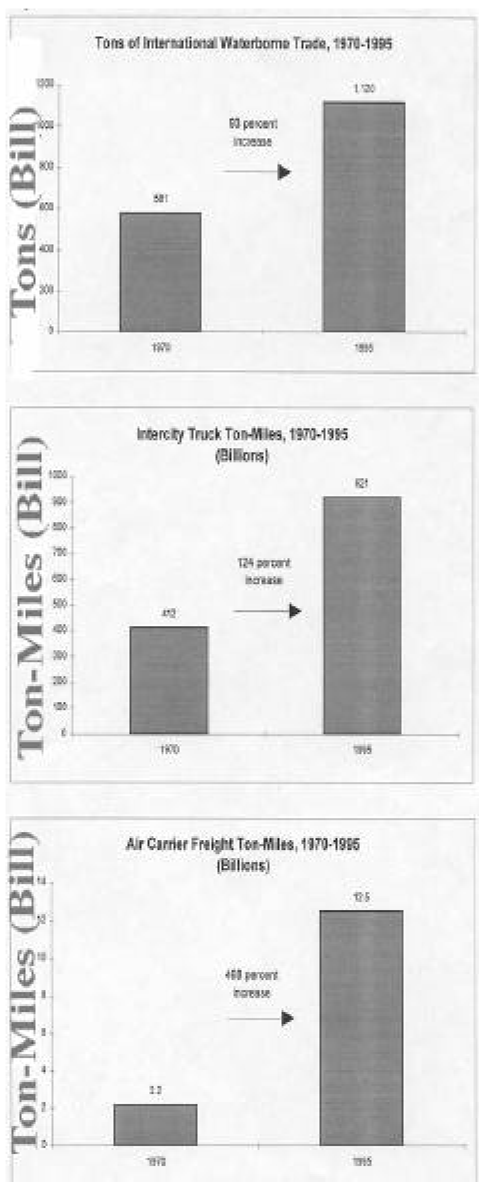


Figure 1. Growth of the Economy and the Passenger Freight Mobility

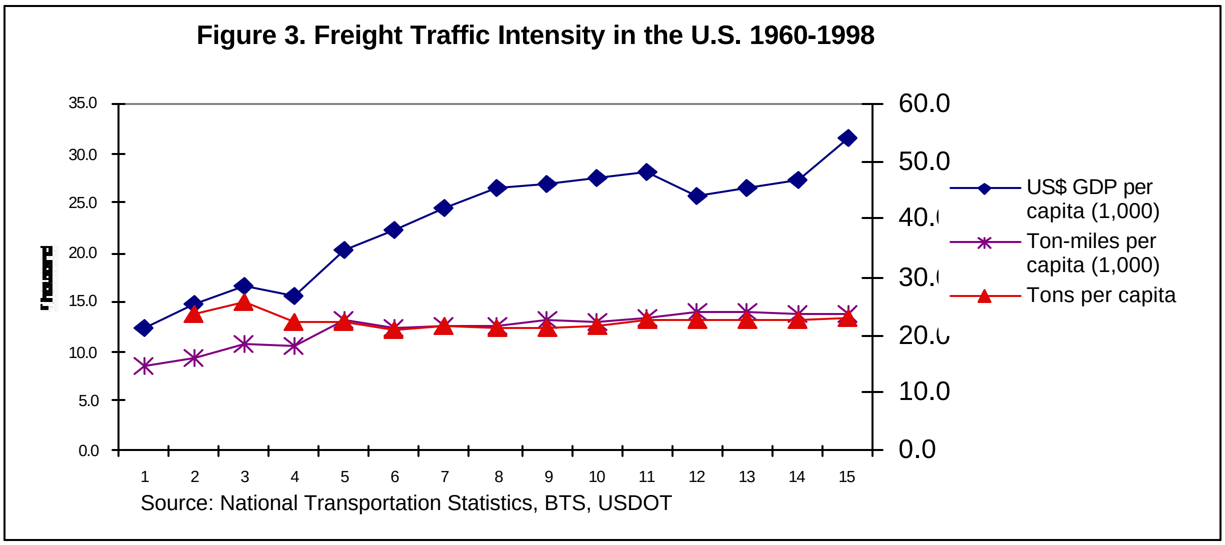
In about the same period (1970-95), the growth in tonnage and ton-miles varied, however, by mode (Figure 2). Intercity trucking ton-miles grew by 124%, while air freight ton-miles grew by 468%.

Figure 2. Growth of Freight Traffic by Modes, 1970-1995



The measure of freight intensity relating freight levels to GDP tell the same story more sharply. Tons per U.S.$ (000) GDP (1992 prices) dropped between 1965 and 1998 by 54% from 1.58 to 0.73 tons. Ton-miles per U.S.$ GDP dropped between 1960 and 1998 by 36% from 0.69 miles to 0.44 miles (Figure 4). Clearly, the economy shows a consistent trend towards lower intensity of freight use.

Figures 3. Freight Traffic Intensity in the U.S 1960-1998



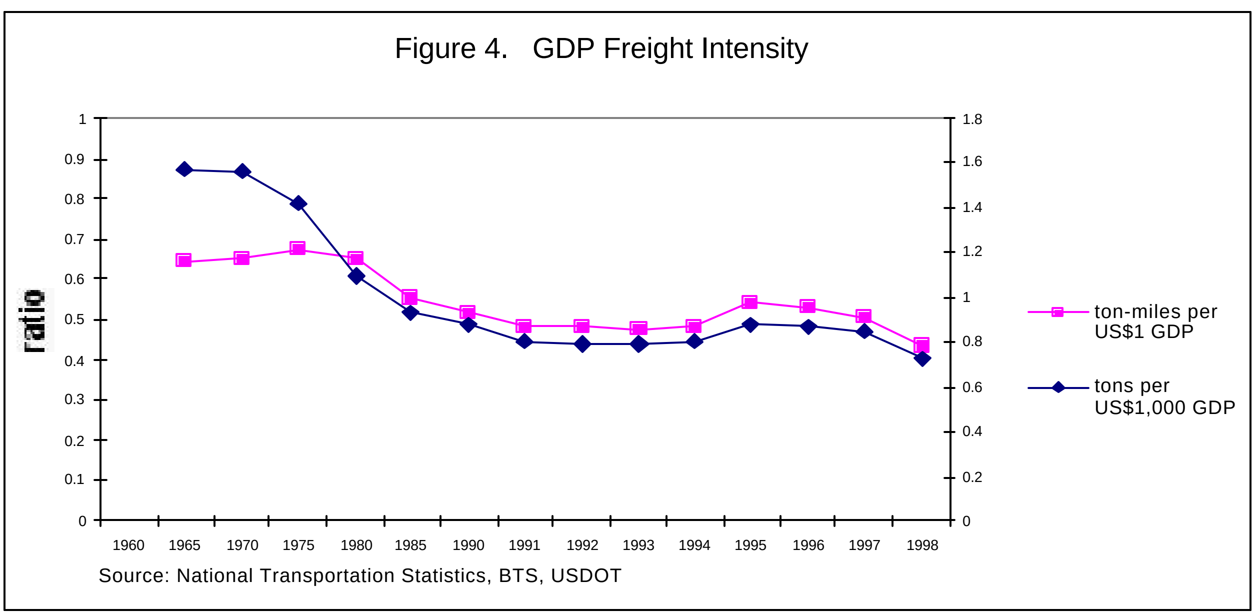
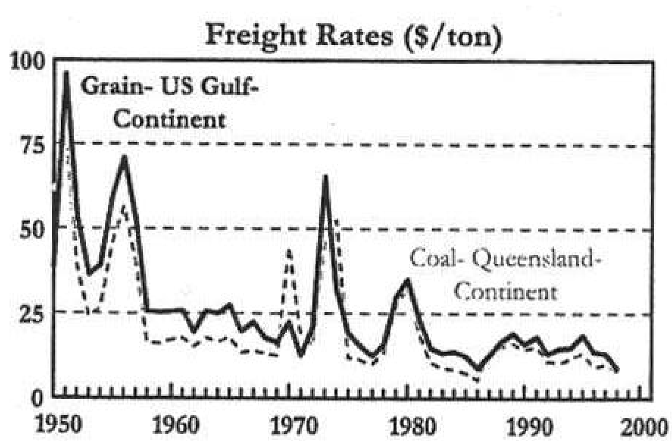


Figure 4. GDP Freight Intensity

Both sets of measures of freight intensity reflect the recent transformation of the U.S. economy, with less and less of the GDP deriving from goods production. The oft-noted increasing shift in the U.S. to a service economy over this period signifies a reduced resource and energy intensity and the consequent lower intensity of goods generation for movement. At the same time in this period, transport technology changes (e.g. containers, The Interstate System, jet aircraft, etc.) continued to lower transport costs sharply. The common measure of shipping costs (the ratio of c.i.f. trade value—measured as cost to the importing country -- to f.o.b. trade value -- measured as it leaves the exporting country) declined from 9.5% in 1950 to about 6% in 1990 (Frankel, 2000). Sharp drops in freight rates as evident in Figure 5 have pervasive effects. In competitive regions, lower transport costs promote expanded markets and improved export opportunities, which in turn enhance their output. As 'peripheral regions' confront the influx of cheaper goods and the resultant import competition, there is restructuring of activities (with firms arriving and exiting), leading to lower production costs and enhanced efficiency in those regions. The outcome of these processes is greater market integration, as various regions in the nation are integrated into the national network of production. In turn, regional specialization of production develops and leads to greater intra-industry and inter-regional trade and freight movements over an expanded

Figure 5. Freight Rates



Source: *No Author*, 2000, Special Feature: Commodities in the 20th Century, Global Commodity Markets, January 2000.

production space. This scenario is in many ways a stylized description of the incorporation of the Southern and Western States into the U.S. national production system in the 1960s and 1970s-- in the context of the emerging transport technologies (Interstate system, jet planes, containers) and the then on-going brisk population shift from the Snowbelt to the Sunbelt States.

One clear upshot of this regional and national economic integration argument is the longer distances over which goods get transported and the sharper rise of ton-miles of freight as compared to tons moved. More light can be thrown on this matter, if we reconsider the freight sector's fortunes for two distinct periods, namely 1960-80 and 1981 to 1998 (Table 1).

Table 1. The Evolution of the U.S. Freight Sector, 1960-98

	(Percentage Increases)	
Indicator	**1960-1980**	**1981-1998**
Tons	11	23
	(1965-80)	
Ton-miles	92	24
Tons / capita	-5.5	4
Ton-miles /capita	59	4
Tons /$U.S.(000)GDP	-31	-33
Ton-miles /$U.S. GDP	-7	-31

A quick look at Table 1 suggests the significant differences between the two periods. The 1960-80 era witnesses a sharp rise (59%) in the ton-miles of freight moved /capita as contrasted with the decline in tons/capita (-5.5%), indicating that relatively smaller freight tonnage is hauled over longer average distances and the spatial integration of the national economy is over longer distances (and areas). There is a decline in the freight intensity of GDP, (31% on a tonnage basis and 7% on a ton-mile basis) indicating the increasing importance of less freight-intensive sectors that make up the GDP.

The second period, 1981-98, exhibits a markedly different pattern. Reversing the trend in the first period, tons /capita start growing modestly, keeping pace with ton-miles /capita growth.

The decline in GDP freight intensity is about the same for both tons and ton-miles. Two comments are in order. First, the trend towards longer average freight hauls noted in the first period seems to be abating in the second period. The average distance of freight haul increased in the first period (1960-80) from 408 miles to 593 and barely afterwards to 597 miles in 1998. Has the process of increasing spatial reach and integration of the U.S. economy, noted in the first period, abated? Second, why does the tonnage moved double its growth rate in the 1981-98 era (as compared to 1960-80 period) at a time when the economy is shifting more towards services and becoming less material-intensive? What changes in the freight services industry and the forces underlying its evolution do these new trends in the 1980s and 1990s suggest?

We argue that this different pattern of aggregate freight indicators in the second period of the 1980s and 1990s reflects the operation in this era of new forces underlying the evolution of the freight sector. As elaborated in the next section, a variety of economic, technological, institutional, and policy changes in the 80s and 90s have converged to promote major innovations in the freight services industry, which in the process has been restructured to offer its users a range of new services at ever dropping costs (e.g. TRB, 1996, Hickling, 1994; Chatterjee, 2000; Lakshmanan and Anderson, 2000, Lakshmanan, Subramanian, Anderson, and Leautier, 2001). An understanding of this recent evolution of the freight services industry and the underlying processes is crucial to an analysis of the role that transport infrastructure investments play in the improvement of freight industry and its contribution to productivity of the economy.

Before proceeding to an elaboration of this argument, two other aspects of the freight industry are worthy of note.

First, in the American economy where the transition to knowledge-intensive sectors is advanced, the characterization of the freight sector in terms of tons and ton-miles is inadequate and somewhat misleading in view of the changes in the value and weight composition of goods. The Commodity Flow Surveys conducted by USDOT Bureau of Transportation Statistics (BTS) in 1993 and 1997 provide a rare measurement of freight by value (in addition to tons and ton-miles), and a richer view of some of the recent changes in the freight services industry.

Table 2 displays the freight moved measured in value terms in 1993 and 1997. The value of freight moved in the U.S. in this period grows three times as fast as GDP. The value of freight to be moved for a dollar of GDP rises between 1993 and 1997 by 6 cents or 6.6%. High value-added sectors are increasingly contributing to freight movements and the size of the economy.

Table 2. U.S. Freight by Value , 1993, 1997

Indicator	1993	1997	(% increase, 1993-1997)
GDP (Billions) Chained 1992 dollars	7054	7270	3
Freight (value)	6335	6944	9.6
Freight (value) / GDP	0.90	0.96	6.6

Source: BTS Commodity Flow Survey, 1993-1997
Special Tabulations by Felix Amatagoe, 2001.

Table 3 throws more light on the varying composition of commodities that make up the freight stream, when ranked by value and ton-miles. The top 5 commodities by value account for just under 40% of the value and 6% of the ton-miles. The top 5 commodities by ton-miles account for a little over 40% of the ton-miles and 10% of the value. However, two contrasting sets of commodities emerge as the top 5 when they are ranked by the different measures of freight—value or ton-miles. The top value commodities derive from knowledge-intensive high value adding industries such as electronics and electrical equipment, motorized vehicles, machinery and textile and leather products. The top commodities in terms of ton-miles are low value raw materials such as fossil fuels, basic chemicals, grains, etc. Since the usual statistical picture of the progress of a freight system derives from the available data on ton-miles, one often misses the trends in the emerging high value adding sectors whose growing importance and freight requirements are changing the spatial reach, nature of operations, functions, and services of the freight services industry.

Table 3. Top 5 Freight Sectors by Value and Ton-Miles, 1993, 1997

Top 5 Sectors by Value				**Top 5 Sectors by Ton-Miles**			
1993		**1997**		**1993**		**1997**	
Sector	**Value/Ton**	**Sector**	**Value/ Ton**	**Sector**	**Value/ Ton**	**Sector**	**Value/ Ton**
Electronic & Other Electrical Equipment, Office Equipment	$19,915	Electronic & Other Electrical Equipment, Office Equipment	$21,955	Coal	$21	Coal	$22
Motorized and Other Vehicles	$6,216	Motorized and Other Vehicles	$5,822	Cereal, Grains	$122	Cereal, Grains	$110
Miscellaneous Manufacturers	$9,727	Textiles, Leather, etc.	$11,591	Basic Chemicals	$539	Other Prepared Foods, Fats & Oils	$1,008
Machinery	$8,356	Machinery	$9,926	Gasoline & Aviation Fuel	$225	Coal & Petroleum Products, n.e.c.	$158
Textiles, Leather, Etc.	$8,266	Other Prepared Foods, Fats, & Oils	$1,008	Other Prepared Foods, Fats & Oils	$873	Basic Chemicals	$446
% of Total Value of Top 5 Sectors	37.6		38.3		10.4		10.6
% of Total Ton-Miles	6.1		6.5		42.8		42.7

Computed from BTS Commodity Flow Survey Data 1993, 1997, as tabulated by Felix Amatagoe, 2001.

Figures 6 and 7 compare the recent American freight experience with those of some major industrialized economies. The ton-miles / GDP freight intensity indicator for the U.S. is declining over time (as in other countries). The U.S. index is much larger than in the European countries and Japan—a reflection of the highly integrated and spatially much larger American economy. The ton / GDP freight intensity indicator exhibits in all countries a common declining trend confirming the on-going shift of these highly industrialized economies towards services and a lower material intensity. The much lower levels of tons / $GDP in the U.S. suggests its further evolution (compared to the other countries) in this path towards greater service intensity of the economy.

Figures 6. and 7. International Comparison of Freight Traffic Intensity I and II

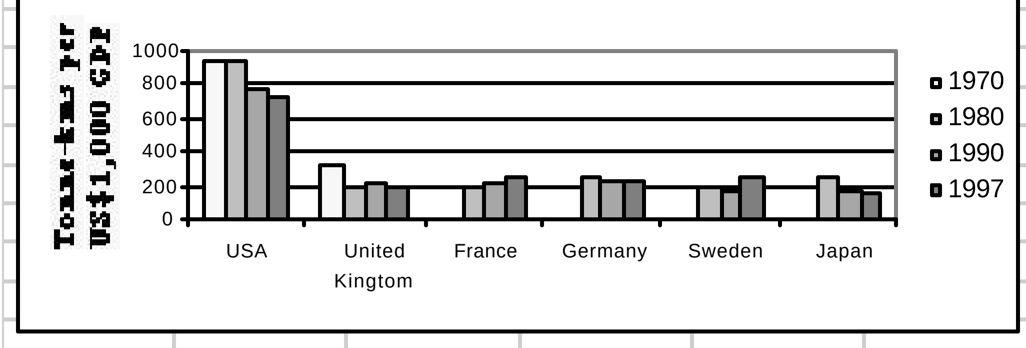


Figure 6. International Comparison (I): Freight Traffic Intensity

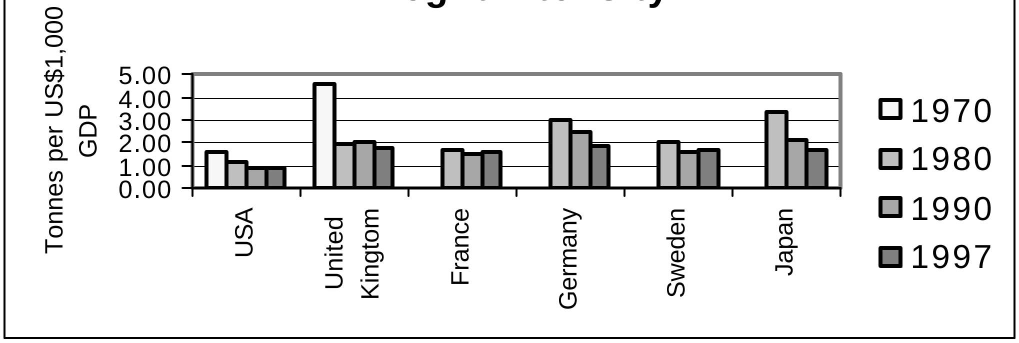


Figure 7. International Comparison (II): Frieght Intensity

The Context and Scope of Changes in the Freight Services Sector

There is a burgeoning literature emerging in the last decade on two aspects of the transformational changes in the freight industry. The first aspect deals with the major changes in the technologies, functions and spatial reach of the production and consumption activities in the U.S. and in the larger global economy, which define the ***context*** in which the freight services industry operates and evolves. The second element of this literature focuses on the qualitative changes in the ***scope*** of the expanded and new services developed by the freight industry in response to this emerging context. Taking advantage of new technologies of transportation and information, transport institutional and policy reforms, and transport infrastructure investments, a new world of freight transport, that is a vastly transformed landscape with many elements of discontinuity and novel and profound changes from the past, has emerged in the last decade and a half (e.g. OECD, 2000; Chatterjee, 2000, 2001; TRB, 1997; Lakshmanan and Anderson, 2000, Lakshmanan, Subramanian, Anderson, and Leautier, 2001). An inquiry into the role of transport infrastructure investments on these freight sector changes and thereby on overall economic productivity requires an understanding of the major elements of these *contextual and scope* aspects of the transformational changes noted above.

