Wider Economic Impacts from Investing in Transportation Infrastructure:

Theory, Measurement, and Practical Significance

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14. ABSTRACT
This report describes how investment in transportation infrastructure can generate economic costs or benefits that may not be captured in the conventional measures used for economic evaluation of proposed investments, and thus need to be measured separately and incorporated into such evaluations. It explains why and how such "wider economic impacts" can originate, identifies where they are likely to be significant, and outlines methods and tools that are available to estimate their economic value. Finally, it compares the advantages of incorporating wider economic impacts into benefit-cost analysis to relying on alternative evaluation methods, and outlines research that FHWA could pursue to improve economic analysts' understanding of wider economic impacts.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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List of Abbreviations

Abbreviation	Term
WEI	Wider economic impacts
WEB	Wider economic benefits
BCA	Benefit-cost analysis
GDP	Gross Domestic Product

Executive Summary

Investing in transportation infrastructure can generate economic consequences that will not be included in the conventional measures of costs and benefits used for economic evaluation of proposed investments. These "wider economic impacts" can arise in several situations: where producing and distributing products – or producing and using transportation service itself – generates unintentional by-products or spillovers ("externalities"); where building new infrastructure expands access to job opportunities, enables more competition, or spurs new development; and possibly where firms reorganize supply chains to take advantage of lower-cost or more reliable transportation service. The most common instances include larger employment agglomerations, improved access and competition in remote geographic regions, and more intensive or diverse land use at sites where new infrastructure improves access. Where investing in transportation infrastructure has these effects, some benefits or costs from improving or expanding infrastructure may not be accurately reflected in the usual measures of consumer and producer surplus to its users, so conventional economic evaluation may unintentionally overlook them.

Specialized methods and tools are then required to value these omitted costs and benefits, and the results must be added to the conventional cost and benefit measures that economic evaluation relies upon to ensure comprehensive and accurate assessment of proposed investments. Although these tools are generally well-developed and widely available, the data required to apply them can be challenging or costly to assemble and their outputs must often be interpreted cautiously, Thus it is important to anticipate where wider economic impacts are likely to arise and whether they are likely to be empirically significant before investing the resources necessary to quantify them.

Some analysts argue that the widespread potential for significant wider economic benefits and the challenges in estimating their magnitude make incorporating them into benefit-cost analysis too difficult, and instead call for using alternative measures such the contribution of infrastructure investment to GDP to evaluate proposed infrastructure projects. However, most of those alternative methods consider less comprehensive or potentially distorted measures of economic costs and benefits, attempt to incorporate non-economic considerations that are difficult to express and value in comparable terms, or are likely to produce very similar assessments while requiring considerable additional effort.

FHWA has supported extensive past research on analyzing wider economic impacts and incorporating their value into economic evaluation of investments in transportation infrastructure. The agency may want to consider supporting additional future research to clarify whether certain economic impacts from expanding infrastructure are accurately captured in benefit-cost analysis or warrant separate valuation, improve methods for estimating wider economic impacts that have been well documented and are potentially significant, and assess the advantages of alternative evaluation methods in capturing their contribution to the value of infrastructure investments.

1. What are Wider Economic Impacts?

The term "wider economic benefits" refers to additional categories of economic benefits that may not be captured by the conventional measures of benefits to infrastructure users and operators that benefit-cost analysis (BCA) of infrastructure investments relies on. Wider economic benefits have been discussed and analyzed primarily in the context of evaluating proposed investments in transportation infrastructure and are mentioned only rarely, if at all, in other applications of BCA such as analyzing proposed investments in different forms of infrastructure, evaluating social service programs, or assessing impacts of government regulations. Recognizing that infrastructure investments have the potential to generate negative effects as well as broader benefits that routine BCA might overlook, common terminology has evolved to refer instead to "wider economic impacts," often abbreviated WEI.

1.1 How Wider Economic Impacts Originate

Investing in transportation infrastructure can generate wider economic impacts when market failures such as externalities (unintentional by-products of production or consumption, often called "spillovers") or inadequate competition arise in markets for products that are transported for sale, or in other markets where transportation plays an important role such as those for raw materials, labor, or urban land. These market failures can prevent benefits or costs resulting from improvements to transportation infrastructure – which originate from their impacts on production costs, market prices, and economic output – from being fully or accurately reflected in benefits and costs to infrastructure users, as they would be if those markets functioned efficiently.