This section of the paper provides the relevant overview, first of the major changes in the broader economic context in which the transport sector operates, and secondly of how the freight sector responds to these contextual changes in the larger economy by developing new functions and services -- which in turn induce changes over time in the functioning of the larger economy.

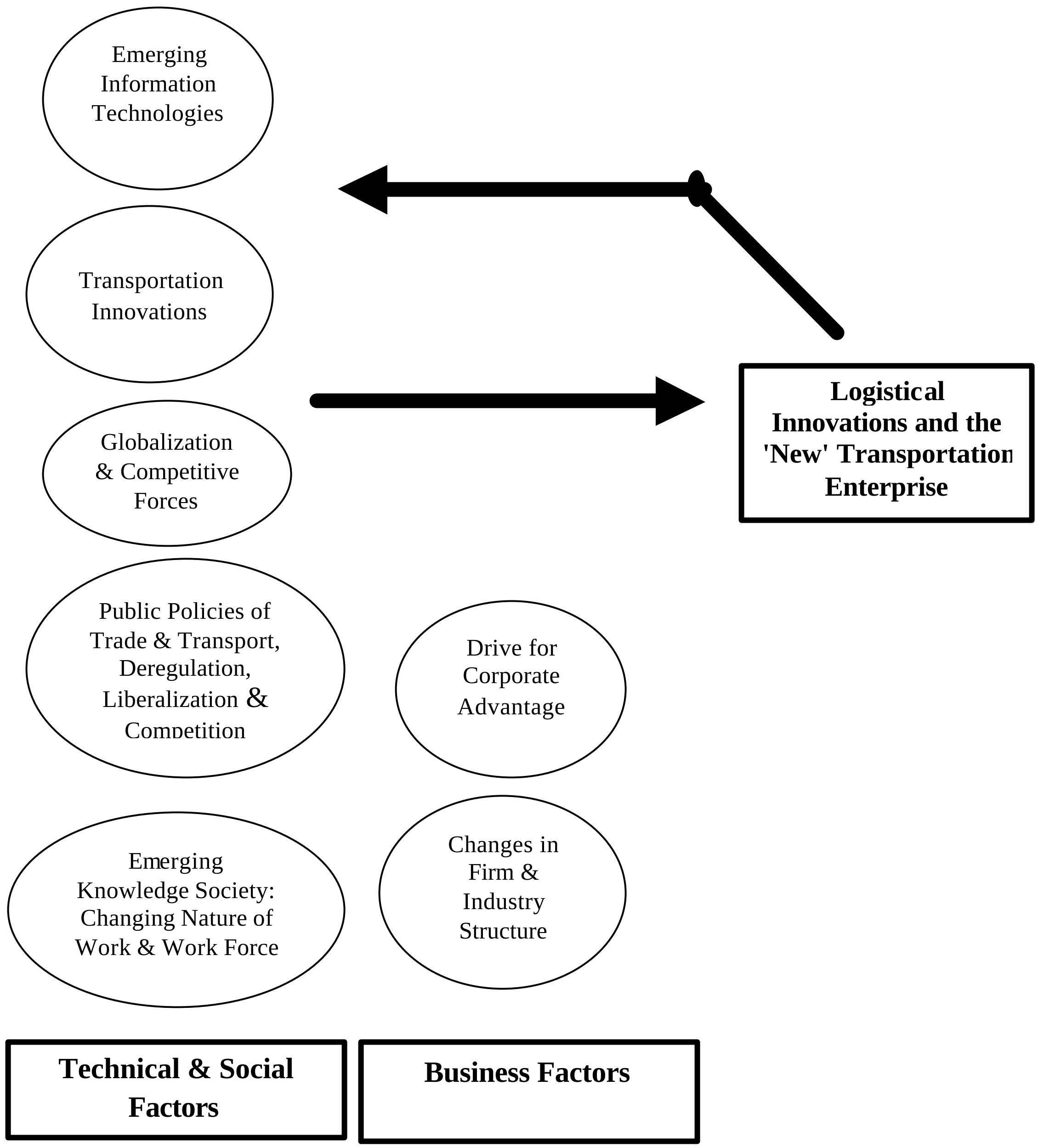
The Changing Context of the Freight Services Sector

As noted above, a variety of technological, socio-economic, and business factors in the last two decades have combined to erect a globally integrated production system for an increasing number of economic sectors—in the process transforming the freight services sector itself in major ways (Figure 8). New developments in the *enabling and space-shrinking technologies* of transportation and communication are fundamentally transforming the space-time relationships in the U.S. and around the world. Innovations in the complementary technologies of transportation and information have led to sharp reductions in costs, and sharp increases in the service quality (speed, time-definite delivery, high frequency, etc.). This combination of lower costs and better services makes possible the nation-wide and indeed world-wide search by production firms for cheaper and better materials, production components and product marketing. This in turn requires functional integration, management and coordination of nationally and indeed globally distributed set of diverse economic activities. The consequence is an increasing division of labor in the production processes as the component activities in many industries are further disaggregated and spatially reallocated.

Recent changes in the public policies in the U.S. related to trade and transport have also promoted interregional and global economic development processes. The advent of free trade regimes (GATT, WTO, NAFTA, etc.) and liberalization policies promoted by the U.S. has expanded U.S. firms' international trade and capital flows in NAFTA, Europe, Asia and all over the world. As production and consumption technologies change in this context, production value increasingly derives from knowledge. Materials, products, services, and transportation are becoming more knowledge-intensive in an increasingly competitive American and global economy (Chatterjee, 2001). To stay competitive in this environment, U.S. production and transportation firms cut costs by broadening the sourcing of raw materials and intermediate products in an increasingly interdependent regional and global markets. Such national and international sourcing of inputs by U.S. production and service firms which maintain lean inventories[1] can only be implemented if reliable and timely freight transport system is available. Further, the increasing trend towards intrafirm trade (deriving from a division of labor on a regional and global basis within American and other OECD multinational firms), which amounted to $800 billion in the mid-90s, is possible only with a responsive freight transport system (World Bank, 2000; Lakshmanan, Subramanian, Anderson, and Leautier, 2001).

[1] Carrying and holding costs represented 25-30% of the value of inventories in US firms due to "product, depreciation and interest" (Chatterjee, 2000b). In 1998, more than 60% of production and sales were processed from direct orders rather than from stock (Gwilliam, 1998).

Figure 8. Factors of Underlying the Transformation of the Transport Enterprise

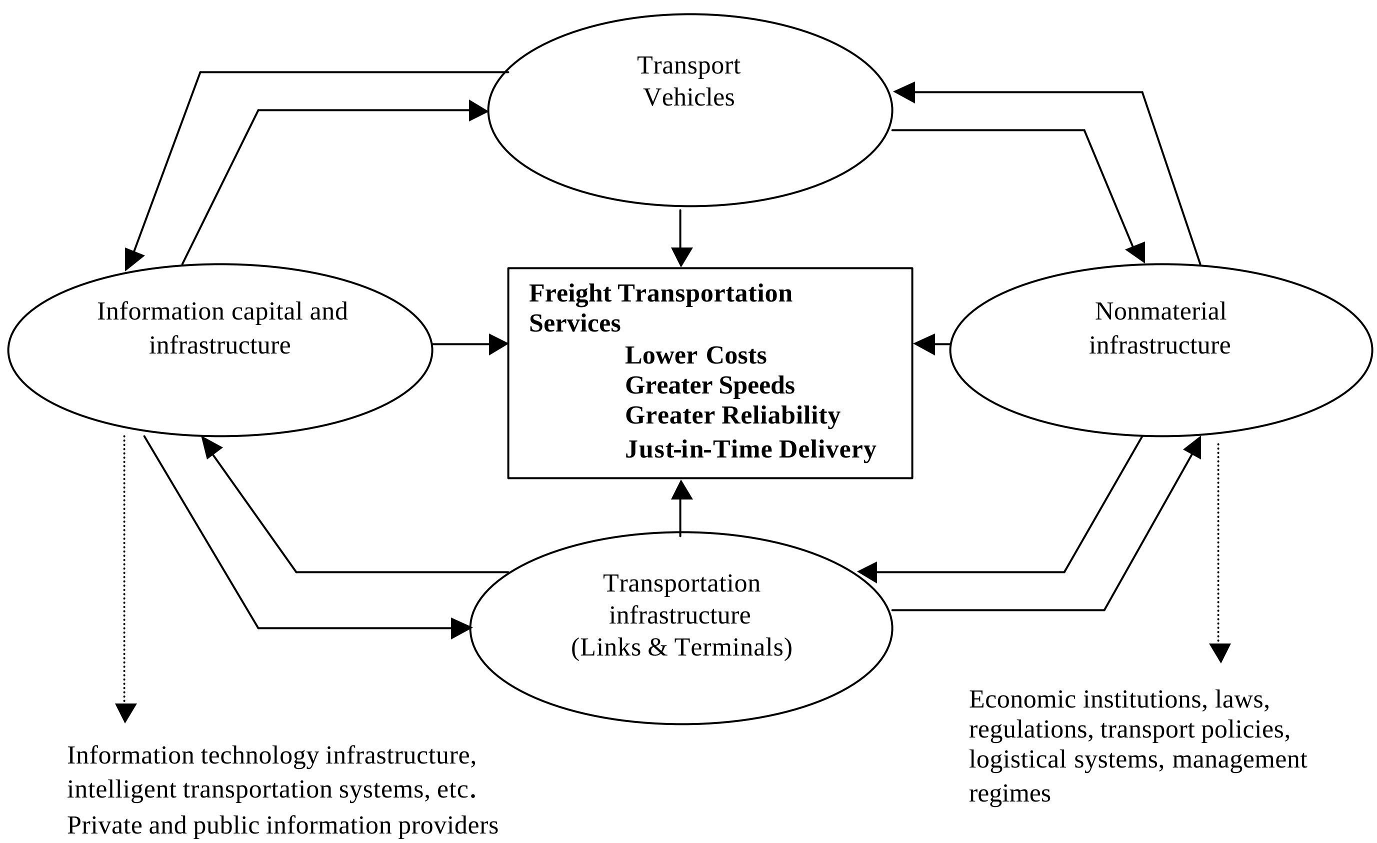


Source: Chatterjee, 2001 **Adapted from OECD, 1996**

The Emerging Freight Services Industry

The innovative and effective ways in which freight transport firms in the U.S. and elsewhere are responding to this challenge of supporting the highly integrated and rapidly evolving national and global production and consumption systems are best understood in a systemic frame. The quantity, variety, and quality of freight transportation services at a point of time are jointly determined by the technologies embodied in the four system components -- vehicles, physical infrastructure, nonmaterial infrastructure, and information infrastructure -- and the interactions among them (Figure 9).

Figure 9. Components of a Freight Transportation System



The traditional discussion of freight services focuses on vehicles and physical infrastructure as the sources of the secular freight service improvements. While jet aircraft, containers, and the Interstate Highway System have contributed significantly to freight improvements, they represent only part of the story. What is only recently generally recognized about freight transportation progress is the role played by two other components -- the nonmaterial infrastructure of the freight transport system, and the complementary information capital and infrastructure--of the transportation system (Lakshmanan, 1998; Lakshmanan and Anderson, 2001). Far less visible than its physical counterpart, nonmaterial infrastructure -- comprising economic institutions, regulations, policies, business logistical systems, the knowledgebase for transport governance, etc. -- facilitates the efficient coordinated use of vehicles and physical infrastructure.

The nonmaterial infrastructure has been changing recently in many ways. The role of the public sector in these changes is two-fold; first, *promoting overall growth* of the freight sector by changing the economic institutions and the economic incentives governing transport. Policies of transport deregulation and liberalization introduced in the last two decades in the U.S. have released competitive forces among transport firms and among transport modes. One consequence has been the dropping costs of freight transport, as evident from Figure 10. Another is the encouragement this new economic environment provides to freight firms to develop innovative businesses opportunities (e.g. Tradenet, third party logistics, etc.); second, *improving operational efficiencies* of the freight services sector by the public sector's promotion of intermodalism and of the spread of Intelligent Transportation Technologies (ITS). In response to this evolving economic, technical, and policy environment, business firms are developing innovative logistical practices helping the entire freight industry.

Figure 10a. Difference Between International Fares (U.S. - Foreign) and U.S. Domestic Fares Adjusted for Distance, Selected Years, 1978-1996.

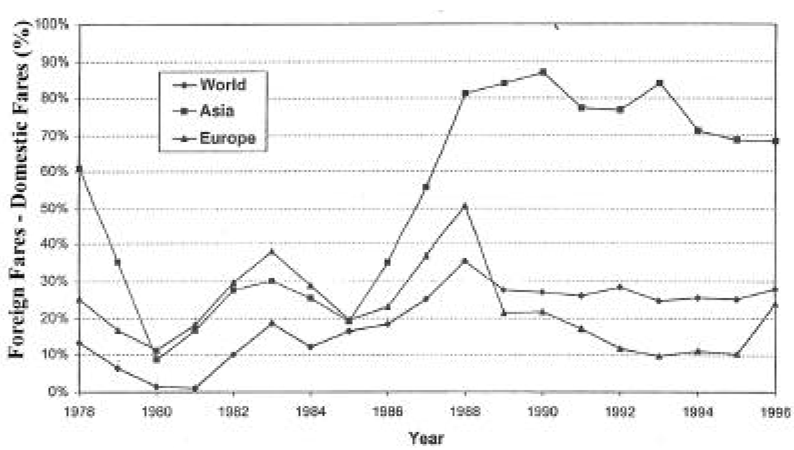


Figure 10b. Operating Costs of Less Than Truckload and Truckload Carriers, 1988-1995, in 1995 dollars per vehicle mile

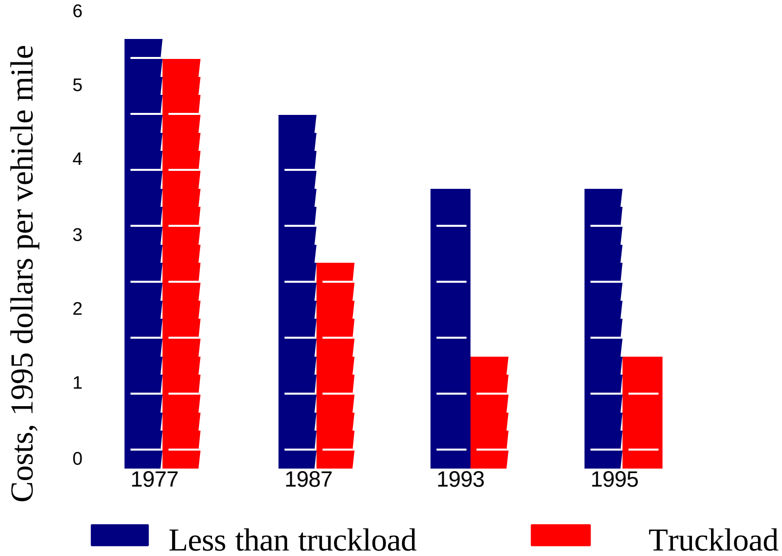
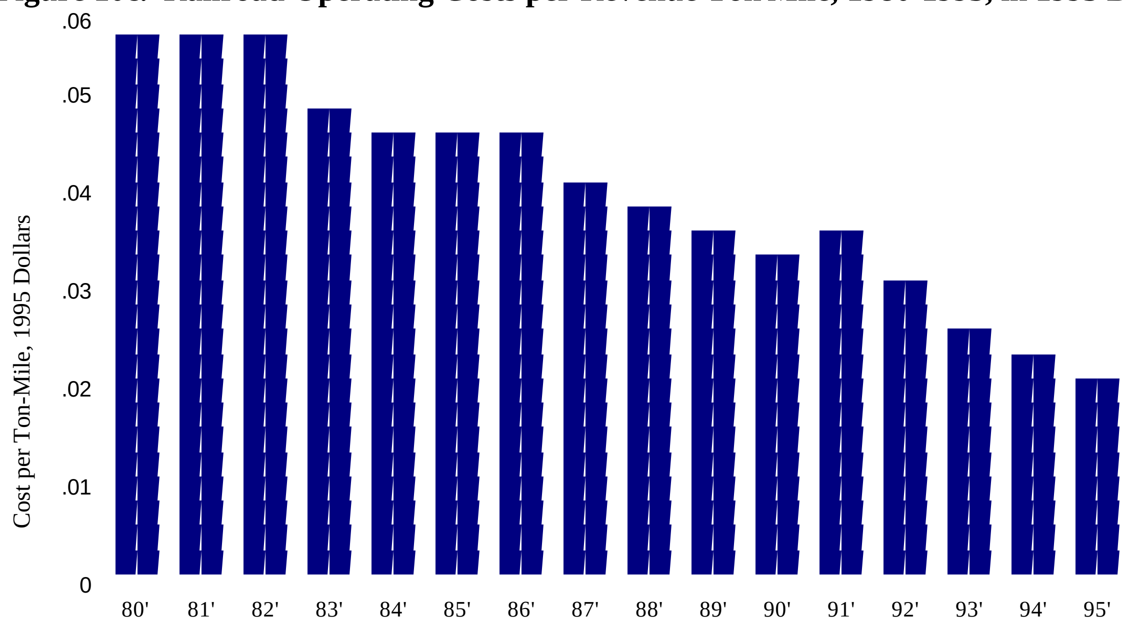


Figure 10c. Railroad Operating Costs per Revenue Ton-Mile, 1980-1995, in 1995 Dollars



Source: Morrison and Winston, 1999

Then, there is the role of the final component, namely the information technologies (IT) in increasing the capacity and functionality of transport operations, transport equipment, and transport infrastructure. IT, comprising a broad range of devices, functions, and supporting tools used in sensing, generating, processing, transmitting, and communicating information, offer vital information to transport operators and travelers, enhancing their responsiveness and efficiency, and making possible other transport innovations.[2]

Customers of the freight services sector in the U.S. and the world economy demand currently a seamless transport service, with the most appropriate route/mode combination with no or low barriers for goods movement across regions and nations. This demand called for a reform of the pre-1990 freight industry structure. In the pre-1990 period, independent factories, supplemented by clusters of Original Equipment Manufacturer and subcontractors, constituted the industrial structure. The focus of freight transport firms was on shipments and material flow. The transport sector emphasized reduction of costs. The logistics function was organized as a separate department, with modest information support and with little or no links to production departments or decisions of the firm.

The post-1990 transport logistical structure is quite different. As global and virtual production firms appear, freight transport services firms innovate and offer to these production firms expanded and new services which can be best described as *the logistical channel* (OECD 1996; Chatterjee, 2001). As transport and information industries were being liberalized and deregulated, logistical innovations such as Just-in-Time (JIT), and quick-response services are reengineering business systems as well as production and commodity flow systems. Containers and cargoes are tracked around the U.S. (and indeed around the globe) and are continually 'visible' in transit to shippers and carriers. What is more, the slow and tedious paper trail that has traditionally accompanied goods to secure clearances (across borders as in NAFTA) from customs, revenue agencies, and financial intermediaries is being replaced by Electronic Data Interchange (EDI) and e-commerce (Lakshmanan, Subramanian, Anderson, and Leautier, 2001). Customs agencies, finance ministries and treasury departments, and regulators are beginning to reinvent their practices governing the flow of goods in this new environment.

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2 Such *knowledge-providing and enabling functions* of IT in transport services have historical antecedents in the sextant and chronometer which enabled more precise global navigation in the 18th Century, in the telegraph which promoted transcontinental rail operations in the 19th Century, and the radio and radar which were so critical to navigation in the 20th Century (Lakshmanan 1998). The current efflorescence of new information technologies at the cusp of the 21st Century is massively transforming transportation industries and the scope of their services.

In the logistical channel developed in this evolving socioeconomic and technological context, freight transport firms not only provide traditional material flow faster, cheaper and more reliably than before; they also offer *new* types of transport and logistical services. These new services are in the form of reliability, timeliness, strategic outsourcing of a corporation's distribution functions, and flexibility in destination choices for customer firms. Such new services provide flexibility and new modes of operation for customer firms, thereby offering the manufacturing and service industry customers additional production value and strategic comparative advantages. Further transportation and distribution concerns are increasingly integrated into strategic decisions of firms, for instance, where to locate their production and warehouse facilities, where to source their intermediate goods, and how to manage their value chains such as using JIT systems, move into e-commerce, and so on. Freight transport firms are actively involved in lowering order cycling times and in implementing the consumer demand oriented "pull" systems of logistics (FHWA, 1998). These changes are incorporated in the supply and value management or integrated logistics processes. Through these processes, the new freight transport services firms help gain system-wide cost reduction *and value addition.*

For a transport public policy analyst, a major analytical issue of interest in this context is to ascertain the role played by public investments and policy in promoting these change processes in the freight services industry and thereby achieving the productivity increases both in the transport industry and in the larger economy -- a task we turn to next.