Benefit-cost evaluation of improvements to transportation infrastructure relies on measuring the value of economic impacts that are directly experienced by travelers and shippers who use it, or by operators and users of commercial transportation services that employ the improved infrastructure. It will thus overlook any component of benefits or costs that is not accurately relayed from the product, labor, or land markets where those impacts originate to markets for infrastructure or transportation services because market failures interfere. Any omitted benefits and costs represent wider economic impacts, which need to be estimated separately and added to those normally captured in benefit-cost evaluation.

1.2 Intellectual Foundations of Wider Economic Impacts

French civil engineer and economist Jules Dupuit introduced the idea of evaluating proposed capital investments in public infrastructure – roadways, bridges, railroads, canals, and water supply systems – in the mid-19th century. Dupuit was particularly concerned with measuring the value of investments that seemed likely to foster major increases in use of the infrastructure they added or improved. He outlined a method to measure the increase in "relative utility" that new or expanded facilities provided to suppliers and users of raw materials or manufactured goods whose production and distribution they facilitated.[1]

Nearly half a century later, the prominent British economist Alfred Marshall developed his closely analogous "consumer surplus" measure of economic benefits that investing in transportation infrastructure could provide.[2] Marshall's measure differed critically from Dupuit's because it measured these benefits indirectly, by assessing economic gains to the carriers of passengers and freight who used the new or expanded infrastructure to provide commercial transportation services, rather than – as Dupuit did – to the ultimate consumers of goods whose production and distribution depended on transportation.[3,4] Although Marshall's consumer surplus measure ultimately became the norm in benefit-cost analysis, this distinction presaged the current debate over whether infrastructure provides benefits beyond those it provides directly to users that need to be accounted for separately when evaluating proposed investments.[5]

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[1] An engaging history of how Dupuit's thinking originated, evolved over time, and contrasted with that of his critics is Ekelund and Hebert (1985). Dupuit's measure not only captured the savings in costs to produce and deliver existing outputs that new infrastructure could provide, but also imputed the value of increased supply and use of products that investments could spur by reducing their delivered prices. By doing so, he introduced the idea that infrastructure investment could open new sources of supply – his example was stone quarried at a more distant but less labor-intensive site – that could reduce the prices of products delivered to customers, even if they were shipped from farther away. Rothengatter (2017, 125-126 and Figure 1) provides an extremely clear explanation of Dupuit's example.

[2] Marshall also developed the analogous measure of producer surplus, which measured benefits accruing to operators (rather than users) of transportation infrastructure.

[3] See Ekelund and Hebert (1985, 433-435) and Rothengatter (2017, 125-126). Like Dupuit, Marshall recognized that expanding infrastructure could provide important economic benefits to both previous users of the improved facilities and additional users who were newly attracted by its improvement. In many ways, the contrast between Dupuit's focus on the consumers of transported products and Marshall's focus on the providers of transportation services who utilized public infrastructure presaged the current debate over whether infrastructure provides benefits beyond those to its users that need to be accounted for separately when evaluating proposed investments.

[4] Like Dupuit, Marshall recognized that expanding infrastructure could provide important economic benefits to both previous users of the improved facilities and additional users it attracted, and his measure imputed its value to the latter as on average equal to half that it provided to original users. Although this is usually cited as the origin of the "rule of one-half," Dupuit had previously used exactly the same reasoning to impute that value of an infrastructure investment to consumers of the increased volume of materials or products that were transported over it.

[5] It is probably important not to attach too much significance to this original distinction, however, because Dupuit's measure would also have overlooked wider economic benefits that arise as consequences of market failures, rather than as artifacts of where in the product supply chain infrastructure's benefits are measured.

1.3 Incorporating Wider Economic Impacts in Benefit-Cost Analysis vs. Alternative Approaches to Evaluation

Wider Economic Impacts thus refers to economic benefits and costs resulting from investments in transportation infrastructure *in addition to* the usual consumer and producer surplus measures of benefits to infrastructure users and providers on which benefit-cost evaluation focuses. Considering wider economic impacts within benefit-cost analysis means identifying missing categories of benefits and costs that should be included but are unintentionally omitted, measuring their value, and incorporating the results into benefit-cost evaluation. Supplementing benefit-cost analysis with estimates of the value of Wider Economic Impacts does *not* refer to replacing it with a fundamentally different approach to economic evaluation of proposed infrastructure projects.

Still, analysts sometimes *do* propose alternative methods for measuring economic impacts of proposed infrastructure investments that are intended to substitute for benefit-cost evaluation rather than to supplement it. These include estimating increases in Gross Domestic Product or other measures of the value of aggregate economic output likely to be generated by infrastructure projects, or calculating projects' localized economic impacts such as gains in employment, retail sales, property values, or tax revenues. Again, these represent fundamentally different approaches to economic evaluation of infrastructure investments from benefit-cost analysis, and incorporating wider economic impacts into BCA does *not* refer to replacing it with these alternative methods, or to supplementing it with estimates of benefits and costs derived using these alternative methods.[6]

1.4 Wider Economic Impacts in Current Evaluation Practice

In contrast to domestic practice, wider economic impacts are increasingly incorporated in economic evaluation of proposed investments in transportation infrastructure outside the U.S. As one example, the United Kingdom Ministry for Transport originally issued formal guidance for measuring wider benefits from proposed investments in highway,

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[6] For an early proposal to use a framework similar to National Income and Product Accounting to estimate benefits from investing in highways, see Tinbergen (1957); Bos and Koyck (1961) apply Tinbergen's suggested method and obtain large estimates of benefits from hypothetical highway investments. A more recent experiment in using increases in firm-level economic productivity to measure benefits from highway investment is the FHWA-sponsored research by Nadiri and Mamuneas (1996a, 1996b). Rothengatter (2017) briefly discusses the potential for using spatial computable general equilibrium (SCGE) and other advanced economic models to estimate welfare impacts of transportation infrastructure investments as a replacement for rather than as a supplement to benefit-cost evaluation, but doubts that such models are yet sufficiently detailed or reliable to permit this. Local economic impact analysis of investments in transportation infrastructure is widely practiced and documented; see for example Weisbrod (1997), or Cambridge Systematics, Inc., Economic Development Research Group, Inc., and Boston Logistics Group, Inc. (2006).

transit, and rail infrastructure as early as 2005, and has periodically revised its guidance to incorporate more detailed estimation methods and updated empirical evidence on their potential magnitude (U.K. Department for Transport 2019, 2020). Other nations that have more recently embraced the potential for wider economic impacts from investments in transportation infrastructure and prescribed methods for estimating them as part of their benefit-cost analysis guidelines include Sweden, Norway, Australia, and New Zealand.

In contrast, benefit-cost analysts in the U.S. continue to approach the concept of wider economic benefits more cautiously, and both their existence and potential magnitude remain controversial in domestic economic evaluation. Some analysts acknowledge their theoretical potential but remain skeptical about the empirical significance of wider economic impacts that might arise from relatively modest investments on the scale of common infrastructure expansion or improvement projects in the U.S., particularly where those would augment transportation networks that are already extensive and well-developed. Although estimates of wider benefits are occasionally included in evaluations of proposed infrastructure projects seeking federal funding, no formal guidance on when or how to estimate their value has yet been issued by U.S. DOT or other federal agencies.

1.5 FHWA Research Related to Wider Economic Impacts

In the late 1990s and early 2000s, FHWA's Office of Transportation Policy Studies sponsored extensive research related to the issue of potential wider economic impacts from highway investment.[7] FHWA's effort was partly motivated by some analysts' perception that benefit-cost analysis could overlook important categories of benefits from investing in highways, and partly by a desire to express benefits in terms such as gains in economic productivity or GDP that were more familiar and potentially compelling to transportation planners and public officials than the consumer surplus measures used in benefit-cost evaluation. The most careful and widely cited research FHWA sponsored was Nadiri and Mamuneas' (1996a, 1996b) study of the contribution of highway investment to economic productivity.

Using detailed data on industry-level output, the value of the nation's highway capital stock, other production inputs (labor, private capital, and materials), and U.S. population and personal income, these authors estimated separate production cost and demand functions for a set of 35 domestic industry sectors. They used this framework to

[7] Publications describing this research and its conclusions include Nadiri and Mamuneas (1996a, 1996b), Federal Highway Administration (1996), Jacobsen (1996), Lakshmanan (1996), Jacoby (1999), and ICF Consulting, HLB Decision Economics, and Louis Berger Group (2001).

disaggregate changes in total factor productivity at the industry level into four distinct sources: changes in prices for production inputs, growth in demand and output, increases in the value of highway capital available to firms, and exogenous innovations in production technology.