Linkages Between Transport Investments, Freight Services Sector, And Overall Economic Performance

Figure 11 outlines the complex and comprehensive linkages between transport public investments, freight services and economic performance. While the focus of this paper is on the effects of transport investments on overall economic performance, these economic linkages need to be framed in the context of other important drivers of the freight services system. In addition to transport infrastructure investments, two other driving forces of the freight industry are consequently listed on the left of the chart: These are the (transport and information) technological factors and public policies of transport governance which, jointly with transport infrastructural investments, determine *the nature and scope* of freight services and thus potentially their influence on overall economic performance.

First, technological factors such as new transport and information technologies yield a variety of transport *service* and *process* innovations which are critical to the logistics process and its fruitful reorganization. Examples of service innovations offered by freight services firms include:

> sourcing of intermediate goods, location of production and warehousing facilities, and other ways of managing the supply chains for customer production firms. Process innovation are exemplified by JIT systems, and the consumer-oriented "pull" systems of logistics.

These freight innovations proliferate, particularly in the supporting environment of new economic incentives and competition generated by the second driver of the freight industry, namely, the on-going reforms of Transport Public Policy initially in the U.S. and currently in many other countries. The two elements of the changing transport public policy pertain to a) overall economic governance (e.g. deregulation, privatization), and b) those governing transport physical flows (e.g. vehicle size/wt. rules, reinvented inspection processes, etc.). Both of these policy sets influence the freight services powerfully; first, deregulation and liberalization policies by changing economic incentives and releasing competitive forces, have enabled and motivated the service and process innovations and logistical improvements; second, the changes in transport physical flow rules—less restrictions on vehicle size/weight attributes and improved ports/ customs rules, etc. -- have influenced transport capacities on transport routes and terminals and logistical potential (Lakshmanan, Subramanian, Anderson, and Leautier, 2001). The variety of service innovations and process innovations in freight services, enabled by this combination of transport and information technologies and public policy reforms, promotes in turn a new set of freight service attributes and the subsequent restructuring of business logistics, as transport infrastructure attributes evolve.

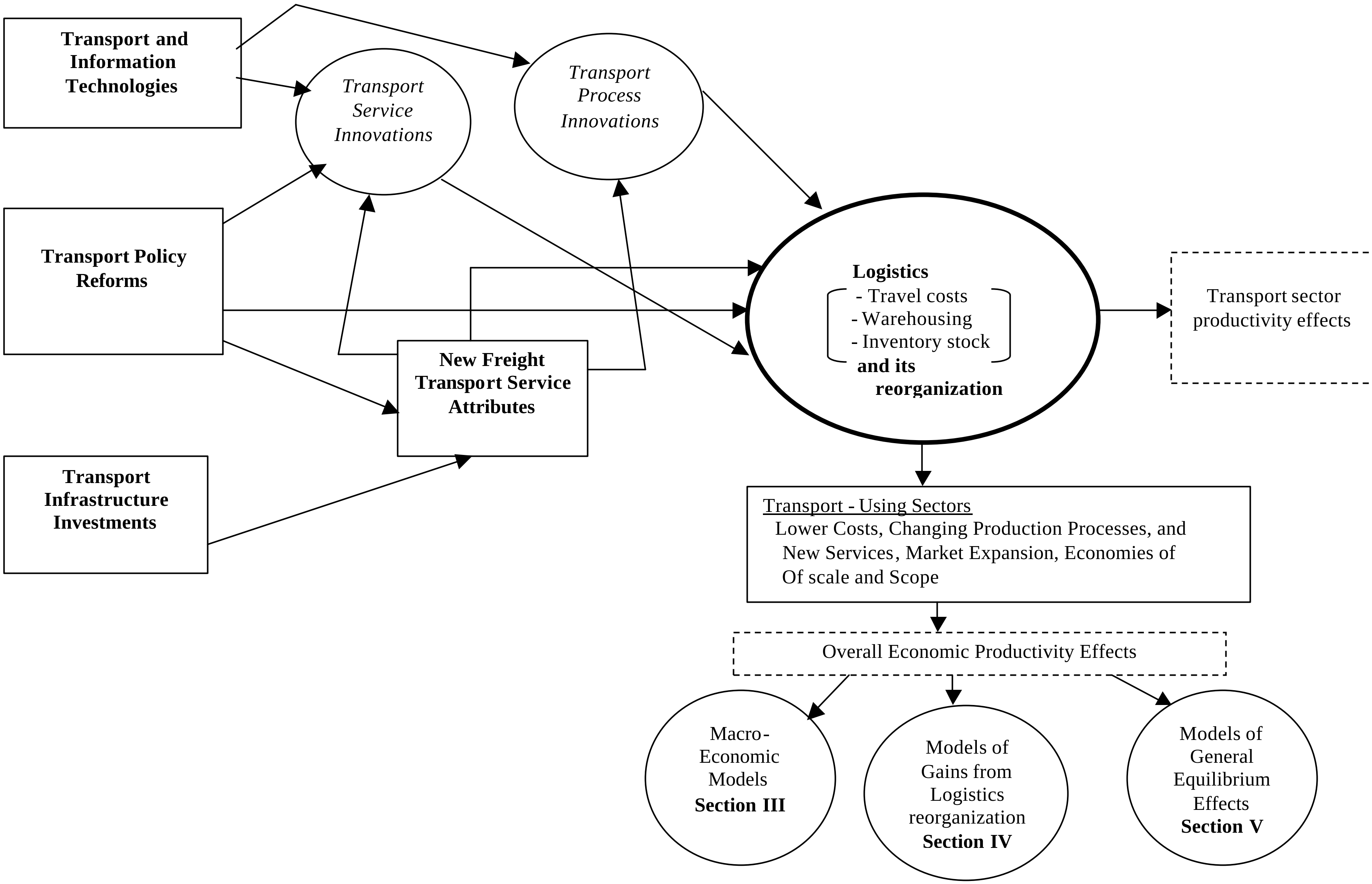


Figure 11. Linkages Between Transport Policy and Investments, Freight Services Sector and Overall Economic Productivity

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.

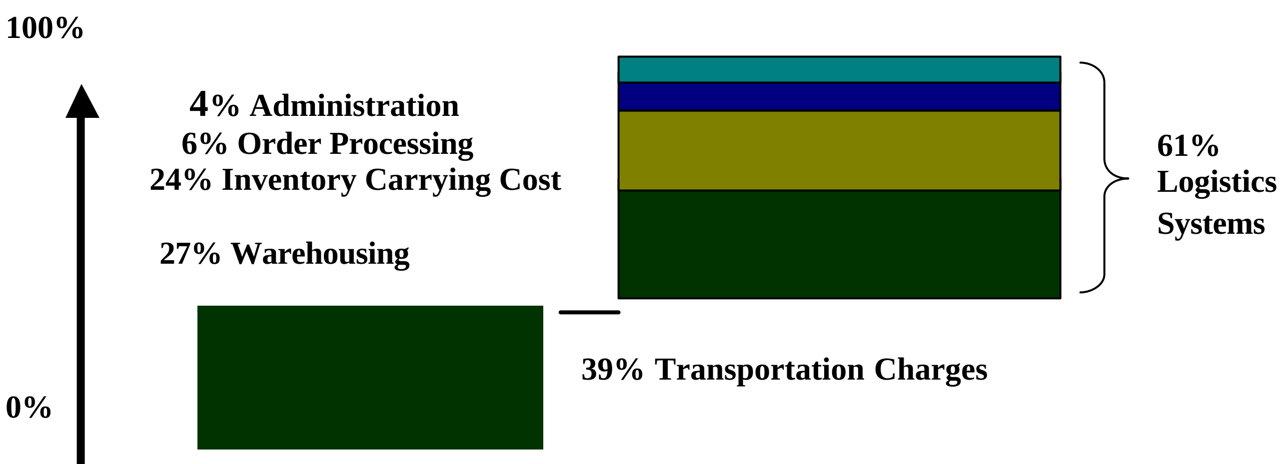
Finally, these freight service attributes and technical innovations converge on the central activity in Figure 11, namely, the logistics process and its restructuring over time. Logistics refers to the integrated analysis and management of a firm's overall supply chain and embraces processes of transportation, 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



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,

3 . By extending JIT right to the consumer, transport firms not only create a seamless market but also provide valu-added services to customers. Producers manufacture in response to customers' orders (increasingly by internet), to which its suppliers of parts and component assemblies have access and respond with appropriate delivery. Transport firms such as FEDEX presort products at points of shipment overseas, distribute direct to US outlets, while informing the US manufacturing firm about the shipment details

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

Type of Project	Number of Projects	Annual Rate of Return
Airports	8	21%
Highways	306	26%
Rail	72	14%
Ports	96	20%
All Transport Projects	**482**	**22%**
All Sectors	**n.a.**	**15%**

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 economies[5]. 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

[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!

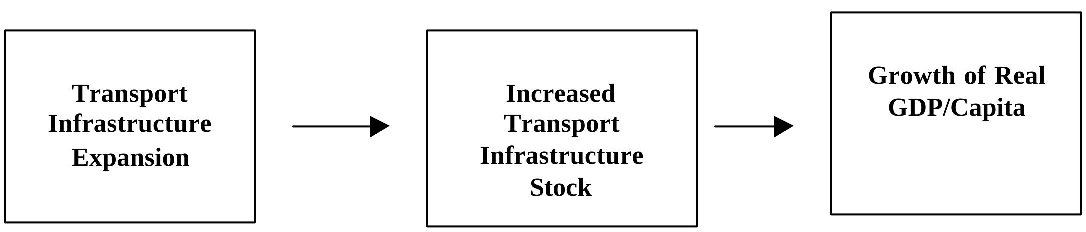
Productivity is a notion representing the efficiency with which economic resources are used. It is measured as a ratio of the value of output produced over some period to a measure of inputs used in the same period. Since productivity is a ratio of output to input, productivity growth implies that the 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[9]. 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

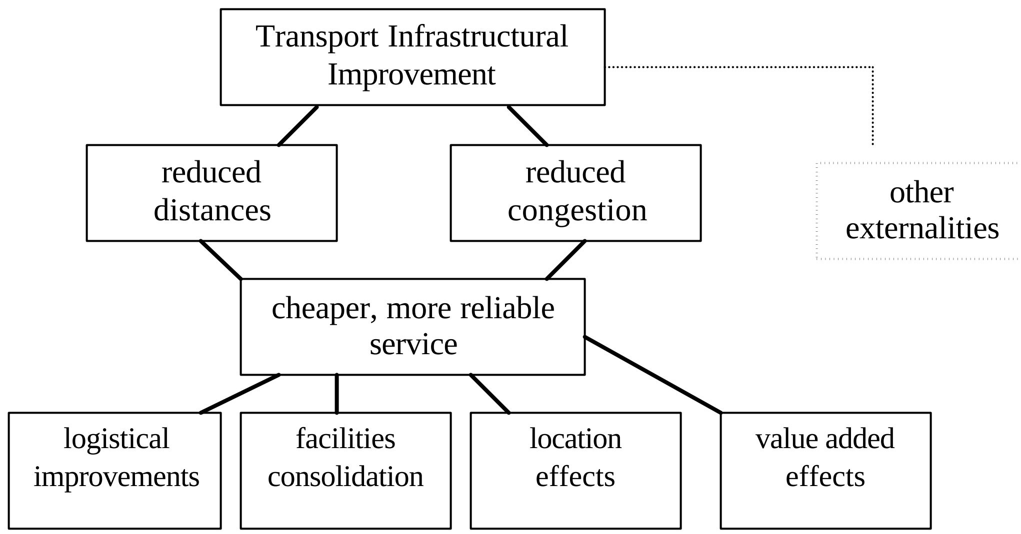
[9] At the same time, they name positive or negative effects on externalities other than congestion.

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).

Figure 14. Microeconomic Impacts

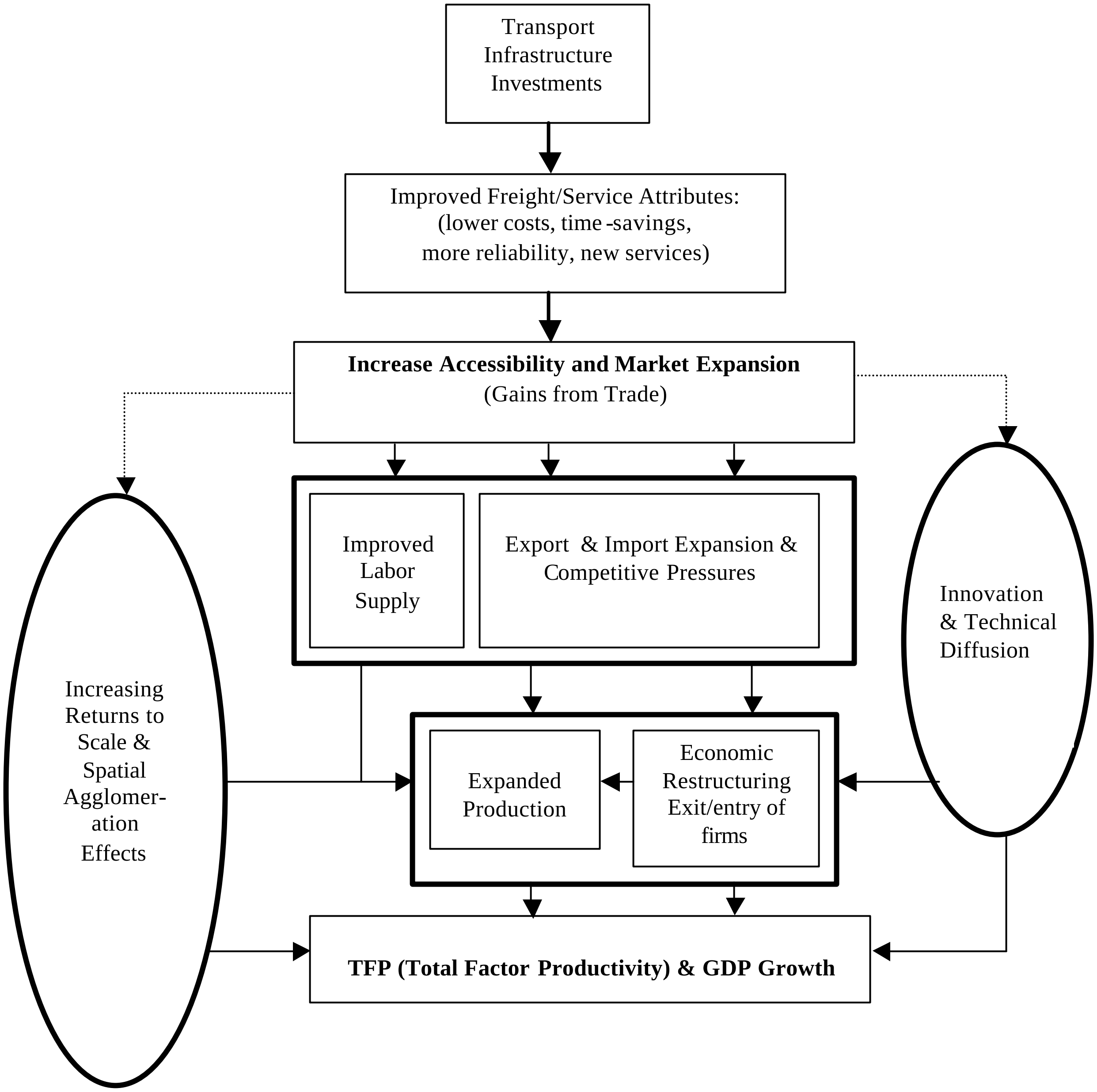


The Spatial/ Regional General Equilibrium Effects Perspective

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.

Figure 15. Transport Infrastructure Supply Freight Services Sector and Full Economic Effects



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.

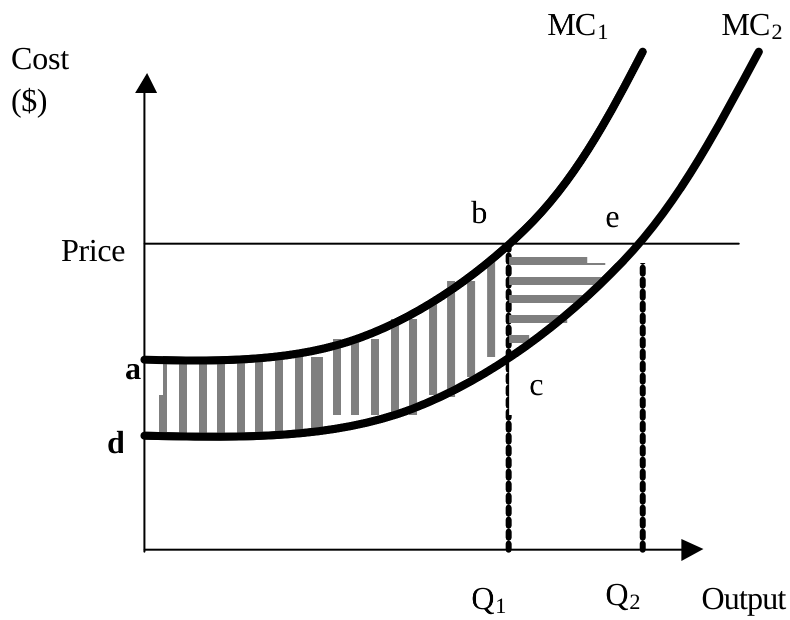
Section V will describe more formally these general equilibrium effects and the dynamic changes.

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



MC_1= marginal cost with infrastructure deficiencies
MC_2= marginal cost with improved infrastructure

Where infrastructure is inadequate, the firms are confronted by high marginal costs (MC_1) at every level of production, and given the market price of their output, produce Q_1 units of output. As infrastructure services are improved, the marginal cost curve shifts to a lower level (MC_2). The result is twofold. There is a total cost savings of *abcd* for the earlier level of output Q_1, and an output expansion effect *bce* as Q_2- Q_1 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:

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

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.

$$e_{PK} = \frac{PK}{Y} \cdot \frac{\partial Y}{\partial PK} \qquad (2)$$

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.

$$C = C(Y, \overline{P}_x, PK) \qquad (3)$$

Where C is the total cost of producing output Y, the vector $\overline{P}_x$ 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:

$$X_i(Y, \overline{P}_X, PK) = \frac{\partial C}{\partial P_i} \qquad \forall_i \qquad (4)$$

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. Aschaeur, 1989; Munnel, 1990). The Cobb-Douglas formulation imposes *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)

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 *magnitude* of this contribution. Some studies make dramatic claims about transport's contribution to American economic growth (Aschaeur, 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.

willingness of the private sector to pay for additional increases in infrastructure and the optimality of provided public capital for the private industries.

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-

1985 period. His claims and counterclaims appeared to have dominated the research agenda for several years.

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[8] framework and obtained statistically significant output elasticities of about 0.15 for core public capital and 0.04 for highway capital stock alone

The Aschaeur-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

[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 Mameneus 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.

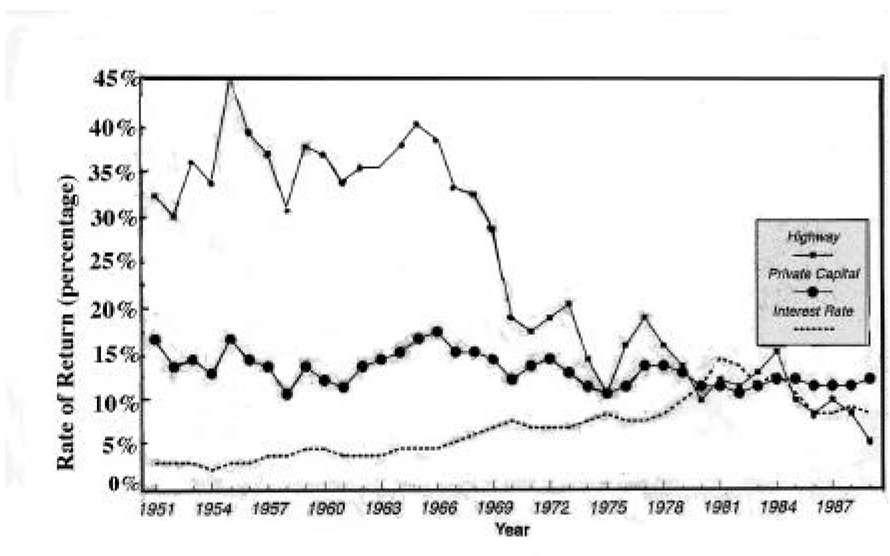


Figure 17. Net Rates of Return of Highway Capital, Private Capital, and Private Interest Rate, 1951-1989, computed by Nadiri and Mamuneas (1996)

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

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

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.