In Nadiri and Mamuneas' model, new infrastructure investment increases the value of highway capital available for firms to use as a production input, which boosts productivity via both direct and indirect avenues. First, more extensive highway infrastructure enables firms to utilize privately-supplied inputs – labor, materials, and private capital (such as vehicles) – more efficiently, which directly increases their productivity. Over time, continued investment in highway infrastructure also lowers firms' production costs, in turn reducing prices and increasing demand for their products and contributing to growth in those firms' output. This indirect effect increases their productivity further by enabling larger-scale production, more efficient use of inputs, and lower production costs. The authors' calculated return on investments in highway capital consists of the more rapid increase in the total value of industries' economic output that results from both sources of increased productivity.

While their analysis captured some categories of benefits that would have been measured in conventional benefit-cost evaluation of investments that expanded the nation's highway capital stock, Nadiri and Mamuneas' method for measuring returns to infrastructure investment also appears to have included some benefits that represented wider economic impacts. These included productivity gains from larger employment agglomerations and from improved matching of workers' skills with the demands of specialized jobs, both of which are now recognized as potential wider economic impacts from infrastructure investment.

Thus, FHWA has some experience in supporting research on wider economic benefits and their empirical significance, although the agency has not continued to pursue the issue actively in recent years. To build upon FHWA's institutional knowledge, this report identifies potential sources of wider economic impacts from infrastructure investment, uses basic economic theory to demonstrate why benefit-cost analysis can overlook potentially important benefits (or costs) and to outline how they can be measured, evaluates their likely empirical significance, and assesses challenges to measuring these wider economic impacts reliably.

2. What Creates the Potential for Wider Economic Impacts?

2.1 A Brief Overview[8]

Investments that improve the performance of an area's transportation system – by adding new connections within a network, increasing the capacity of existing routes, or improving the reliability of service it provides – increase the speed at which people and freight can move, thus reducing travel and shipping times. Faster travel initially brings households, workers, and firms closer together in terms of time and enables them to interact more readily, exactly as if they were located closer to one another. Over time, it may also change the actual geographic distribution of economic activity, by inducing households and firms to relocate to sites whose improved access makes them more advantageous locations to live, work, or do business.

Together, these responses create three major sources of economic benefits:

- Better accessibility and closer proximity effectively increase the density of economic activity and by doing so streamline interactions among firms, their workers, and consumers, leading to gains in worker and firm productivity *beyond* those that result from faster travel and savings in time.
- Locations where new investments in infrastructure improve accessibility become more attractive opportunities for private development, which can create benefits by changing the type and intensity of land use there.
- Faster or easier travel can increase the supply of labor by providing some workers with access to a wider range of jobs, leading others to work longer hours, or even inducing some new workers to enter the labor force, while also rearranging the geographic pattern of employment opportunities and creating potential new ones.

The economic benefits from these changes in economic activity will normally be reflected in increased use of new or expanded infrastructure for personal travel and moving freight. Thus, they will be fully captured in the usual measures of increased consumer surplus that infrastructure users – travelers and freight carriers – experience, and correctly incorporated in benefit-cost evaluation of proposed investments.[9] But market failures can prevent benefits that originate in product, labor, or land markets

[8] This section is adapted from Laird and Venables (2017, pp. 2-3).

[9] Improving transportation infrastructure can also create additional benefits to emergency service providers, construction vehicles, and other specialized users.

from being fully or accurately translated into the usual measures of consumer surplus gains to infrastructure users. Where they do, those measures may not accurately capture the economic value of the new investments that create these benefits.

Potential market failures include economic or environmental externalities (both positive and negative), inadequate competition and the exercise of pricing power by suppliers it enables, and distortions introduced by taxes on labor income or by regulation of land development. These can arise in markets for products that depend on shipping for their manufacture and distribution, for specialized labor, for urban land parcels, and even in markets for transportation services themselves. Their presence introduces the potential for infrastructure investments to have wider economic impacts that can be overlooked in economic evaluation unless they are measured separately. These wider impacts can be positive (benefits) or negative (costs), and the same investment can lead to negative impacts in some locations that partly or fully offset wider benefits that occur elsewhere.