Table 6. Summary of Studies of the Productivity Effects of Highway Infrastructure and Other Public Capital

				Public Infrastructure		Private Inputs		
Study	**Sample**	**Type of Estimation**	**Sector or Output Measure**	**Type**	**Elasticity**	**Type**	**Elasticity**	**Notes**
Ratner 1983	U.S. Aggregate, 1949-73 (Time Series)	Production function, Cobb-Douglas	Private business sector output	Public capital: non-military, government owned equipment & structures	Output elasticity: 0.05-0.06	Labor/capital, capital adjusted for capacity utilization	L: 0.71-0.72 K: 0.22	
Costa, Ellson and Martin 1987	U.S. 28 States, 1972 (Cross Section)	Production function, Translog	All sectors manufacturing non-agriculture	State and local public capital	0.20 for all sectors, .19 for manufacturing, 0.21 -0.26 for non-agriculture	Capital, labor	K:-0.06-0.11	Public capital complementary to labor
Keeler and Ying 1988	U.S 9 Regions, 1950-1973 (Time Series/Cross Section)	Cost function, Translog	Trucking industry	Federal-aid highway capital stock	Cost elasticity: –0.07	Capital, labor, fuel, other materials and services		
Deno 1988	U.S. 36 Metropolitan Areas, 1970-1978 (Time Series/Cross Section)	Profit function, translog	Manufacturing	Highways and bridges; water; sewer	Output supply elasticity of highway/ bridge capital: 0.31-0.57	Capital, labor		Highway capital complementary to private capital in growing regions; complementary to labor in full sample
Mills and Carlino 1989	U.S. Approx. 3000 Counties, 1970-80 Growth (Cross Section)	Determinants of county employment and population growth, Simultaneous equation estimation	Total employment, Manufacturing employment, Population	Interstate highway density	Over decade: 0.54 total employment: 0.17 population			
Aschauer 1989	U.S. Aggregate, 1949-1985	Production function, Cobb-Douglas	GNP/private capital	Non-military public capital and core public capital	Non-military 0.39 core 0.24	Labor/private capital	0.38	
Munnell 1990	U.S. Aggregate, 1948-1987	Production function, Cobb-Douglas	GNP	Core public capital	0.31 – 0.39	Capital, labor	K: 0.56 L: 0.11	

Table 6. continued

				Public Infrastructure		Private Inputs		
Study	**Sample**	**Type of Estimation**	**Sector or Output Measure**	**Type**	**Elasticity**	**Type**	**Elasticity**	**Notes**
Aschauer 1990	U.S. 48 States (Cross Section)	Determinants of average annual growth rate	State per capita income	Average total highway mileage, 1960-85; disaggregated into rural and urban mileage	Total: 0.22-0.37 Rural: 0.24-0.40 Urban: 0.10-0.17			Higher pavement quality contributes to growth: vehicles/highway mile as congestion measure retards growth
Duffy-Deno and Eberts 1991	U.S. 28 Metropolitan Areas, 1980-1984 (Time Series/Cross Section)	Simultaneous equations; personal income and public investment	Per capital personal income	Public capital	Personal income elasticity of public capital 0.08	Capital, labor, energy		
Eisner 1991	U.S. 48 States, 1970-1986 (Time Series, Cross Section,	Production function, Cobb-Douglas and Translog	Gross State Product	Public capital insignificant, highway 0.05-0.07 in time series; public capital 0.16, highway 0.06 in cross section	Capital, labor	K: 0.29 L: 0.77	Uses data from Munnell 1990; estimates of first differences sensitive to scale constraints	
Tatom 1991	U.S. Aggregate 1950-1988 (Time Series)	Production function, translog, 1^{st} differences	Private business sector output	Public capital	0.03, not significant	Capital, labor energy	L/K: 0.69 E(price): -0.06	Energy price variable derived from 1^{st} order condition on energy use

Table 6. continued

				Public Infrastructure		Private Inputs		
Study	**Sample**	**Type of Estimation**	**Sector or Output Measure**	**Type**	**Elasticity**	**Type**	**Elasticity**	**Notes**
Garcia-Mila and McGuire	U.S. 48 States, 1969-1983 (Time Series/Cross Section)	Production function, Cobb-Douglas	Gross State Product	Highway capital	0.04	Capital structures, capital equipment, labor	Total K: 0.47 L: 0.36-0.45	
Hulten and Schwab 1991	U.S. 9 Regions, 1951-1986	Multifactor productivity	Manufacturing	Public capital	Not significant	Capital, labor, materials		Model predicts significant coefficient on K if public capital operates through production function; but K coefficient is significant & public capital coefficient is insignificant; interpretations unclear
McGuire 1992	U.S. 48 States, 1969-1983 (Time Series/Cross Section)	Production function, Cobb-Douglas (state fixed effects); translog	GSP	Highway capital	C-D (fixed eff.): not significant translog: 0.24	Capital, labor	K: 0.23-0.46 L: 0.70-75	First-differencing to correct measurement errors in public capital yielded insignificant highway output elasticities

Table 6. continued

				Public Infrastructure		Private Inputs		
Study	**Sample**	**Type of Estimation**	**Sector or Output Measure**	**Type**	**Elasticity**	**Type**	**Elasticity**	**Notes**
Hulten and Schwab 1991	U.S. 9 Regions, 1951-1976 (Time Series	Multifactor productivity	Manufacturing	None		Capital, labor		No observed role for public infrastructure in different interregional growth rates
Morrison & Schwartz 1992	U.S. States	Cost function		Annual cost reduction due to infrastructure investment varies between 15-30%				
Carlino & Voith 1992	U.S. States	Production function						Highway density in states increases productivity by 21%, urbanization impact 38%
Jones, Miaow, Lee and Rickert 1993	U.S. States, 1983-1989 (Time Series/Cross Section)	Production function, Cobb-Douglas, 5 equation system	GSP/L	Lane mileage, vehicle miles traveled, separate urban and rural, different groups of highway classes	VMT: 0.16-0.23 LM, total: 0.09-0.14 urban VMT, LM: positive rural VMT,LM: negative	Capital /labor	K/L: 0.36-0.38	Endogenous congestion and VMT
Moomaw and Williams 1991	U.S. 48 States, 1954-1976 (Time Series/Cross Section)	Multifactor productivity	Manufacturing	Highway density	Significant positive effect			Use regional dummies with state data
Nadiri-Mamaneus 1996	U.S. 1947-1989	35 Industries	Highway capital, non-local highway capital	Cost elasticity -0.044				Net rate of return for highway capital, contribution to TFP growth by industry

Table 6. continued

				Public Infrastructure		Private Inputs		
Study	**Country**	**Type Of Estimation**	**Sector Or Output Measure**	**Type**	**Elasticity**	**Type**	**Elasticity**	**Notes**
Mera 1973, '75	Japan 8 Regions 1954-1963 (Time Series/Cross Section)	Production Function, Cobb-Douglas	Primary, Secondary, Tertiary	Transportation and communication; 3 other categories	0.35** for transport & communications in secondary; 0.39-0.42 in tertiary; transp. and comm. Not used in primary	Capital, labor	K: 0.15-0.33 L: 0.55-0.85, according to sector	
Elhance & Lakshmanan 1988	India National 1950-1979 (Time Series) And 6 States 1970-1971 (Cross Section)	Normalized restricted cost function, Translog, with endogenous private adjustment to publicly supplied infrastructure	Manufacturing Value Added	Economic infrastructure (roads, rail, electric capacity); Social infrastructure (hospital beds, etc.)	Economic infrastr. cost elasticities; at state level, -0.04 to -0.47; at national level - 0.01 to - 0.03	Capital, labor energy, materials		Adjustment period of about 5 years
Seitz 1995	Japan	Production function						GDP/land area a function of capital, labor, road system attributes & level of urbanization
Johansson 1993 Johansson & Karlsson 1994	Sweden 280 And 284 Munic. 1980-1988 (Time Series/Cross Section)	Production function, Cobb-Douglas	Aggregate income, Industry -level income	Highway capital, Public transit capital, Road accessibility	Highway 0.12-0.18; Public transp. 0.18-0.20; Road accessibility 0.20-0.27	Capital, labor	K: 0.47-0.50	Adjustment periods of 14-26 years, depending on industry
Seitz 1993	Germany 1970-1989 (Time Series/Cross Section)	Cost function, Translog, industry fixed effect time series	Real output, 31 Industries	Road mileage, Road capital	Negative and significant	Capital, labor		Roads complementary to private capital, substitute for labor; these effects small

Table 6. continued

				Public Infrastructure		Private Inputs		
Study	**Country**	**Type Of Estimation**	**Sector Or Output Measure**	**Type**	**Elasticity**	**Type**	**Elasticity**	**Notes**
Seitz 1994	Germany 1970-1989 (Time Series/Cross Section)	Cost function, Translog, industry, Fixed effect time series	Public capital, "Core" public capital	On demand for: 0.36 on demand for L:-0.13 to -0.15	Capital, labor	Rental elasticity of K demand, -0.04; wage elasticity of L demand, -0.09		
Conrad And Seitz 1994	Germany, 1961-1989 (Time Series/Cross Section)	Cost function, Translog	Gross output, 3 Sectors; Manufacturing, construction, Trade & transport	Public capital	Negative & significant	Capital, labor, material		Estimated shadow price of public infrastructure approx. Half of user cost of private capital; decrease in pub infrastr. Partially responsible for observed productivity decline
Lynde And Richmond 1992	United Kingdom Aggregate, 1958-89 (Time Series)	Cost function, Translog	Manufacturing	Public capital	Significant cost reduction effect	Capital, labor		Public capital complementary to private capital; aggregate constant returns to scale with public capital
Lynde And Richmond 1993	United Kingdom Aggregate 1966: 1-1990; 2 (Time Series)	Cost Function Translog (Cointegrated)	Manufacturing, Value added	Public capital	Significant cost reduction effect	Capital, labor, materials		Public capital contributes 17% of manufacturing productivity growth

Table 6. continued

				Public Infrastructure		Private Inputs		
Study	**Country**	**Type Of Estimation**	**Sector Or Output Measure**	**Type**	**Elasticity**	**Type**	**Elasticity**	**Notes**
Anderson, Anderstig And Harsman 1990	Sweden 70 Commuting Regions 1970 and 1980 (Cross Section)	Production function, Variable returns to scale	Aggregate income	Main roads, railroads, airport capacity accessibility	Roads significant in 1980; rail significant in 1970; airports significant only when interacted with R&D	Capital, labor	K: 0.25 L: 0.28; 0.57-0.75 combined with knowledge capital	
Prud'homme 1993	France, 22 Regions, 1981-1988 Growth (Cross Section), 1988 (Cross Section)	Production function, Cobb-Douglas	Aggregate income/L	Public capital	Significant only when measured per unit of L times land area	Capital/labor	K/L:0.20-0.26	

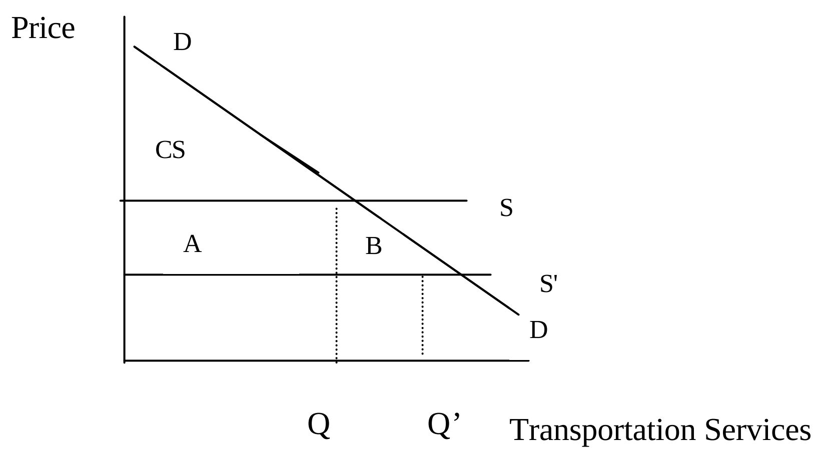
IV. MICROECONOMIC BENEFITS

Microeconomic benefits refer to improvements in the productivity of individual firms due to investments in transportation infrastructure. Depending on market structure, the benefits may accrue to firms themselves as increased profit, be passed along to consumers as lower prices, or some combination of the two. Cost Benefit Analysis is the conventional means of assessing microeconomic benefits. In this section we review these benefits and the extent to which they may be captured in a CBA framework.

The first and most obvious of these benefits is the reduction in inbound and outbound transportation costs. Highway infrastructure improvements – which may include additions of new roads, expansion or improvement of existing roads, and expansion of effective capacity though implementation of ITS – reduce costs for two reasons. First, as the network expands the density of its links increases, making point to point trips less circuitous and thereby reducing distances. (As the network evolves over time and becomes highly connected, however, the marginal impact of link additions on distances decreases.) Second, addition of new roads and capacity expansions on existing roads may decrease congestion and thereby travel times. Since congestion implies that fewer trips can be achieved with the same capital and labor, and since fuel efficiency is lower in congested driving conditions, reductions in congestion translate into reductions in transportation costs. Naturally, induced travel of both freight and passenger vehicles may offset some of the congestion reductions.[10]

The basic analysis by which reductions in transportation costs are captured in a CBA framework is illustrated in Figure 18. Here the demand function DD represents the number of trips that would be made at different costs. At a high cost there are only a few trips made. These are trips whose economic benefits are great enough to justify the cost. As the cost declines, less beneficial trips can be economically justified, thus we have the downward sloping demand function. Before the infrastructure improvement, the intersection of the demand function and the horizontal supply function determines the number of trips made Q. The area CS defined by the difference between DD and SS summed up from zero to Q is the initial level of user benefit provided by the transportation system. This gap between what people are willing to pay and the market price is known as the *consumer surplus.*

Figure 18. User Benefits



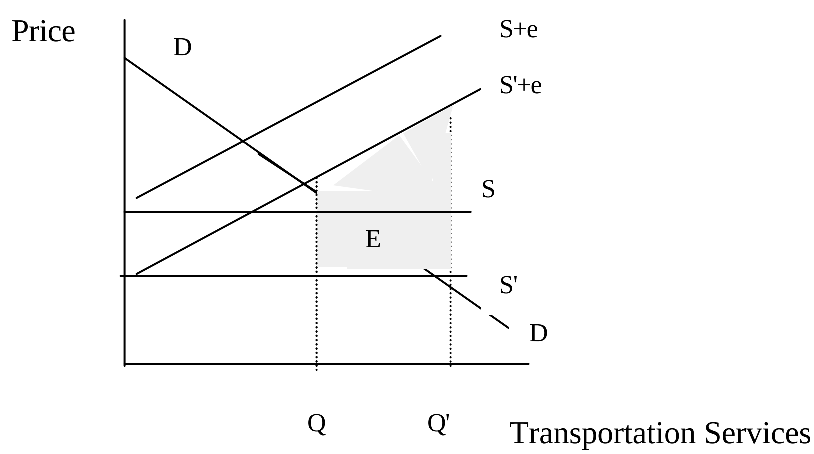
The effect of an infrastructure improvement is a downward shift in the supply function to S'. This leads to an increase in the number of trips made to Q' The increase in user benefit has two components: the area A which represents the reduction in cost enjoyed on all trips that were made prior to the infrastructure improvement and B which is the user benefit on the incremental trips (Q'-Q). This theoretical argument provides the rationale for a very straightforward calculation of benefits. The summed areas A + B are determined by calculating a per-trip reduction in cost – including tolls (where relevant) and factors such as labor, capital depreciation and fuel costs which can be estimated as functions of the change in travel time and distance – and multiplying by the number of trips. Since the number of trips are different before and after the infrastructure improvement, the user benefit is approximated by the "rule of half": ½(S-S')(T+T').[11] This general procedure is repeated for personal transportation users as well as

[10] Induced travel does not imply that benefits are negated. Even if all congestion reduction is lost due to increased demand, more transportation services are delivered while holding congestion delay constant.
[11] For a review of CBA applied to transportation projects, see Mackie and Nellthorp (2001).

freight transportation users and the sum of freight and personal benefits are weighed against the project cost.

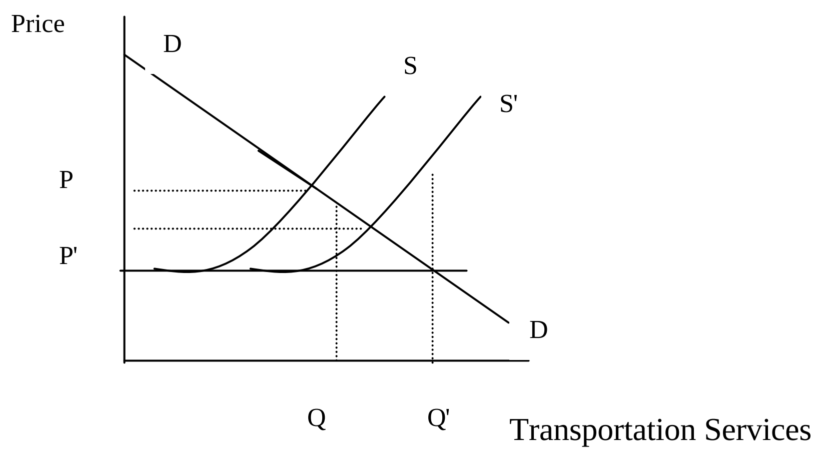
A number of refinements on this method are possible. In particular, provision of transportation services may have a number of negative or positive external effects. Air pollution, for example, is a negative external effect that increases with the number of trips made Q. Figure 19 shows a case where the private cost of travel is S is augmented by an external cost e. Because of the upward sloping nature of the S+e functions, the estimated benefit (in this a *social benefit*) will be lower than the user benefit in Figure 18 by the amount E which represents the extra external cost imposed by the increase in trips. Naturally, if the result of the project is to reduce pollution, a positive adjustment a positive adjustment is needed. In order to implement this adjustment, it must be possible to calculate the net change in external cost in monetary terms and subtract it from the calculated user benefit.

Figure 19. CBA with Externalities



Where congestion is an issue, the horizontal supply function may be replaced by one with an upward sloping segment to account for the fact that beyond some design capacity travel time is an increasing function of the number of users. The effect of the infrastructure improvement is then to increase the design capacity, thus shifting the upward sloping segment to the right as in Figure 20. The user benefit is defined as in this case as ½ (P-P')(Q+Q'). In this case, the scope of the analysis must be fairly broad because congestion on various elements of an infrastructure network tends to be interrelated. For example, if the analysis addresses the addition of a lane to a particular road, it is generally necessary to assess impacts on travel time not only on that road but on all roads that are sufficiently connected to experience positive or negative congestion impacts from the road widening. (Only in the unlikely case that the cost of travel is equal to its marginal cost can the analysis be limited to a single road, Mohring, 1993.) It is also possible that induced trips for personal transportation may negate much of the benefit that might otherwise have accrued to freight users.