2.2 More Detailed Analysis of Wider Economic Impacts

Investments that expand the coverage or increase the capacity of transportation facilities or networks reduce the "user costs" of passenger travel and freight shipping. They do so by increasing travel speeds and reducing operating costs for cars and freight trucks, economizing on travel time for users of public transportation services, or increasing railroads' or waterborne shippers' operating speeds.[10]

Where products that utilize transportation services for their production and distribution are sold in competitive markets, reductions in transportation costs will be reflected in lower delivered prices, which will in turn lead to increased consumption, output, and shipping of those products and the materials used to make them. As illustrated below, the resulting increases in consumer and producer surplus in product markets will normally be reflected in increased consumer surplus from use of the transportation services that firms depend on to produce and deliver their products, whether those firms utilize commercial freight carriers or operate their own shipping services "in house."

The case of passenger travel is slightly more complex, but the result is similar. Improvements to infrastructure used by operators of public transportation services will be reflected in faster speeds and lower costs, which in turn will reduce travel costs for

[10] The user cost of personal travel is usually defined to include both monetary costs such as vehicle operating expenses or fares charged to passengers, plus the economic value of travelers' time. In freight transportation, user costs include vehicles' operating expenses, the value of drivers' or crew members' time, and the inventory value of the cargo being transported; shippers who use commercial transportation services pay the first two components in the form of charges for carrying freight, while those who operate their own transportation subsidiaries incur those costs directly.

passengers and increase usage. In the absence of market failures, benefits from faster travel, lower costs, and increased use will all be transmitted accurately into gains in consumer surplus from transportation service operators' use of the improved infrastructure. Where households "produce" their own transportation services using privately-owned vehicles, increased travel speeds and lower costs resulting from improvements to road infrastructure will enable their members to access more attractive employment opportunities and more desirable retail, social, or recreational attractions. The added benefits they experience as a result will be fully reflected in their savings in travel time, lower costs, and more frequent travel, and thus measured accurately by the gains in consumer surplus they experience from using the improved infrastructure.

2.3 Measuring Benefits in Normally Functioning Markets

Figure 1 and Figure 2 illustrate the example where an investment in transportation infrastructure enables faster shipping times and thus lowers shipping costs for products transported via the improved roadway, rail line, waterway, or other facility.[11] In competitive markets, lower shipping costs reduce delivered prices of goods whose suppliers rely on freight transportation to assemble raw materials and distribute their products to retail outlets or customers. Figure 1 shows the effect of a decline in transportation costs – for example, shipping by truck – on the market for a product where faster delivery speeds and lower freight charges (or truck operating costs, where producers operate their own transportation subsidiaries) reduce the cost for producing and delivering it. This is shown as a downward shift in its supply curve from S_1 to S_2, a distance that equals the reduction in transportation costs to produce and deliver the product.

In response to the downward shift in its supply curve, the delivered price of the product declines from P_1 to P_2, and because demand is sensitive to its price, its consumption increases from Q_1 to Q_2. As Figure 1 shows, the decline in price is smaller than the savings in shipping costs because the supply curve slopes upward, reflecting producers' increasing costs to supply more of the product.[12] Both consumers and producers benefit from the reduction in price and the resulting increase in the quantity that is produced and sold. The increase in consumer surplus to previous buyers of the product is the rectangular area P_1abP_2, which measures their savings from being able to purchase it at the new lower price, while triangle abc measures the gain in consumer surplus to new

[11] The graphical analysis shown here is adapted from Commonwealth of Australia Bureau of Transport Economics (1999, pp. 19-23) and Just *et al*. (2004), Chapter 4.

[12] This is not a necessary condition; if producers' costs to supply the product were constant, the supply curves in Figure 1 would be horizontal, and only consumer surplus would increase.

buyers who are attracted by its lower delivered price.

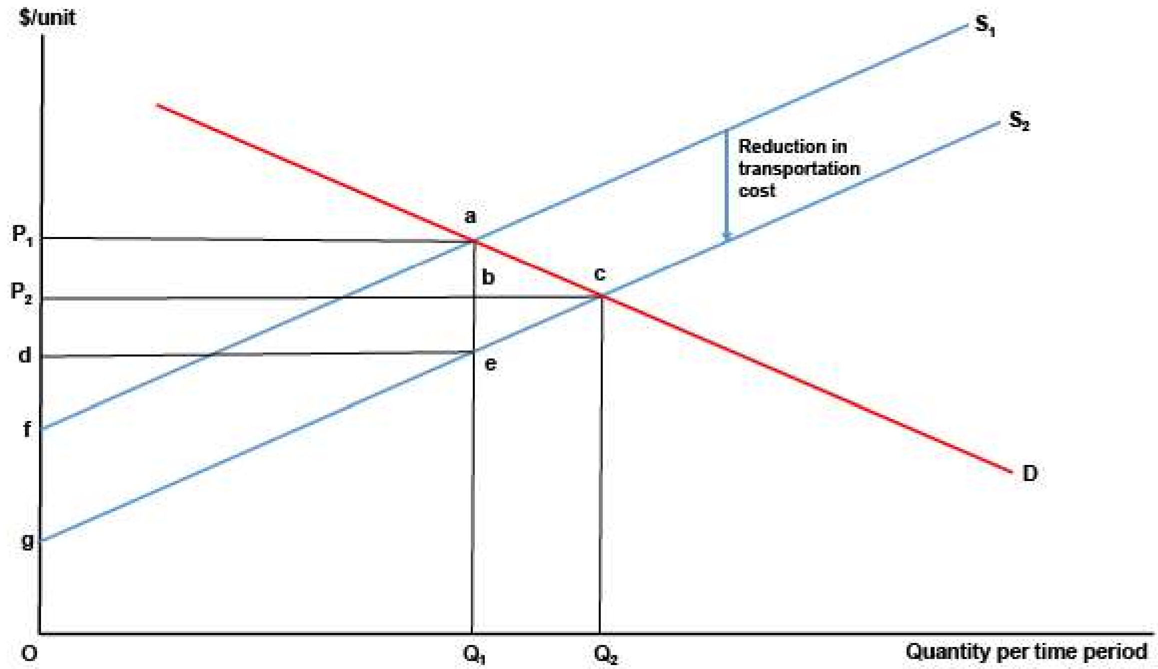

Figure 1. Benefits from Reduced Transportation Costs as Measured in Product Markets

Producers also benefit, in part because the product's price declines by less than their savings in transportation costs to produce and deliver it, which increases their short-term profits (or "producer surplus"). The decline in total revenue they now receive for the quantity they originally produced and sold (Q_1) is exactly equal to previous buyers' cost savings, area P_1abP_2, but suppliers' savings in transportation costs to produce and deliver the original quantity decline by the larger rectangle P_1aed. Because suppliers' costs decline by more than does the revenue they receive from producing and distributing the previous quantity Q_1, their producer surplus increases by the difference between the two, or area P_2bed.

Suppliers also benefit from producing and selling more of the product to meet increased demand, and triangle bec measures the second component of their increase in producers' surplus. Its area is equal to the additional revenue they receive from selling the larger quantity, measured by the rectangular area Q_1bcQ_2, minus their incremental costs to produce and deliver the additional quantity, area Q_1ecQ_2; the difference between their increased revenue and added costs is their gain in producer surplus on the increased quantity they sell, measured by triangle bec. Thus, the total gain to producers is equal to the sum of areas P_2bed and bec, or the total area P_2ced. As indicated above, consumers benefit by the area P_1acP_2, so combined benefits to consumers and producers are the entire area P_1aced.

Figure 2 shows the effect of the decline in shipping costs enabled by the investment in new or expanded infrastructure in the market for freight transportation services used to assemble raw materials and distribute products. It contrasts with Figure 1, where the horizontal axis measured the quantity of a finished product that is delivered and sold. Instead, the horizontal axis of Figure 2 combines the quantities of materials and finished products shipped with the distances they are carried to measure the total number of ton-miles of freight transported in the course of producing and distributing the product.[13] Because freight vehicles utilize the vehicle-carrying capacity that highway, rail, or water infrastructure provides, the horizontal axis of Figure 2 also reflects freight carriers' increased "consumption" of the services that the new or expanded infrastructure provides.[14]

As a specific example, investing in improved or expanded highway infrastructure increases the speed at which freight trucks can operate. By doing so, it reduces various time-related components of the cost of providing trucking services, including drivers' wages, the hourly depreciation cost of vehicle capital, and the inventory cost of the cargo being carried. The result is a decline in the total cost to truck operators for moving each ton-mile of cargo they carry. Where for-hire trucking companies operate in a

[13] The increase in ton-miles in Figure 2 will be exactly proportional to the increase in product output and consumption in Figure 1, with the proportionality constant equal to the number of ton-miles required to transport each unit of output.