Figure 20. Congestion Effects

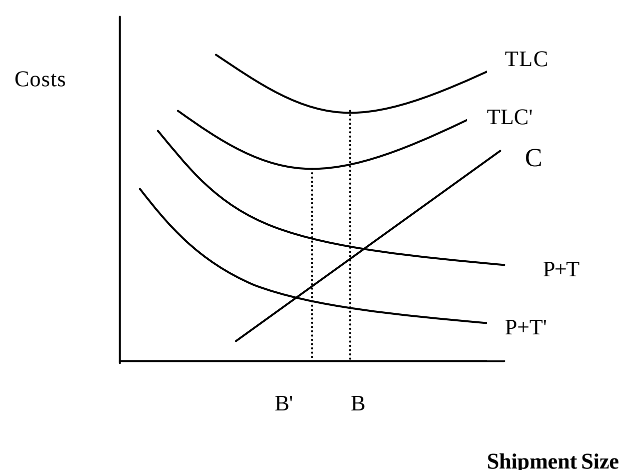


CBA can be extended to address these and a number of other market distortions that result in divergence between private benefits and social benefits. (Venables and Gasiorek, 1999, Part 1.) However recent research indicates that there are a number of benefits from transportation infrastructure whose analysis lies beyond the conventional supply and demand for transportation services. These include logistics costs effects, facilities consolidations, and other location effects. In what follows we describe these effects and challenges of capturing them in a CBA framework. We also address the issue of imperfect competition, which can result in underestimates of total welfare gains.

Total Logistics Costs

The savings arising from reduced freight cost also include non-transportation cost elements such as storage, interest and insurance costs. Suppose a manufacturing firm has to receive a fixed quantity *m* of some material input in each one-year production cycle. One of the decisions the firm must make is whether to receive the input in one large order or in a number of smaller shipments. Define *total logistics cost TLC* as the sum of procurement, carrying, and transportation costs associated with that input. Procurement costs P will be lowest if one large shipment is received because it will only have to be ordered and processed once. Transportation costs *T* will also be lower because it is generally cheaper on a per unit basis to ship large batches of goods. However carrying costs *C*, which include interest, insurance and storage costs, will be lower if the input is received in small shipments so that the amount held in inventory is minimized. (This is one of the principal benefits of Just In Time systems.)

Figure 21. Total Logistics Costs



Adapted from McCann, 1998

Thus the optimal input shipment size – and the associated optimal level of inventory – depends on the trade-off between procurement and transportation costs on the one hand and carrying costs on the other. A similar argument can be made with respect to the firm's outputs. By delivering goods more frequently and in smaller batches the firm saves on inventory carrying costs by purchasing more (or better) transportation services.

This is illustrated in Figure 21 where the sum of transportation and procurement costs *P+T* and carrying costs *C* are graphed against the average size of shipments *B*. The optimal *B* is found where $TLC = T+P+C$ is at a minimum. When a reduction in transportation cost from T to T' occurs – shown here as a downward shift in the $P+T$ schedule – the effect is a decrease in the optimal B. Thus, cheaper freight services leads to reduced storage, insurance and interest costs associated with carrying inventory. (For a theoretical treatment of the effect of transportation cost on optimal shipment size see McCann, 1988.) Of course, maintaining lower inventory increases the risk that the production process will be interrupted because a shipment of some critical input is late. Thus, if freight services are unreliable, greater than optimal inventory must be maintained as a buffer against risk. Improvements in freight services in recent years – brought about in part by application of information and communications technology – have improved the reliability of delivery within narrow time windows, thus allowing producers to reduce inventory and thereby reduce carrying costs. This illustrates that improvement in the quality, as well as reductions of the cost, of freight services yield benefits.

Empirical research on the impacts of improved transportation services on the logistics costs of firms is relatively thin, but a couple of studies provide some interesting insights. A 1995 study by Hickling, Lewis, Brod sought to measure the production benefits of a general reduction in freight travel times for firms in a variety of production sectors. The study employed an intensive interview technique on a small sample of firms, collecting detailed information on logistics practices and asking managers to speculate as to how a reductions in travel time, with corresponding reductions in travel time variances, would translate into reduction in logistics costs.

A compilation of some of their results is provided in Table 7. The first measure is an elasticity of logistics costs with respect to travel time. For example, the elasticity of .548 indicates that a 1% reduction in average freight travel time will lead to a .548% reduction in logistics costs for the surveyed firms in the medical and surgical instrument industry. The numbers in the next two columns indicate, for example, that a general 20% reduction in freight travel times will yield savings equivalent to slightly less that 1% of total sales in the same industry.

Table 7. Measures Of Travel Time Reduction Impacts On Costs (Hickling, Lewis, Brod, 1995)

Industry	Logistics cost / travel time elasticity	Logistics cost savings as % of sales	
		20% reduction in travel time	45% reduction in travel time
Retail Food	.055	.04%	N/A
Automotive Parts	.234	.20%	.45%
Telecommunication Equipment	.103	.02%	.05%
Medical / Surgical Instruments	.548	.88%	1.98%

These results should be regarded with caution, since they are based on a very small sample and they are derived from speculation rather than actual practice on the part of the firms. But the variation across industries – ranging from negligible benefits for food retail to very substantial benefits for medical and surgical instruments – are interesting. The report explains that only a portion of savings are derived from reduced transportation costs, with reductions in inventory carrying costs comprising another significant component of savings. This in part explains why medical and surgical instrument producers, which carry very high value inventories, can reap greater benefits from transportation improvements than the other industries. Thus, incorporating inventory carrying costs calls into question the conventional wisdom that transportation improvements are relatively unimportant for high value added industries.

A very recent study by Shirley and Winston (2001) attempts to draw an empirical link between the provision of road infrastructure and inventory levels. Theory suggests that lower transportation costs and higher reliability allow firms to maintain lower inventories. If costs and reliability are related to the capacity and condition of highway infrastructure, then inventories should be inversely related to highway infrastructure expenditures. Estimating an econometric specification derived from the theory of logistics costs on firm level data from the Census Bureau's Longitudinal Research Database, the authors find empirical support for this hypothesis. Their results indicate, however, that the marginal inventory reductions for each dollar of infrastructure expenditure are declining over time.

Of course, not all decisions with respect to shipment size reflect the shipping firm's preference to reduce inventories. A survey of British producers of food and drinks found that the most important force leading them to consume more transportation services was pressure from customers (retailers, distributors, etc.) to receive shipments in a more timely fashion so that they could reduce *their* inventories (McKinnon and Woodburn, 1996). Either way, more and better transportation services lead to greater coordination of production schedules and a system-wide reduction in inventory carrying costs.

Consolidation of Facilities

Firms may relocate facilities in response to an infrastructure improvement that alters the spatial distribution of freight accessibility and costs. For example, construction of a circumferential highway (beltway) may attract producers away from urban locations with rail and water access to more peripheral locations along the highway where they can have good access to truck freight services. Generally, such shifts should not be counted as conferring benefits because they increase income in one locale at the expense of another (Forkenbrock and Foster, 1990). There are situations, however, where the locational shift induced by improved freight service leads to increased production efficiencies. In these cases there is a general increase in productivity, which should be attributed to infrastructure improvement.

One such case is where reduced freight costs allow a multifacility firm to concentrate its production on a smaller number of locations in order to take advantage of scale economies. One of the most persistent themes in the theory of industrial location is the trade off between scale economies and transportation costs. Imagine a manufacturing firm that wants to sell its product in a large number of urban markets dispersed throughout a regional or national economy. If its production technology has scale economies, it will minimize production cost by producing in a single location to serve all markets. However it will minimize delivery costs by producing in smaller facilities located near important markets. It must therefore choose some optimal configuration of facilities and locations based on the counteracting effects of scale economies and transportation costs. If freight costs decline – whether from improved infrastructure, technical progress, or enhanced productivity in service provision – the firm will have an incentive to close some facilities and expand others, or build one or more large-scale facilities in new locations.[12] In this case there is a transfer of jobs and income from locales where closures occur to locales where expansions occur, but there is also an aggregate efficiency benefit due to scale economies.

Empirical studies show that consolidation of facilities can lead to very substantial savings in logistics costs. For example, a case study of a firm in the medical and surgical products industry with $1.8 Billion in sales in 1990 is provided in Hickling (1995). As Table 8 indicates, this firm was able to consolidate its 16 distribution centers into 6 larger regional centers, resulting in an overall 19% reduction in logistics cost.

Table 8. Logistics Cost Savings due to Facilities Consolidation, Medical and Surgical Products Case Study

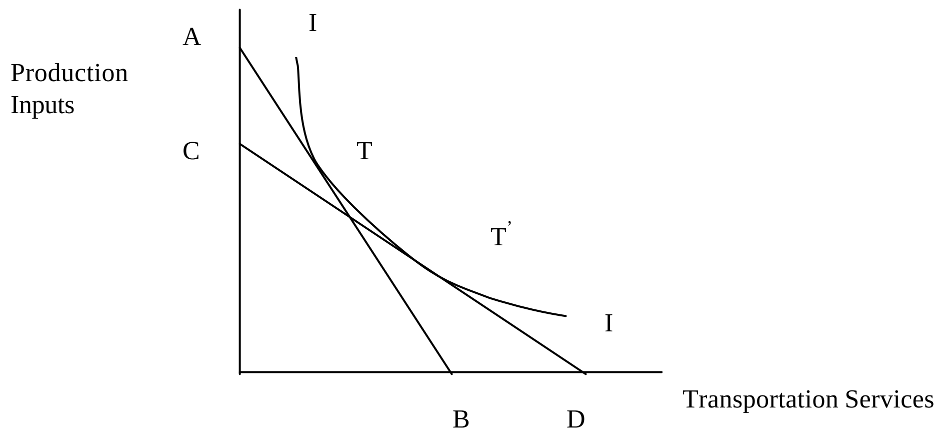
	Before Consolidation	**After Consolidation**	**Savings**
Distribution Facilities	16	6	
Costs ($Millions)			
Transportation	22	18	18.2%
Warehousing	9	7	22.2%
Inventory Carrying	11	9	18.2%
Total Logistics Costs	42	34	19.0%

Hickling (1995)

A useful way to look at the consolidation effect is as a substitution between production inputs and transportation services (HLB, 2001). Achieving scale economies means that on a per unit of output basis, the firm will be able to purchase fewer inputs of labor, capital, and other inputs. Since the scale economies are achieved by consolidating facilities, however, they come at the expense of more ton-miles of transportation services.

[12] Even in the absence of scale economies, there may be benefits from spatial concentration of production. For example, if there is uncertainty in the level of demand in individual markets, concentration of production may have the effect of pooling risk – aggregate demand is more predictable than local demand (Comacho and Persky, 1990.)

Figure 22. Substitution Framework



Adapted from HLB, 2001

This substitution is depicted in Figure 22 by the isoquant II, which defines different combinations of production inputs and ton miles that can be combined to produce a given amount of output. If transportation costs are reduced, the slope of the iso-outlay line AB is reduced to the line CD. The points of tangency define the optimal combination before (T) and after (T') a reduction in transportation costs.

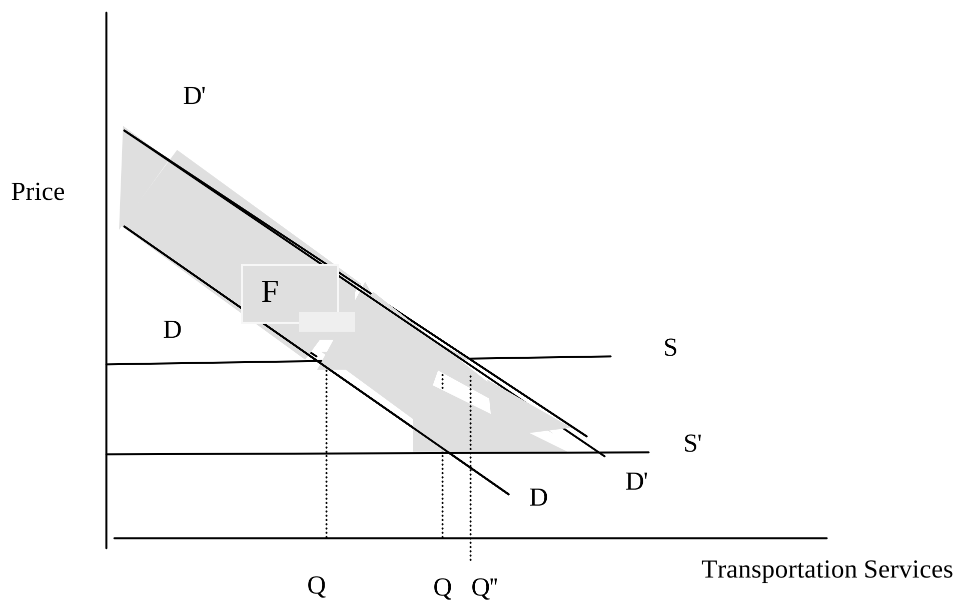
In fact, the same sort of logic can be applied to the effect of reduced transportation costs on TLC. As transportation gets cheaper, firms may choose to reduce inventories by increasing the number of inbound and outbound trips. Thus transportation services are substituted for inputs that include working capital, warehouse space and insurance.

Incorporating Logistical Savings and Consolidations in CBA

We have described two responses to reduced transportation costs – decrease in shipment size and consolidation of facilities – that allow firms to increase productivity but require increased inputs of transportation services. (In the former case increased services arise as a fixed number of ton miles are distributed over a larger number of smaller shipments, in the latter the number of ton miles actually increases – thus both effects contribute to an increase in the number of vehicle miles). This relationship is illustrated in Figure 23, where DD is the demand function before the cost reduction and S is the initial constant supply function. When S shifts down to S', there is a short term response represented as an increase from the initial demand level Q to Q'. In the longer run, the firm may adjust its shipment size and consolidate its facilities, which results in a shift to a new demand function D'D' and thus a further increase in transportation services to Q".

This has significant implications if the reduction in transportation costs is the outcome of an improvement in highway infrastructure. For one thing, it implies that the induced freight travel effect of expanded capacity may be greater than a static demand analysis would predict. Conventional cost-benefit analysis, which seeks to measure the increase in user benefit due to the short run shift from Q to Q', would therefore underestimate the benefits accruing to freight-using firms from highway improvements. Even if it were possible to anticipate the larger increase in demand from Q to Q", the rule of half approach would still significantly underestimate user benefits. The full estimate must capture the value proportional to F in Figure 23 and add it to the components A and B of conventional CBA. This requires an method to predict the shift in the demand function, rather than just the increase in the quantity demanded.

Figure 23. Shift in Demand for Services



Measurement of this demand enhancement effect presents a tremendous challenge for the implementation of CBA. This problem has been addressed in a number of reports by HLB Decision Economics Inc. (Lewis, 1991; HLB, 1995, 2001). For example, some magnitude of inventory reduction must be defined for a particular level of transport cost reduction arising from an infrastructure improvement. Even more challenging will be estimation of structural shifts such as the consolidation of facilities after infrastructure is improved. Thus, the HLB research provides not only a challenge to conventional CBA methods but also defines the need for extensive empirical research into the interrelationship between the cost and quality of freight transportation services and a whole range of business decisions including inventory policy and the number and location of facilities.

As an illustration of the methods employed, Lewis, 1991 proposes a simple approach to estimating the shift in the demand function. Define the demand function before the improvement in transportation infrastructure as

$$P_0 = a - bQ_0$$

where P is an operating cost per vehicle mile and Q is total demand measured in vehicle miles. Given an estimate of the elasticity of demand

$$N = \frac{\partial Q}{\partial P} \cdot \frac{P}{Q}$$

then by substitution

$$a = P_0 + \left(\frac{P_0}{N} \right)$$

$$b = P_0 / NQ_0$$

The effect of the infrastructure improvement is measured in terms of a variable ΔQ defined as the percent change in transportation services required by the transportation provider to give the same level of service after the improvement. For example, if 5000 vehicle miles were required before the improvement and 4000 are required after the improvement, $\Delta Q = -.2$.[13] If the result of the improvement is a rightward shift in the demand function to

$$P_1 = a' - b'Q_1$$

the new parameters can be estimated as

[13] This is an appropriate measure only where the infrastructure improvement has the effect of reducing distances between origins and destinations. If the effect were strictly congestion reduction, an alternative measure of demand, such as vehicle service hours, would be appropriate.

$$a' = \frac{P_0 + \left(P_0 / N \right)}{1 + \Delta Q}$$

$$b' = \frac{P_0 / N Q_0}{\left(1 + \Delta Q\right)^2}$$

Using this approach, the additional benefit area F in Figure 22 can be estimated based on observed cost and service demand values and estimates of the price elasticity and the effect of the infrastructure improvement on service provision[14] This basic framework suffers from a number of strong assumptions – such as that the level of output remains fixed and that logistics costs savings are known *a priori* – which are addressed in further elaborations of the model (HLB, 2001).

While this approach is an important step, a direct causal link between reduction in transportation costs and the demand shifts should be inferred with a great deal of caution. Given the theoretical arguments and empirical evidence described above, it is tempting to attribute the major logistical transformations described in Part 1 of this report to reductions in transportation costs due to investment in infrastructure. While the macroeconomic studies indicate a link between investment and productivity, there is not much empirical evidence to specifically link changes in logistical practices to transportation costs other than the preliminary work by Shirley and Winston. For example, McKinnon and Woodward's (1996) survey of British firms found only very limited evidence that declining transportation costs were a major driver behind facilities consolidation and declines in average inventories. Consolidation of facilities is part of a long term trend and the move to JIT inventories may arise as much from new control technologies and the heightened awareness of inventory management as from declining transportation costs. Nevertheless, the availability and scope of transportation infrastructure is a key enabling factor behind these trends.

We turn now to two classes of economic benefits that are generally not included even in the most recent work on assessing the benefits of transportation infrastructure, but which may

[14] A complete derivation is provided in appendix D of Lewis, 1991.

represent important mechanisms by which cheaper and more reliable services are translated into improved productivity for individual forms: location effects and value added effects.

Location Effects

There are a number of ways that improvements in transportation infrastructure may contribute to productivity growth through mechanisms that involve the location choice of the firm. For example, infrastructure investments promote productivity when firms are able to take advantage of *agglomeration economies* – essentially a class of external scale economies – by locating in large clusters. Agglomeration economies arise for various reasons, including scale economies in the provision of public infrastructure to concentrated centers of demand (*urbanization economies*), reductions in the cost of transferring intermediate goods among diverse firms linked together in the production chain (*juxtaposition economies*) and spillovers of knowledge and labor skills that occur when firms in the same industry cluster together (*localization economies*.) The notion of agglomeration economies has long been used by geographers as a conceptual tool to explain the emergence of cities, and has gained empirical support from recent econometric studies that attribute significant productivity benefits to economic agglomeration (Ciccone and Hall, 1996.)

Naturally, the benefits of agglomeration are at some point offset by the costs of congestion. In this sense major investment in infrastructure for freight movements within, as opposed to between, production centers expand the potential for agglomeration to the extent that they offset growth in congestion (Weisbrod and Treyz, 1998.) These may be some of the most important benefits that arise from major urban infrastructure improvements such as Boston's Central Artery / Tunnel project (the Big Dig).

Expansion of transportation infrastructure – especially the Interstate Highway system – has expanded the range of possible locations for producers of goods and services. "Greenfield" production sites located at the periphery of metropolitan areas or in rural areas have been sought by many producers to economize on land costs. Thus, just as firms are able to reduce inventory carrying costs by increasing their use of transportation services, firms choosing peripheral locations along highways reduce land costs while consuming more transportation services.

It may seem contradictory to argue that transportation infrastructure promotes productivity on the one hand by allowing firms to cluster together in cities and on the other by allowing firms to spread out into the periphery. But this must be viewed in light of the fact that different firms benefit from different locations. The product life-cycle model (Vernon, 1966) argues that products and the industries that produce them pass through stages in their histories over which their main business requirements evolve. At an early stage of development, acquiring appropriate labor skills, developing product innovations, and market penetration are the key concerns, while at a later stage, implementing process innovations, and economizing on the cost of inputs such as labor and land are the main competitive strategies. The spatial analogue to this argument is that early stage firms do best in urban core locations while late stage firms do best in the periphery. The main point is that a transportation system that provides sufficient capacity and connectivity benefits firms by expanding the range of locations from which they can choose.

As in the case of facilities consolidation, this runs counter to the conventional wisdom whereby location shifts should not be counted among the benefits of highway infrastructure. That argument is correct so far as the shifts simply reflect transfers of identical production activities from one location to another. But the spatial shifts described here are productivity enhancing and in therefore they produce real benefits.

Transportation and Value Added

So far we have discussed the microeconomic benefits of transportation system improvements in terms of cost reduction. Improved infrastructure allows firms to economize on transportation and other logistical costs; production costs due to scale and agglomeration economies; and land costs. Cost reductions translate into productivity enhancements[15] and therefore they can explain much of the impact of transportation infrastructure on productivity growth that has been observed in the macroeconomic literature.

[15] HLB 2001 demonstrates the link between cost reduction and productivity growth, section 3.5.3.

Another way that transportation infrastructure can enhance productivity is by *adding value* to the output of either the freight using firms or the transportation service provider. Take fresh fish as an example. The best way to add value to a fish is do nothing to it – except get it to the consumer quickly. Fresh fish is worth more than salted, frozen, or otherwise processed fish. Improvements in transportation service that make it possible to get a fish from Maine to St. Louis in less than 24 hours after it is caught are a major source of productivity enhancement. The justification for interpreting this as a case of adding value, rather than just reducing costs, is that the fish can only be produced in one or a few places and may have a scarcity value elsewhere. Thus, transportation makes it possible for the fish producing firm not only to expand markets but to reach markets where its output has a higher value than in its local market. A similar argument can apply to a variety of products that are produced in a limited number of locations because of highly specific skills or resources.

As another example, consider a machine that is used in a production process. The firm that uses the machine will pay more for it if they can be certain that it will never be out of service for more than a few hours. The firm that produces the machine will able to make such a guarantee – and therefore charge a higher price – if they know that it will be possible to ship necessary parts to the machines location if there is ever a breakdown. Thus the availability of high-quality transportation service increases the value of that machine.

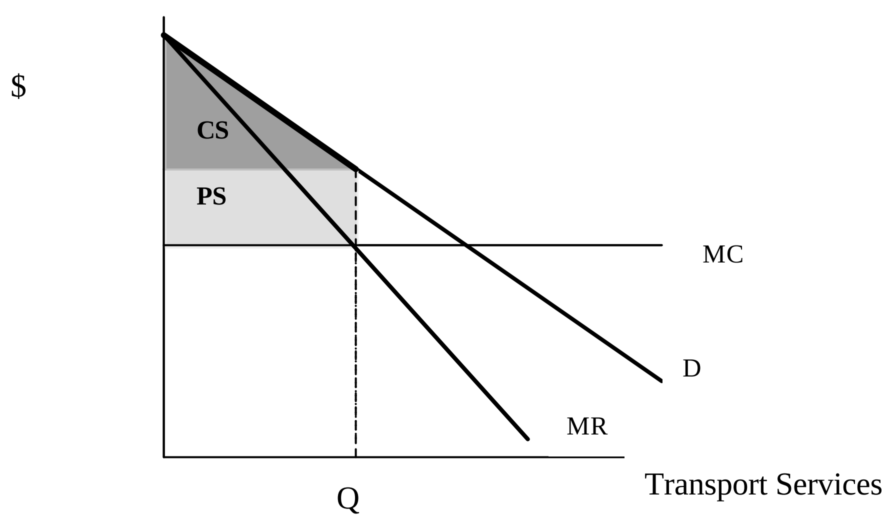
Improved infrastructure can also add value to the services of transportation providers. For example, higher capacity and implementation of ITS infrastructure can help trucking firms deliver goods not only cheaper but within narrower time windows. They can also provide real time tracking information and a high level of flexibility regarding the volume, location and frequency of shipments. All of this makes the service more valuable to the client. (In assessing these benefits, care must be taken to avoid double counting – for example, the increase in the value of a trucking firm's services may be equivalent to the logistics cost savings of its client.)

Market Structure and CBA

There is an additional problem that emerges with CBA in the presence of imperfect markets. Figure 24(a) illustrates the case of a provider of transportation services who is a monopolist. The monopolist is able to earn extra profits by providing the service up to the level where its marginal cost (MC) is equal to the marginal revenue (MR), rather than where MC (supply) equals demand (D) as would be expected in a perfectly competitive market. The result is that the total level of services provided is lower than would be the case under perfect competition and the price is higher. Therefore the benefit to consumers (consumer surplus: CS) is also lower. However there is also a benefit the provider in the form of extra profits. This is known as producer surplus (PS) as shown in the figure. The total welfare benefit from the provision of the service is the sum on CS and PS, which is still lower than CS would be under perfect competition.

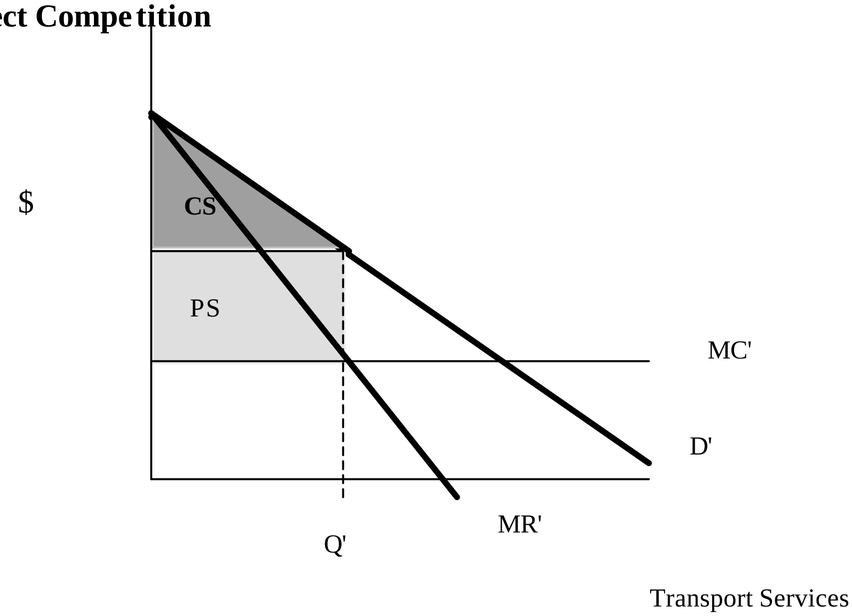
Suppose there is an investment in infrastructure, such as a new highway or rail terminal, which reduces MC to MC'. The result is an increase in both CS and PS. Since CBA seeks to measure all welfare gains, no matter to whom they accrue, both increases should be counted in total benefit. Application of the rule of half as in conventional CBA, however, will only capture the change in CS – and in fact may underestimate the change in CS.[16]. Thus CBA is inclined to underestimate benefits of transportation projects if markets for transportation services are imperfect.

Figure 24(a). Imperfect Competition



[16] The reason CBA will underestimate CS relates to the way that a reduction in transportation cost translates into a reduction in price. Suppose the producer sets its price by a markup m over marginal cost: p = mc(1+m). Now suppose the mc is reduced to mc'. The new price is mc'(1+m). p-p' = (mc'-mc)(1+m), thus the reduction in price is greater than the reduction in the marginal cost of production.

Figure 24(b). Imperfect Competition



This sort of market distortion is not limited to the case where there is imperfect competition in the market for transportation services. The same applies if there is a monopolist in a freight consuming goods or service market. Benefits of investments in transportation infrastructure may be assessed from the perspective of derived demand for transportation services. In this case, the supply function in Figure 24 is of a producer whose marginal cost is reduced because of cheaper transportation. Part of the benefit goes to an increase in CS and part to an increase in PS. Again, the rule of half approach will underestimate the combined benefit.

Venables and Gasiorek (1999) have addressed this problem through a series of simulations. Envisioning a situation where an infrastructure improvement has reduced the transportation costs of a monopolist who sells goods into a neighboring region, they calculate first the conventional CBA benefit and then total welfare gain as defined in Figure 24. Their simulations indicate that CBA would have underestimated total benefits by anywhere from 10 to 40%, depending upon the size of the reduction in transport costs, the elasticity of the demand function, the slope of the marginal cost curve, etc.

The results of the simulations tell us two things. First, there is at least a potential for significant underestimation of benefits under imperfect competition. Second, in order to capture the full benefit we would need knowledge of a variety of parameters (demand elasticities and marginal cost functions in non-transportation markets, for example) that are normally far beyond the scope of project assessment studies. More information and a more comprehensive analytical framework are needed.

The foregoing discussion is set in a context where the firm's level of production is assumed to be independent of freight transportation costs. An enduring theme in economic geography is that reduced transportation rates make it possible for firms to expand the geographical scope of their markets, thus increasing output and the demand for transportation services. To some extent, market expansion may be viewed as a transfer effect, whereby production in one place is displaced by competition from somewhere else, and should therefore not be included as a benefit of infrastructure investments. Competition over space, however, may lead to regional specialization which yields improvements in aggregate productivity. We turn to this issue in the section on general equilibrium effects below.

V. GENERAL EQUILIBRIUM EFFECTS

In the previous section, we focused on efficiency gains accruing to individual firms as the result of improvements in transportation services, how those gains translate to welfare gains, and how welfare gains can be captured by cost-benefit analysis (CBA). By focusing on the effects on individual firms we have taken a partial equilibrium view. We now shift to the question of how the effects on individual firms redound throughout the entire economy – the general equilibrium view.

Since we are concerned with the issue of assessing economic benefits, a related question is how and whether general equilibrium effects can be captured in the general CBA framework or whether new approaches to evaluation are needed. A couple of notes are in order at the outset. First, it is not fair to say that conventional CBA ignores general equilibrium effects. These effects can be captured in CBA under fairly strong assumptions about scale economies and competition. (However, it is one thing to say that such effects are captured in theory and quite another to say that they are captured in practice.) Second, while it may be possible to identify types of general equilibrium impacts that are not captured in CBA, there is an important question as to whether the magnitude of these impacts justifies a shift to more complex and less tested analytical frameworks. It has been argued that as one moves to impacts that are less directly connected to the infrastructure improvement in question, the "additionality" to the assessment of benefits becomes too small to worry about (Mackie and Nellthorp, 2001.) A counter argument is that effects may be amplified, rather than dampened, as they spread throughout the economy. In the case of such "cumulative causation," failure to take a general equilibrium view may lead to gross underestimation of both positive and negative economic impacts (Venable and Gasiorek, 1999.)

In the remainder of this section we review the general equilibrium concept of gains from trade as it arises first from the traditional notion of comparative advantage and in the framework of imperfect competition. We end with some speculation about needed empirical study and the development of new assessment methodologies.

Gains from Trade

One of the most important economic trends to have occurred over the 20th century is a shift from system of local, regional or national autarky to one of specialization and trade, culminating in the process of economic globalization. Specialization and trade is economically feasible only to the extent that efficiency benefits exceed the cost of interregional shipment and the speed and reliability of shipment make it possible to coordinate production schedules across long distances. Thus, freight cost reductions and quality improvements lead to efficiency gains from trade. These efficiency gains arise for two reasons:

- Each region has a different endowment of natural resources, labor (availability and skills), capital goods, and institutions, that make it highly efficient in some categories of production and less efficient in others. Specialization and trade allows regional resources to be concentrated in those forms of production for which they are best suited. This is basically David Ricardo's theory of *comparative advantage*, whose theoretical extensions are explored in the Heckscher – Ohlin – Samuelson framework (Findlay, 1995.)

- Even if regions have similar endowments of resources, there is still a benefit to interregional trade *via* scale economies that are realized as producers target broader markets. Furthermore, production and trade across a national (as opposed to regional) market makes it possible to provide consumers with a broader variety of goods. This is the explanation of gains from trade provided in the *new economic geography* (Fujita, Krugman, and Venables, 1999; Venables and Gusiorek, 1999.)

We address these two bases for specialization and trade in turn and expose the importance of freight transportation in the realization of gains from trade.[17]

Comparative Advantage

The theory of comparative advantage has its roots in the 19th century when the British economist David Ricardo argued against the "corn laws" which restricted imports of agricultural commodities into Great Britain. Corn law supporters argued that there could be no possible economic justification for importing grain since British agriculture was at least as efficient as agriculture in countries from which cheap imports originated. Ricardo countered that even if Britain had a small efficiency edge on other countries in agricultural production, it had a very large efficiency advantage in manufacturing production. Since there were fixed amounts of labor and capital resources available in Britain, British agricultural production had a high opportunity cost because it diverted resources from more lucrative manufacturing production. Thus even though Britain had an absolute advantage over its potential trading partners in both agriculture and manufacturing, it had a comparative advantage only in manufacturing. British agriculture was at a comparative disadvantage because of its high opportunity cost. Therefore, if foreign grain were imported and resources were transferred from agriculture to manufacturing, both Britain and its trading partners would be better off.

Ricardo's ideas were essentially refined into the Hecksher-Ohlin theorem, which says that if two countries have different relative endowments of capital and labor, they will both benefit if the labor rich country exchanges labor intensive goods for capital intensive goods from the

[17] An additional reason that is often cited for economic benefits from trade is the increase in competitive pressure which induces firms to increase efficiency and adopt technical innovations (SACTRA, 1999).

capital rich country. The basic message is the same: all trading partners are better off if they specialize in those things they have the best capabilities to produce and trade with other countries than if they seek to achieve self sufficiency by producing a large variety of goods. An important caveat to this, however, is that gains from trade can only be realized to the extent that they exceed the transportation costs needed to achieve them. Therefore one of the most important benefits of improved transportation infrastructure arises from its role in enabling gains from trade.

Note that this is a *general equilibrium* benefit. It does not arise due to improved productivity in individual production units, but rather from a redistribution of production that leads to higher aggregate productivity. Imagine two regions A and B. Suppose that region A has higher productivity in agriculture than region B and region B has higher productivity in manufacturing than region A. Begin from an initial condition in which both A and B produce sufficient agricultural and manufacturing output to satisfy their own demands. Now if they switch to a situation where A produces all the agricultural goods for both A and B and B produces all the manufactured goods for both A and B, the aggregate productivity of the combined economy of A and B will have increased productivity *even if the productivity of individual production units remains constant.* To the extent that improved transportation infrastructure makes the transition from autarky to trade possible, it yields economic benefits.

The theory of comparative advantage has been the major economic argument in favor of liberalizing international trade. It has provided intellectual ammunition to the proponents of expanded international trade through the GATT/WTO mechanism as well as proponents of regional trading blocks such as the European Union, NAFTA, MERCOSUR and others. One might assume therefore that economic benefits in the form of gains from trade arise primarily from investments in infrastructure built mainly for international trade: international shipping and air facilities, international bridges, facilities for rapid border clearance etc. In fact, recent experience shows that such infrastructure, along with complementary institutional change, is critical to the success of regional economic integration initiatives (Lakshmanan *et al*, 2001.) The role of infrastructure in trade creation, however, extends more broadly to the national infrastructure system. For example, a recent study by the Bureau of Transportation shows that

10.4% of U.S. freight movements over domestic road and rail infrastructure are ultimately to support international trade.

More importantly, the notion that transportation infrastructure yields economic benefits that come in the form of gains from trade applies just as well to domestic trade as to international trade – especially in an economy as large and diverse as ours. The United States economy is a *multiregional* economy comprising a set of distinct but highly integrated economic regions, each with a system of urban centers and resource hinterlands. Over time, these regions have become more highly integrated. For example interregional linkages among the southeast, the west, and the traditional economic core regions have strengthened. The theory of comparative advantage applies just as well here as it does in, say, Europe where diverse regional economies exist within national frontiers. A condition of autarky, where each region is relatively self sufficient, producing most of the goods and services consumed within its borders, is less efficient than a condition of specialization and trade, whereby all regions produce for national and international markets.

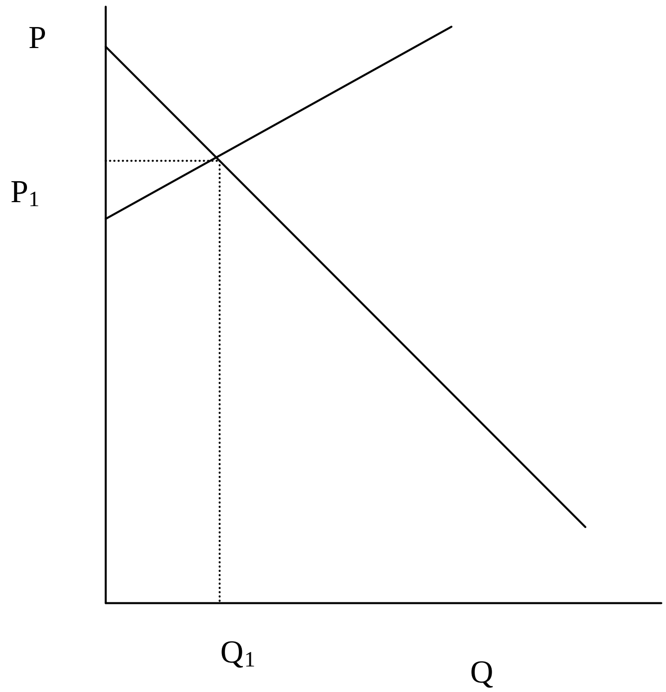
The railroads, the inland and coastal waterways, and the National Highway System provide the critical links that make regional specialization and interregional trade possible. Evidence of the increasing specialization over the second half of the twentieth century is found in the fact that ton-miles of freight grew more rapidly than tons of freight, especially in the period for 1960 to 1980 (see Table 6.) Under a system of autarky and regional specialization, the same number of tons might be shipped, but the average distance of shipment would be much greater in the latter. Thus growth in the average distance over which a ton of freight is shipped is consistent with increasing regional specialization and interregional trade. Evidence of the role of transportation costs in regional specialization is found in a study based on the 1993 Commodity Flow Survey, which showed that interregional movements of commodities is inversely related to transportation cost (Anderson *et al.,* 1998.)

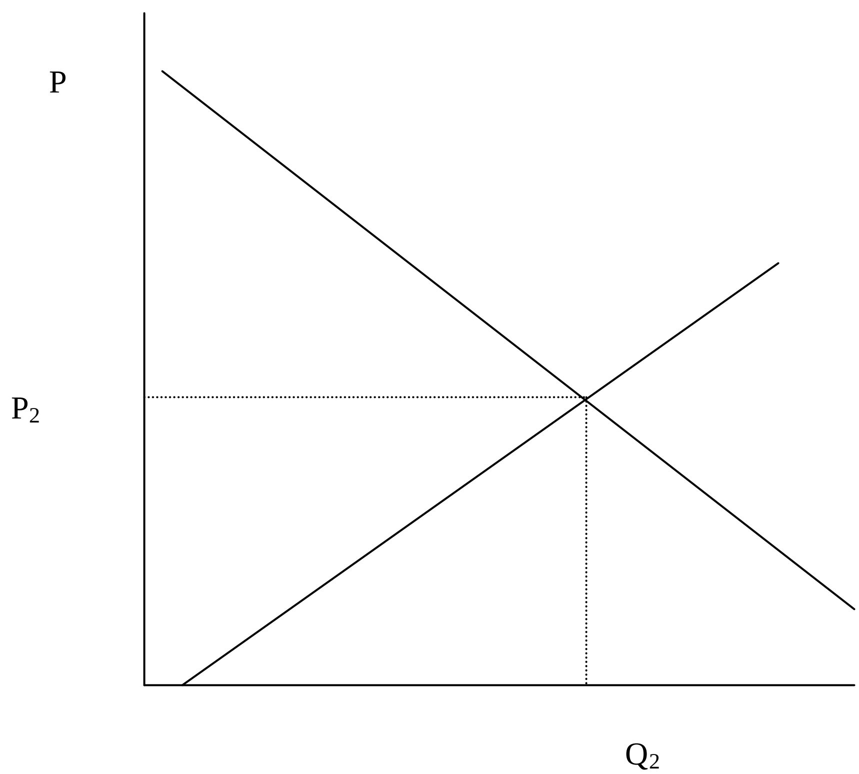
What implication does this have for assessing the benefits of transportation investments? Any project that makes interregional trade easier and cheaper results in improved efficiency (and thereby reduced costs) for those goods that are shipped interregionally. At first blush it might seem that CBA, with an apparently partial equilibrium orientation, will miss this benefit. However, under of conditions of perfect competition the increase in trade will occur up to the point where the cost reduction from specialization and trade is just offset by the transportation cost. Thus, the benefits derived from increased travel (component B in Figure 18) captures the gains from trade.