[14] Operators of commercial transportation services (such as truck and barge operators) do not explicitly purchase the services that publicly provided infrastructure (such as highways and inland waterways) supplies, because those services are not exchanged in conventional markets. Instead, they usually pay indirectly for those services in the form of taxes on the fuel they consume (as well as other incidental taxes and fees) and compete with other users to access infrastructure services on a first-come, first-served basis. Consequently, benefits from infrastructure improvements are customarily measured in markets for *transportation* services, rather than in a hypothetical "market" for *infrastructure* services or use. In contrast, commercial transportation services such as trucking, waterborne shipping, and some limited passenger-carrying services (such as intercity bus travel) are supplied and purchased in explicit markets, so benefits from changes in their prices and use that result indirectly from investing in improved infrastructure can be measured directly in those markets. However, some firms produce freight transportation services "in house" rather than purchasing them from commercial operators, and households (as well as some businesses) almost universally provide transportation services for their members (or employees) using vehicles they own and operate on publicly provided highway infrastructure. Once again, no formal market exists where these firms and households purchase infrastructure services; nor are the transportation services they use publicly provided infrastructure to produce explicitly bought and sold. Nevertheless, benefits that infrastructure investments provide indirectly to those firms and households are measured as if markets for their transportation services existed, rather than attempting to measure those benefits in a theoretical market for infrastructure services.

competitive market, these savings in their operating costs will be reflected in lower freight rates, while firms that operate their own shipping services will experience the cost reduction directly. In either case, lower shipping costs will ultimately be reflected in lower delivered prices for transported products, as illustrated in Figure 1.

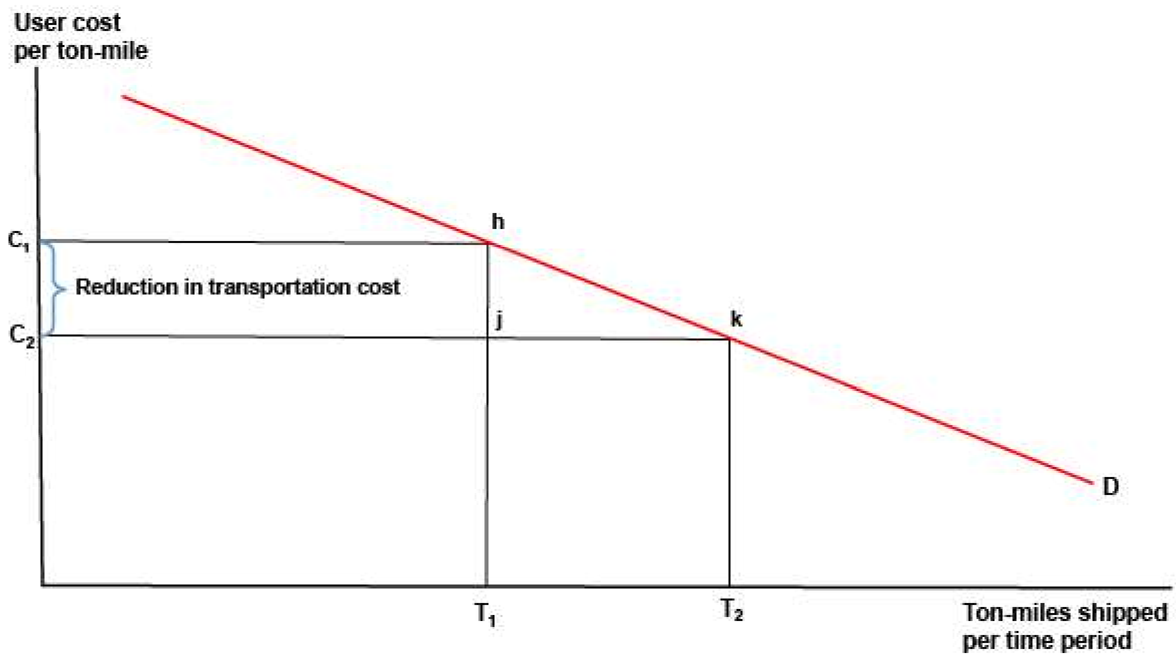

Figure 2. Benefits from Reduced Transportation Costs as Measured in the Market for Transportation Service

The decline in freight carriers' operating costs is shown in Figure 2 as a downward shift in the user cost (or supply) function for freight transportation services from C_1 to C_2. This decline in transportation costs corresponds exactly to the reduction in the cost of producing and delivering a product that was shown previously in Figure 1 as a downward shift in its supply curve from S_1 to S_2. The increase in the number of ton-miles shipped, shown as the movement from T_1 to T_2 in Figure 2, measures the increase in ton-miles of freight transportation service necessary to carry the additional raw materials required to produce the larger quantity of products sold, and to distribute those products to customers.