This is illustrated in Figure 25, which represents the production of the same good in two regions with identical demand functions but different supply functions. The lower supply function in region B means that it has a superior endowment of resources for production of the good in question. Thus, the price in region B is lower than in region A. If trade is allowed to occur, and if transportation were costless, the good will be shipped from B to A up to that point where prices are equalized and excess supply in B is just offset by excess demand in A. If transportation is costly, a somewhat smaller flow would occur and a price difference equal to the transportation costs would remain. If the transportation cost declines, the amount of trade will increase. Thus, increases in the demand for transportation services are good indicators of gains from trade.

This argument is fine from a theoretical perspective, but it suffers somewhat in the implementation. CBA is normally applied *ex ante* – that is the calculation is made before the infrastructure investment is made. (Otherwise it would be of little use as a decision tool.) This means that the analyst must *predict* the increase in the demand for transportation services in order to make the rule of half calculation. Accurate predictions of the full range of economic integrations that may occur after the addition of a major infrastructure improvement is a challenging requirement that is seldom met in applied CBA. Not only would changes in aggregate trade flows need to be predicted, but since this is a relatively long-term phenomenon the timing of the changes must be estimated in order to conduct appropriate discounting. Some attempts have been made to incorporate competitive business expansion impacts into CBA (Weisbrod and Treyz, 1998) but they are rather *ad hoc* and generally only applied to changes in output for a single region or cluster of regions.

Figure 25. Two Region Case





An initial step toward assessing the magnitude of gains from trade attributable to infrastructure investments would be to conduct a series of *ex post* cost benefit analyses where the observed trade impacts are measured some years or decades after an improvement is made. The Commodity Flow Survey could be used to compare changes in trade flows between 1977 and 1993 or 1997. It would be necessary to use multivariate statistical analysis to estimate the component of trade growth that can be attributed to the change, and since it would be difficult to isolate the impact of individual projects the analysis might have to apply to a cluster of investments, such as a set of major regional additions to the interstate highway network.

This *ex post* approach would serve both as a means of assessing the magnitude of the benefits from highway construction that arise due to growth in interregional trade and as a means of comparing benefits calculated after the fact to those found in ex ante CBA studies for the same projects.

The New Economic Geography

While the theory of comparative advantage is one of the most powerful analytical frameworks ever developed by economists, there are aspects of trade that it does explain very well. Comparative advantage essentially says that gains from trade arise out of diversity across nations or regions in terms of natural resources, capital, human capabilities and institutions. But many of the most important trade relations occur between places that are in fact very similar. For example, the largest bilateral trade relationship in the world is between Canada and the U.S., two countries that are quite similar in terms of most critical economic endowments. Furthermore, the largest share of the goods flowing in both directions -- from the U.S. to Canada and from Canada to the U.S. -- are from the same industry: automobiles and automotive components. Neither the strength of relationship between similarly endowed nations nor the preponderance of intraindustry over interindustry trade is consistent with the predictions of the theory of comparative advantage.

A new analytical framework has emerged -- called the "new economic geography" -- which addresses just such situations and provides a host of new insights into the spatial configuration of economic activities. Where the theory of comparative advantage is driven by variations in endowments, the new economic geography is driven by *scale economies*.

At the risk of over simplification, consider again the example of region A and region B, who between them must satisfy a certain level of demand for both agricultural and manufacturing output. Assume this time that there is no inherent difference in productivity for either industry between the two regions. In the absence of scale economy, aggregate productivity will be the same under either autarky or specialization. Now assume that scale economies can be realized at the industry level, such that the productivity of agriculture is an increasing function of the amount of output produced in a particular region. The same applies for manufacturing. If this is the case, aggregate productivity will be higher if one region specializes in agriculture and the other specialized in manufacturing – although it doesn't matter which region specializes in which industry.

Naturally the theory is more complicated than this. It develops a new framework for trade by exploiting the analytical breakthrough of Dixit and Stiglitz (1977) who incorporated scale economies into a general equilibrium model assuming a monopolistically competitive market structure. In this model, product variety is the critical component of competition so that all firms produce distinct but substitutable goods. Consumers' utility functions are defined in such a way that they prefer to consume a variety of goods rather than to concentrate their production on a small number of goods. Thus goods are imperfect substitutes. This means each firm has some degree of monopoly power and can therefore set its price above its marginal cost. The cost structure for each firm includes a fixed component and a constant marginal cost, which results in a downward sloping average cost function indicative of scale economies.

By opening up trade, producers in each region are able to reach broader markets for their unique goods, allowing them to move down their average cost curves and earn greater profits. Naturally this market expansion effect is limited by interregional transportation costs, and any reduction in transportation costs yields increased trade benefits. In the long run, however, more firms -- each providing a unique product variety -- will enter any market where profits are being earned. The presence of more firms shifts the demand curves of all preexisting firms downward until excess profits are exhausted. Thus it is entry of new firms that brings about an equilibrium.

While this view lacks some of the formal elegance of the perfect competition general equilibrium, it has a number of advantages. For one thing, its emphasis on product differentiation as opposed to direct price competition among producers of perfectly substitutable goods is in keeping with the long term trend away from commodity production towards highly differentiated and specialized goods. Growth in consumer utility in recent decades has been due not only to the quantity of goods consumed, but also to the ever increasing variety of goods -- especially consumer electronics and other categories of goods where constant product innovations define the competitive environment. Furthermore, the fastest economic growth has occurred in consumer and producer services, which are also highly differentiated. Thus, while neither perfect competition nor monopolistic competition accurately describes the entire economy, the real world is getting less like the former and more like the latter.

Another advantage is that by adopting imperfect competition and scale economies, this view is able to tackle a whole range of explicitly spatial phenomena, such as agglomeration and persistent regional differences in wages, which mainstream economic theory has largely ignored. In fact, many of the results emerging from the new economic geography are concepts that geographers have espoused for decades but have failed to present in a formal general equilibrium framework.

Finally, the new view provides theoretical underpinnings to a variety of observations found in the empirical literature on international and interregional trade which do not make much sense from the comparative advantage perspective. For example, the strategy by which some urban regions attain competitive advantage on a global scale by specializing in the production of one or a few high value added commodities, which has been observed by Porter (1990), is consistent with results on agglomeration. Returning to the example of Canada-US trade, a recent study of regionally detailed trade flows found that trade between regions contiguous across the border (such as Ontario and Michigan) tended to be intraindustry rather than interindustry trade. This is consistent with the notion of trade in highly specialized varieties in order to benefit from scale economies, as described in the new economic geography view. Trade between more widely separated regions (with higher transportation costs) tended to be interindustry and therefore more consistent with the comparative advantage view (Brown and Anderson, 1999).

If one accepts the proposition that monopolistic competition is a more realistic theoretical basis for the functioning of many markets, then the following question arises: Is CBA an accurate method for evaluating transportation infrastructure investments when the industries that consume transportation services are monopolistically, rather than perfectly, competitive? This question was recently addressed in a study commissioned for the Standing Advising Committee on Trunk Roads Assessment in the United Kingdom (Venables and Gasiorek, 1999).

The answer to the question is no, for two reasons. The first reason we have already discussed: under imperfectly competitive markets, certain types of benefits are hidden from the rule of half approach to CBA. The second reason is perhaps less evident: in a world of imperfect competition and scale economies, certain general equilibrium effects are too small to be ignored.

To illustrate this, the authors developed a computable general equilibrium model (CGE) based on hypothetical data and parameters incorporating the principals of monopolistic competition as described above. It includes two or more hypothetical regions, each with endowments of two primary inputs: immobile capital and labor, which is mobile in the long run. Equilibrium wage rates are determined at the regional level. Each region is assumed to include some competitive and some monopolistically competitive industries and input-output parameters describe the linkages among industries in terms of intermediate goods flows. Since firms will enter any monopolistically competitive industry where excess profits are being earned, expansion will occur in industries and regions whose profits expand due to a change in transportation costs.

As in the case of the partial equilibrium simulations described earlier, the CGE results show that total welfare gains from a reduction in transportation costs are greater than would be revealed by CBA. The magnitude of this difference increases with the demand elasticity for transportation services, the degree of market power for transport-using firms, the strength of inter-industry linkages and the strength of agglomeration economies.[18] The underestimate identified by the simulations are in the 30% range with some as high as 60%. It is important to bear in mind that these are purely hypothetical estimates from simulations incorporating what the authors believe to be reasonable parameter values. Other observers suggest that the underestimates would be much smaller.[19]

Because of the multiregional structure of the simulation, it was possible to identify circumstances where reductions in transportation costs would have differential regional impacts. In the general equilibrium context, these deviations arise for some interesting reasons:

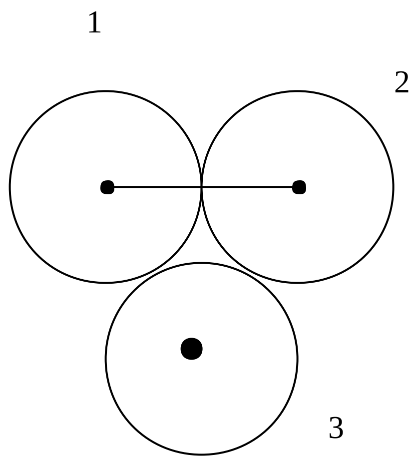
- *Symmetric regions*: In a simulation where one competitive and one monopolistically competitive industry are both located in two regions with identical resource endowment, CBA was shown to underestimate total welfare gains by roughly the same amount as in the partial equilibrium simulations described earlier. The welfare gain was slightly larger in the general equilibrium case because extra gains by the monopolistically competitive firms were passed on to the perfectly competitive firms via input-output linkages.

- *Agglomeration:* In an economy with two monopolistically competitive industries and two symmetric regions, reduction in transport costs were shown to promote agglomeration whereby each of the two industries became concentrated in only one region.[20] Total benefits are again higher than would be found by conventional CBA and shared equally by the two regions only if the two monopolistically competitive industries are of the same size. If one industry is larger, then the region where that industry agglomerates enjoys greater benefits.

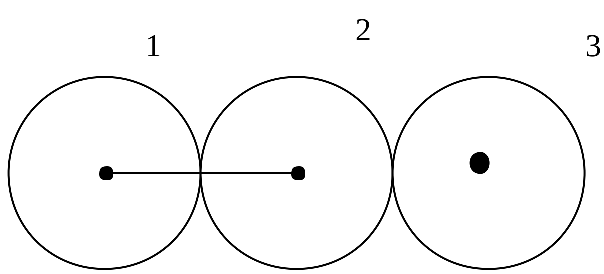
[18] These general interpretation of Venables and Gasiorek results are found in SACTRA, 1999.
[19] SACTRA (1999) quotes Newbery as arguing the effects would be roughly one tenth as high as the simulation results suggest.
[20] This result depends on the assumption that within-industry input-output linkages are stronger than between-industry linkages.

Figure 26. Configuration of Three Regions

a)



b)



- *Center and periphery:* A simulation was devised to illustrate the case where one region has higher wages before the reduction in transportation cost occurs. The results indicate that if transportation costs are so high as to result in virtual autarky in the initial case, marginal reductions in transportation cost will cause wages to diverge. At that point, firms are attracted to the more lucrative market, but eventually wage increases in the center region cause shifts in the other direction. Thus, past some critical level of transport costs reductions will result in wage convergence. For this reason, an inverted U-shaped relationship between transportation cost and regional income equality is indicated. So the effect of a transport investment on interregional equity depends on the initial context and may be very difficult to predict.

- *Three region case*: With three equidistant regions as indicated in Figure 26a, there is a reduction in the cost of transportation between regions 1 and 2. The results indicate an increasing share of monopolistically competitive production in 1 and 2 at the expense of the share of three. Also wages increase in 1 and 2 and decline in 3. Thus while overall welfare increases in the three regions combined (at a rate higher than CBA would have captured), the reduction in transportation cost between 1 and 2 causes both a relative and absolute decline in the welfare of region 3.

- *Linear economy*: In figure 26b, the three regions are arranged in a linear fashion so that region 2 is more central and the distance between 1 and 3 is greater than any other interregional distance. In this case region two will always have a higher level of monopolistically competitive production because of its superior accessibility to markets. If the transport cost between 1 and 2 is reduced the effect on region 2 will be small, but region one will benefit in terms of both wages and output at the expense of region 3.

- *Networks and superadditivity:* A further simulation in which the transport costs from 1 to 2 and from 2 to 3 were reduced simultaneously produced an especially important result. The welfare gain from the simultaneous reduction yielded welfare gains that were more than the sum of the welfare gains from reducing the two transportation links independently.

Implications For Evaluation Methodologies

The results of the Venables and Gasiorek (1999) simulations have a variety of implications. For one thing, they reinforce the message that in an imperfectly competitive world, conventional CBA analysis tends to underestimate benefits of transportation investments. They also show that specific transport cost reductions can have spatially variable impacts and that reductions that are beneficial in the aggregate can be detrimental to certain places – a result that economic historians will hardly find surprising! More generally, they illustrate the point we made earlier that the benefits accruing from an infrastructure investment depend on the *context* within which the investment is set. For example, the effect of a transport investment on relative regional incomes depends on their initial values and the initial degree of economic integration. Effects of improving a single link in a multiregional network depend on the spatial configuration of the regions. And the benefits accruing from one infrastructure project may depend on other projects that are being carried out simultaneously.

But what is the implication for the evaluation of individual projects? The importance of context as highlighted in these results suggests that is unlikely that a simple one-size-fits-all framework can identify all the potential benefits and costs of non-marginal infrastructure projects. Is it therefore necessary to abandon CBA and adopt more complex and flexible CGE models as the standard framework?

To answer this, we must be mindful of the fact that both the theoretical and especially the empirical development of these models is in its infancy. CGE models as they exist today have a number of down sides:

- They are complex and highly demanding of data, much of which is not easily available;
- They are generally calibrated by means of a zero degrees of freedom method rather than by means of multivariate statistics, so there is no way to assess how well they fit the data;

- Because they involve so many non linear relationships, signs of effects often change on critical values (the inverted-U shaped relationship above) and therefore results are highly volatile and sensitive to small changes in parameter values.

For these reasons, CGE models are probably best used in the kind of illustrative mode in which Venables and Gasiorek used them. There strength is in pointing out the kinds of effects that are likely to be important, rather than in predicting specific outcomes of specific events.

The most prudent course is therefore to continue using CBA -- including the most current methods to adjust for externalities, demand shifts etc. -- as an initial quantitative estimate of the efficiency of any project, but to follow up with more qualitative analyses to determine whether the CBA results are likely to underestimate or overestimate true net benefits. In these more qualitative analyses, the types of issues pointed out in the new economic geography should be given special attention.

Technology Shifts

There have been times in history when expanded freight services have made radical changes in the structure of production possible. For example, the development first of canals and later of railroads made it possible for huge areas of the central lowlands of the US to be developed for specialized agriculture serving a national market. To a degree this fits into the standard comparative advantage argument described above, except that rather than a shift from autarky to specialization it 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.

Another example is the industrial revolution in textile production that occurred on a global scale in the 19th century. In this case, improved freight made it possible to develop a production system that required the movement of materials inputs of cotton from production region (US South, Egypt, India) to production centers in England and New England. Thus, unlike the example above where freight made it possible for a specialized production region to reach broader markets, in this case freight made it possible for widely separated but complementary regions to be integrated into a specialized production system. Again, this story has elements of comparative advantage, but it involves a fundamental shift in technology made possible by improved freight. The key issue is this, while both the Heckher-Ohlin theorem and the new economic geography assume production technologies which are exogenous and fixed, historical examples suggest that new trade opportunities have at times given rise to technological shifts, resulting in an endogenous change in the production technology.

The two historical examples illustrate the role that freight improvements play in fundamental shifts in technology. It is likely that freight improvements provide opportunities for more marginal shifts on an ongoing basis. For example, the interstate system not only allowed producers to seek out locations with lower land costs, but also allowed them to implement more space-intensive technologies to enhance efficiency. Reductions in the cost of global trade due to innovations such as containerization set the stage for a general transformation to global production systems whereby inputs and components are sourced internationally.

It would be very difficult to predict such technological impacts for any specific infrastructure project. It is very possible, however, that this effect plays a significant role in explaining the link between transportation infrastructure investment and productivity growth as observed in the macroeconomic studies described earlier.

While it almost impossible to predict technical shifts, a lot could be learned from *ex post* empirical studies that attempt to identify them. Case studies of industries that have undergone rapid transformations in production technologies or logistical organization could be seek to determine whether technological progress was either enabled or spurred on by new or improved freight transportation options. Such studies need not be limited to goods producing industries, but could also include large scale retail operations which are currently in a phase of rapid technological transformation.

Lessons Learned

Freight transportation continues to play a critical role in the U.S. economy. In recent years this role has been reinforced by qualitative changes in the nature and scope of freight services offered. Not only have the costs of freight services declined, but firms in the freight service sector now offer a broader range of enhanced services allowing freight-using firms more flexibility to restructure their logistical and production activities, and thereby achieve non-transportation cost reductions. This is in large part the outcome of novel applications of IT in the freight service sector and continued public investment in transportation infrastructure. Given its central role in the development of the highway network, FHWA has a critical interest in a better understanding of the role of transport investments in enabling freight service firms to achieve these logistical improvements and related efficiencies, which not only enhance these firms' productivity, but also that of transport using firms in the larger economy.

Prior to the seminal work of Koichi Mera in the 1970's, assessments of the economic impacts of investments in transportation infrastructure were limited to appraisals of individual projects. Such appraisals provided relatively little insight into the broader role that transportation infrastructure plays in aggregate economic growth and productivity. Despite variations in data, methods, and the magnitude of the effects they uncovered, the sequence of macroeconomic analyses conducted in the U.S. and abroad over the past twenty five years has identified a persistent, positive influence of transportation investments on aggregate economic performance.

While it is important to know that highway and other transportation investment programs are conferring economic benefits, macroeconomic studies tell us relatively little about the actual mechanisms through which these benefits arise. Policy formulation must address not only the question of whether to invest in infrastructure, but also the question of which among an array of potential projects will yield the greatest economic return. In order to answer this second question, it is necessary to open up the "black box" of macroeconomic studies and attribute economic benefits to specific mechanisms that may vary across projects due to location, network relationships, and other contextual factors.

In this paper we have looked at the underlying mechanisms from two perspectives: the microeconomic (partial equilibrium) perspective and the general equilibrium perspective. From the microeconomic perspective, individual firms benefit from cheaper, better, and faster freight services – benefits that can be captured in a conventional CBA framework. But cheaper and better transportation services may lead to savings in non-transportation inputs as well. For example, presented with lower transportation costs producers may choose to reduce inventories or consolidate facilities, even if it means consuming more transportation services. Important work is underway to incorporate these types of effects into CBA calculations.[i] There are still other possible benefits that, to date, have not been incorporated into the CBA model. For one thing, improved infrastructure increases the locational flexibility of firms, which in turn can lead to a variety of efficiency improvements. Also, there are a number of ways in which improved infrastructure allows firms to *add value* – this includes both providers of transportation services and freight-consuming producers of other goods and services.

The general equilibrium perspective highlights a different kind of benefits from improved transportation. These benefits arise from economy-wide adjustments and redistributions. The key notion here is *gains from trade*, whereby aggregate efficiency is enhanced when cheaper or better transportation promotes interregional and international specialization and trade The theory of comparative advantage tells us that producers and consumers are better off when each region specializes in those goods and services it can produce most effectively. High quality, affordable transportation makes this possible. The "new economic geography" shows that in the presence of scale economies and imperfect markets, reduced transportation costs can lead to a host of economic transformations that yield aggregate economic benefits. One of the most important lessons from this emerging line of theory is that the impacts of transportation improvements are *context dependent*. So, for example, the outcome of a new corridor connecting two regions depends on such things as the state of the pre-existing transportation network; the relative size, wage level, and state of economic development of the two regions; and the degree of type and competition of markets functioning in both regions. Clearly, if this is the case, economic assessments must incorporate a broader range of interrelationships and data than is typical in current practice.

Beyond conventional gains from trade, better transportation can also lead to major shifts in technology that bring about improvements in aggregate efficiency. Specialized commercial agriculture, the industrial revolution, and the globalization of production all represent technological transformations that would not have been possible without non-marginal improvements in transportation systems. Smaller, more incremental technological shifts most probably arise with each successive boost in transportation performance.

With the exception of the direct cost and time savings that are captured in conventional CBA, our ability to measure any of the main categories of benefits described here is relatively poor. Many of the impacts we describe have only been derived from theory or demonstrated by means of hypothetical simulation. Some experts, while conceding that a broad range of indirect benefits may exist, argue that the values of these benefits are probably small and therefore conventional CBA is sufficient.[ii] Others counter that once you abandon assumptions of perfect competition and constant returns to scale, indirect effects can be cumulative and large.[iii]

Given our degree of uncertainty about many of these benefits, research along two avenues is warranted. The first is the expansion of our analytical toolbox to include a broader range of economic mechanisms. This includes further elaboration of CBA to capture the effects of logistical transformation, productivity-enhancing location shifts, and value-added effects. It also includes the development of more comprehensive frameworks such as CGE (Computable General Equilibrium) models. While the application of these models to transportation analysis is still a nascent field, a lot can be learned from operational models that are currently applied to international trade, tax policy and a number of other fields.

The second avenue of research comprises *ex post* assessment of major infrastructure projects and programs. By means of a more historical perspective we can ask a number of critical questions such as: To what extent did improved infrastructure lead to increased specialization and expansion of markets? How do freight service firms take advantage of improved infrastructure to offer cheaper and better services? What logistical, technological and locational innovations followed in the years after the project's completion? How did such economic adjustments translate into higher productivities and incomes? Naturally, such assessments must be more than just case studies; they must apply appropriate analytical methods to identify those economic changes that can be attributed to the infrastructure improvement from those that would have occurred without it.

Such a research program is ambitious, but its payoffs may be great. Its goal will be to create both a better understanding of the role of transportation in the economy and better analytical capacity to support more informed decisions about transportation infrastructure decisions in the future, and an increased capacity to serve the Department of Transportation Strategic missions of improving the national economy and national competitiveness.

REFERENCES

Aaron, H. J., 1990. "Discussion of 'Why is Infrastructure Important,'" in A. H. Munnell, ed., *Is there a Shortfall in Public Capital Investment?* Federal Reserve Bank of Boston, Boston, pp. 51-63.

Amendola, G., G. Dosi & E. Papagni, 1993. The Dynamics of International Competitiveness, *Weltwirtschaftliches Archiv*, 133(1): 103-132.

American Association of State Highway and Transportation Officials, 1998. *Transportation and the Economy: National and State Perspectives*. Washington, D.C.

Andersson, Å., C. Anderstig, and B. Hårsman, 1990. "Knowledge and Communications Infrastructure and Regional Economic Change," *Regional Science and Urban Economics*. 20, 359-376.

Anderson, William P., Pavlos Kanaroglou, Mark Brown, and Patrick DeLuca, 1998. "Transportation and the US Space Economy," prepared by the McMaster Institute for Energy Studies for the U.S. Department of Transportation.

Aghion, P., and P. Howitt, 1998. *Endogenous Growth Theory.* Cambridge Mass: The M.I.T. Press.

Apogee Research Inc., 1991. *Case Studies of the Link Between Transportation and Economic Productivity*, Mimeo. Prepared for the Federal Highway Administration.

Aschauer D. A., 1989. "Is Public Expenditure Productive?", *Journal of Monetary Economics*, vol. 23., pp. 177-200.

Aschauer D. A., 1990. "Highway Capacity and Economic Growth," *Economic Perspectives*. September/October, 14-24.

Bell, M.E. and T. J. Mcguire, 1997. *Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance,* Transportation Research Board, Washington, The National Academy Press.

Brown, W. Mark and William P. Anderson, 1999. “The Influence of Industrial and Spatial Structure on Canada - U.S. Regional Trade”, *Growth and Change*, 30(1):23-47.

BTS (Bureau of Transportation Statistics), 1995. *Transportation Statistics Annual Report: The Economic Performance of Transportation,* Washington. D.C.

Business Week, 2000. Logistics and Fulfillment: e commerce meets the Material World, *Business Week*, Special Section, June 26.

Carlino, G.A. and E. Mills, 1987. "The Determinants of Country Growth", *Journal of Regional Science*, Vol. 27., pp. 39-54.

Carlino, G.A. and R. Voth, 1992. "Accounting for Differences in Aggregate State Productivity", *Regional Science and Urban Economics* 22: 597-617.

Chatterjee, L., 2000a. *Transportation Logistics in Value and Supply Chains*, Research Report prepared for the Bureau of Transportation Statistics, U.S. Department of Transportation.

Chatterjee, L. 2000b. *Transportation, Globalization and Competitiveness: A Review and Synthesis of the Literature,* Research Report Prepared for the Bureau of Transportation Statistics, U.S. Department of Transportation.

Ciccone, A. and R.E. Hall, 1996. "Productivity and Density of Economic Activity", *American Economic Review,* 86: 54-70.

CRA (Charles River Associates), 1968. *The Role of Transportation in Regional Economic Development*. Report prepared for the Office of Regional Economic Development. U.S. Dept. of Commerce.

Clark, J. G., 1966. *The Grain Trade in the Old Northwest*, Urbana, University of Illinois, 9-13.

Comacho, A. and J. Persky, 1990. “Variability and Location,” *Environmental and Planning A*: 22:69-77.

Conrad, K. and H. Seitz, 1994. "The Economic Benefits of Public Infrastructure," *Applied Economics*, 26. 303-311.

Costa, J. S., R.W. Ellison and R. C. Martin, 1987. "Public Capital, Regional Output, and Development: Some Empirical Evidence," *Journal of Regional Science*, vol. 27., pp. 419-3.

Dicken, P., 1998. *Global Shift*, Guilford, NY.

Diewert, W.E., 1974. "Applications of Duality Theory" in *Frontiers of Quantitative Economics* (eds) M.D. Intriligator and D. A. Kentric Amsterdam, North Holland.

Dixit, A. and J.E. Stiglitz, 1977. "Monopolistic Competition and Optimum Product Diversity" *American Economic Review*, 67(3): 297-308.

Eisner, R., 1991. "Infrastructure and Regional Economic Performance: Comment", *New England Economic Review*, September/October, 47-58.

Elhance, A. P. and T.R. Lakshmanan, 1988. "Infrastructure-Production System Dynamics in National and Regional Systems; An Econometric Study of the Indian Economy," *Regional Science and Urban Economics*. 18, 513-531.

Eno (Eno Transportation Foundation), 1997. *Intermodal Freight Transport in Europe and the United States*, D.C., Eno Transportation Foundation.

Jack Faucett Associates and A. T. Kearney, Inc., 1993. "Industry Studies of the Relationship between Highway Transportation and Productivity", Draft final report on contract, No. DTFH61-91-C-00058, FHWA. August, pp. 31-42.

Findlay, Ronald, 1995. *Factor Proportions, Trade and Growth*, Cambridge MA: MIT Press.

Fisholow, A., 1965. *American Railroads and the Transformation of the Ante-Bellum Economy* Cambridge, MA: Harvard University Press, pp. 306-11.

Forkenbrock, David J. and Norman S.J. Foster, 1990. "Economic Benefits of a Corridor Highway Investment," *Transportation Research A*, 24:303-312.

Forslund, U.M., and B. Johansson, 1995. "Assessing Road Investments: Accessibility Changes, Cost-Benefit and Production Effects", *The Annals of Regional Science* 29: 155-174.

Fujita, M., Paul Krugman, and A.J. Venables, 1999. *The Spatial Economy*, The M.I.T. Press. Cambridge, Mass.

Garcia-Milà, T. and T. J. McGuire, 1992. "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics*. 22, 229-241.

Garcia-Milà, Y and T. J. McGuire, and R. H. Porter, 1993. "The Effect of Public Capital in State-Level Production Functions Reconsidered," Mimeo, Institute of Government and Public Affairs, University of Illinois at Chicago.

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

Grossman, G. M. & E. Helpman, 1991. *Innovation and Growth in the Global Economy*, MIT Press, Cambridge, MA.

E. F. Haines, J. Mak, and G. M. Walton, 1975. *Western River Transportation; The Era of Early Internal Development, 1810-1860*. Baltimore: Johns Hopkins University Press, pp. 111-118.

Harris, Chauncy D., 1954. “The Market as a factor in the localization of Production”, *Annals of the Association of American Geographers*, 44: 315-48.

Heyman, Hans, Jr., 1965. "The Objectives of Transportation" in *Transport Investment and Economic Development*. (ed) Gary Fromm, Brookings Institutions, Washington, DC. pp. 18-33.

Hickling Corporation, 1994. *Measuring the Relationship between Freight Transportation Services and Industry Productivity*, National Cooperative Research Program. Transportation Research Board.

Hickling, Lewis, Brod Inc., 1995. *Measuring the Relationship Between Freight Transportation and Industry Productivity: FINAL REPORT*, NCHRP 2-17(4), Washington: Transportation Research Board, National Research Council.

HLB Decision Economics Inc., 2001. *Cost-Benefit Analysis of Highway Improvements in Relation to Freight Transportation: Micro-Economic Framework*, Draft Report, Federal Highway Administration, July 12, 2001.

HLB Decision Economics Inc., 1995. *Measuring the Relationship Between Freight Transportation and Economic Productivity*, NCHRP report 2-17(4).

Hirschman, A., 1958. *The Strategy of Economic Development*. Yale University Press, New Haven.

Hulten, C.R. and R. M. Schwab, 1991. "Public Capital Formation and the Growth of Regional Manufacturing Industries," *National Tax Journal*. 43: 121-34.

Hulten C. R. and R. M. Schwab, 1984. "Regional Productivity Growth in U.S. Manufacturing: 1951-78", *American Economic Review*, 74: 152-162.

ICF, HLB, and Louis Berger, 2001. *Freight Benefit / Cost Study,* Report presented to U.S. Federal Highway Administration, February.

.Johansson, B., 1993. "Infrastructure, Accessibility, and Economic Growth", *International Journal of Transport Economics* XX, 2:131-156.

----------------, 1998. *Infrastructure, Market Potential and Endogenous Growth,* Jönköping International Business School Working Paper, Jönköping, Sweden October 20.

Johnsson, B. and C. Karlsson, 1994. "Transportation Infrastructure for the Mälar Region," *Regional Studies*, 28, 169-185.

Jones, D. W., S.-P. Miaow, R. Lee and S. Rickard, 1993. *Performance-Based Measures of the Transportation-Productivity Linkage: Multivariate Assessment of Relationships Between Measures of Highway Performance and Economic Productivity. Final Report on Phase II* Report prepared for the Federal Highway Administration (Oak Ridge National Laboratory).

Keeler, T. E. and J. S. Ying, 1988. "Measuring the Benefits of a Large Public Investment; The Case of the U.S. Federal Aid Highway System," *Journal of Public Economics,* Vol. 36, pp. 69-85.

Kelejian, H. and D. P. Robinson, 1994. "Infrastructure Productivity: A Razor's Edge," University of Maryland, College Park. Draft.

Kasarda, J. D., 1996. Transportation Infrastructure for Competitive Success, *Transportation Quarterly*, 50(1): 35-50.

Kendrick, J. W., 1977. *Understanding Productivity,* Baltimore: The Johns Hopkins University Press. Chapter 3.

Krugman, P. R., 1991. *Geography and Trade*, IT Press, Cambridge, MA.

Krugman, P.R. 1999. "The Role of Geography in Development", *International Regional Science Review*, 22, 2: 142-161.

Lakshmanan, T.R., W.P. Anderson, and M. Jourabchi, 1982. "Regional Dimensions of Factor and Fuel Substitution in U.S. Manufacturing" in *Structural Economic analysis and Planning in Time and Space* (eds.) A. Anderson, T. Puu, W. Isard, and U. Schweizer Amsterdam, North Holland.

Lakshmanan, T.R., 1989. "Infrastructure and Economic Transformation" in Å. Anderson, D. F. Batten, B. Johansson, and P. Nijkamp, eds. *Advances in Spatial Theory and Dynamics*, North-Holland, Amsterdam. pp. 241-261.

Lakshmanan, T. R., and W. P. Anderson, 2000. NAFTA: A Case Study of Trade and Transportation Integration, *Journal of Applied Regional Science*, 5: 1-15.

Lakshmanan, T.R., U. Subramanian, W.P. Anderson and F. Leautier, 2001. *Integration of Transport and Trade Integration* Book Series in 'Directions in Development', World Bank. Washington. D. C.

Leroy, S. F. and J. Sonstelie, 1983. "Paradise Lost and Regained: Transportation Innovation", *Journal of Urban Economics*, Vol. 3,. pp. 67-89.

Lewis, D., 1991. *Methodologies for Evaluating the Effects of Transport Policies on the Economy*. National Cooperative Highway Research Program Report 342., Transport Research Board, Washington, D.C.

Lucas, R. E., 1988. "On the mechanics of economic development", *Journal of Monetary Economics*, 22(1):3-42.

Lynde, C. and J. Richmond, 1992. "The Role of Public Capital in Production", Review of Economics and Statistics, 74, pp. 37-44.

Lynde C. and J. Richmond, 1993. "Public Capital and Long-Run Costs in UK Manufacturing", *Economic Journal*. 103, pp. 880-93.

Mackie, Peter and John Nellthorp, 2001. "Cost Benefit Analysis in Transport" in K.J. Button and D.A. Hensher (eds.) *Handbook of Transportation Systems and Traffic Control,* Oxford: Pergamon.

McCann, Philip, 1998. *The Economics of Industrial Location: A Logistics-Costs Approach*, Heidelberg: Springer.

McKinnon, Alan C. and Allan Woodburn, 1996. "Logistical Restructuring and Road Freight Traffic Growth: An Empirical Assessment," *Transportation*, 23:141-161.

McGowan, K., 1997. The Rise in Global Sourcing and Logistics Implications for Shippers, *Transportation and Distribution*, 38(10): 83-87

McGuire, T., 1992. "Highways and Macroeconomic Productivity: Phase Two," Mimeo. Report for the Federal Highway Administration. Institute of Government and Public Affairs, University of Illinois a Chicago.

Mera, K., 1973. "Regional Production Functions and Social Overhead Capital: An Analysis of the Japanese Case," *Regional and Urban Economics*, Vol. 3., pp. 157-186.

Mera, K., 1975. *Income Distribution and Regional Development*, University of Tokyo Press, Tokyo, Chapter IV.

Mills, E. S. and G. Carlino, 1989. "Dynamics of Country Growth" in Å. Anderson, D. F. Batten, B. Johansson, and P. Nijkamp, eds., *Advances in Spatial Theory and Dynamics*. Amsterdam, North Holland, pp. 195-205.

Miller, R. B., 1979. *City and Hinterland; A Case Study of Urban Growth and Regional Development*. Greenwood, CT. pp. 86-87.

Mohring, Herbert, 1993. "Maximizing, Measuring, and *Not* Double Counting Transportation-Improvement Benefits: A Primer on Closed and Open Economy Cost-Benefit Analysis", *Transportation Research B*, 27B:413-424.

Moomaw, R. L. and M. Williams, 1991. "Total Factor Productivity Growth in Manufacturing: Further Evidence from the States," *Journal of Regional Science*. Vol. 31: 17-24.

Munnell, A. H., 1990. "Why has Productivity Growth Declined: Productivity and Public Investment," *New England Economic Review*. January/February: 2-33.

Myrdal, Gunnar 1957. *Economic Theory and Underdeveloped Regions* , London, Duckworth.

Nadiri, M. Ishaq, 1993. *Infrastructure Capital and Productivity Analysis: Cost and* Profit *Function Approaches.* Paper prepared for Apogee Research, Inc and for the U.S. Army Corps of Engineers.

Nadiri, Ishaq, M. and T. P. Mamuneas, 1996. *Constitution of Highway Capital to Industry and National Productivity Groups*. Report prepared for FHWA. Office of Policy Development.

R. Nurske, 1953. *Problems of Capital Formulation in Underdeveloped Countries*, Basil Blackwell, Oxford.

Office of Economic Affairs, 1987. "Effects of Structural Changes in the U.S. Economy on the Use of Public Works Service," U.S. Department of Commerce.

OECD, 2001. Assessing the Benefits of Transport. ECMT Publication, Paris.

Porter, Michael, 1990. *The Competitive Advantage of Nations*, New York: Free Press.

Pred, A., 1966. *The Spatial Dynamics Of U.S. Urba-Industrial Growth* Cambridge: M. I. T. Press.

Prud'homme, R., 1993. *Assessing the Role of Infrastructure in France by Means of Regionally Estimated Production Functions,* paper presented at the Workshop "Infrastructure, Economic Growth and Regional Development: The Case of highly Industrialized Developed Countries," Jönköping, Sweden, June.

Ratner, J. B., 1983. "Government Capital and the Production Function for U.S. Private Output," *Economics Letters*, vol. 13, pp. 213-217.

Ray, G., T.R. Lakshmanan and W.P. Anderson, 2001. "Increasing Returns to Scale in Affluent Knowledge-Rich Societies", *Growth and Change,* 32: 493-512.

Romer, P.M., 1986. "Increasing Returns and Long-run Growth", *Journal of Political Economy,* 94 (5) 1002-1037..

__________, 1990. "Endogenous Technological Change", *Journal of Political Economy,* 98 (5) part 2: 71-102

Rosenstein-Rodan, Paul N., 1943. "Problems of industrialization in Eastern and Southeastern Europe", *Economic Journal*, vol., 53, pp. 202-11.

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

Sasaki, K., S. Kunihisa, O.M. Sugiyama, 1995. "Evaluation of road capacity and its spatial allocation", *Annals of Regional Science* 29: 143-154.

Seitz, H., 1994. A Dual Economic Analysis of the Benefits of the Public Road Network," *Annals of Regional Science,* 27: 223-239.

Seitz, H., 1994. "Public Capital and the Demand for Private Inputs," *Journal of Public Economics,* 54. 287-307.

Shah, Anwar, 1992. "Dynamics of Public Infrastructure, Industrial Productivity and Profitability," *Review of Economics and Statistics*. 74:1, pp. 28-36.

Shepard, R. W., 1970. *Theory of Cost and Production Functions*, Princeton, Princeton University Press.

Shirley, Chad and Clifford Winston, 2001. *An Econometric Model of the Effect of Highway Infrastructure Investment on Inventory Behavior*, Project Status Report to FHWA, May 2001.

Solow, R. M., 1956. "A Contribution to the Theory of Economic Growth", *Quarterly Journal of Economics, 70 (1)*: 65-94.

Swan, T.W., 1956. "Economic Growth and Capital Accumulation", *Economic Record*, *32: 334-361*.

Transportation Research Board, 1991. Primer on *Transportation, Productivity and Economic Development*. NCHRP Report 342, Washington, D.C.

Transportation Research Board, 1995. Measuring the Relationship Between Freight Transportation and Industry Productivity. NCHRP Report 2-17(4). Final Report, Washington, D.C.

Transportation Research Board, 1999. Economic Trends and Multimodal Transportation Requirements, NCHRP Report 41, D.C., National Academic Press.

Venables, Anthony J. and Michael Gasiorek, 1999. *Welfare Implications of Transport Improvements in the Presence of Market Failure*, Report to the Standing Committee on Trunk Road Assessment, London: Department of Environment, Transport and the Regions.

Vernon, R., 1966. "International Investment and International Trade in the Product Cycle," *Quarterly Journal of Economics*, 80:190-207.

Vickerman, R. W., 1991. "Transport Infrastructure in the European Community: New Developments, Regional Implications and Evaluation," in R.W. Vickerman, ed. *Infrastructure and Regional Development*, London, p. 31.

Weisbrod, Glen and Frederick Treyz, 1998. "Productivity and Accessibility: Bridging Project-Specific and Macroeconomic Analyses of Transportation Investment," *Journal of Transportation Statistics*, 3:65-79.

Wigran, R., 1984. "Productivity and Infrastructure: an Empirical Study of Swedish Manufacturing Industries and their Dependence on Regional Production Milieu" in *Economic Faces of the Building Sector* (eds). F. Snickars, B. Johansson, and T. R. Lakshmanan, Swedish Building Institute, Stockholm.

World Bank, 2000. *Entering the 21st Century, World Bank Development Report, 1999-2000,* World Bank, Washington, D.C.

Youngson, A. J., 1967. *Overhead Capital*; *A Study in Development Economics*. Edinburgh University Press, Edinburgh.

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[i] Lewis 1991; HLB 1995, 2001.
[ii] See for example Mackie and Nellthorp, 2001
[iii] Venables and Gasiorek, 1999.