To provide this increase in service, freight carriers – truck operators, in the case of highway infrastructure – utilize an exactly proportional increase in the quantity of services that the improved infrastructure provides. Again, however, the services public infrastructure provides are not explicitly bought and sold, so it is more convenient to measure the benefits from changes in their implicit prices and levels of use in the market for transportation services, rather than illustrating a fictitious market for the services that transportation infrastructure provides.[15]

Rectangle C_1hjC_2 in Figure 2 measures the savings in transportation costs to suppliers of transportation-using products for producing and delivering the quantity they previously sold. By definition, it must equal area P_1aed in Figure 1, since that area measured exactly the same savings. This savings captures the benefits to *both* consumers (their gain in consumer surplus, area P_1abP_2 in Figure 1) and producers (their gain in producer surplus, area P_2bed in Figure 1) of the product that result from the savings in transportation costs on the number of ton-miles (T_1 in Figure 2) that were required to produce and distribute the quantity originally produced and sold (Q_1 in Figure 1).

Triangle hjk in Figure 2 reflects the benefits to product suppliers – who are the users of trucking services – from purchasing the *additional* transportation services necessary to produce and distribute the increased amount of the good they sell at its lower delivered price. The area of triangle hjk is equal to one-half of the reduction in transportation costs ($C_1 – C_2$) times the increase in the number of ton-miles of materials and products shipped (T_2 – T1), which is exactly the same as the area of triangle aec in Figure 1.[16] Benefits to both suppliers (triangle abc in Figure 1) and consumers (triangle bec in Figure 1) from increased production and sale of goods that rely on trucking are therefore fully captured by the gain in consumer surplus to users of the additional transportation services necessary to meet increased product demand.[17]

Thus where markets for transportation services and for the products they are used to

[15] As indicated previously, benefits from infrastructure investment to households and firms that produce transportation services for their internal consumption are also measured as if they were bought and sold in markets where changes in their prices and consumption can be measured.

[16] In Figure 1, the distance ae equals the reduction in transportation costs for producing and distributing each unit of the product, and ($Q_2 – Q_1$) measures the increase in the amount of that product produced and sold. The area of triangle aec in Figure 1 is equal to ½*ae*($Q_2 – Q_1$). The distance ($T_2 – T_1$) in Figure 2 will bear the same relationship to ($Q_2 – Q_1$) in Figure 1 as do the distances hj in Figure 2 and ae in Figure 1; specifically, hj/ae and ($T_2 – T_1$)/($Q_2 – Q_1$) will both equal the number of ton-miles required to transport each unit of product. (If the number of ton-miles required to produce and distribute each unit of the product remains unchanged, the distance (T2 – T1) in Figure 2 will be equal to (Q2 – Q1) in Figure 1.) Since the area of triangle hjk in Figure 2 is equal to ½*hj*($T_2 – T_1$), the areas of triangle aec in Figure 1 and hjk in Figure 2 will thus be equal.

[17] Once again, these benefits could in theory be measured by gains in consumer surplus from lower prices and increased use of infrastructure services themselves, but these would be identical to the more readily measurable gains to users of trucking services. Where firms and households produce and consume their own transportation services, it is again convenient to measure benefits from changes in their costs and quantities as if they were exchanged in markets for those services, rather than from changes in those firms' and households' use of highway infrastructure services.

produce and deliver are competitive, and neither the production of transportation services nor the goods they carry generate externalities, *all of the benefits from investments transportation infrastructure can be measured by increases in consumer surplus in the markets for transportation services that utilize the improved infrastructure*.[18] Again, the logic can seem more complicated in the case of personal transportation, but it is exactly analogous: travelers using public (or "common carrier") transportation services act similarly to firms that purchase commercial freight shipping services, and like trucking firms, public transportation operators in turn utilize the services infrastructure provides.[19] Where households (or businesses) use their own vehicles to supply transportation for their members (or employees), they are analogous to firms that operate freight transportation subsidiaries "in house," in that both employ the services infrastructure provides as one input to their production processes.

Because of these similarities, the same result applies: benefits from improving transportation infrastructure will typically be measured correctly by increases in consumer surplus to travelers who use the new or improved facilities, whether they are commuting to jobs or traveling to shopping districts, recreational attractions, or other destinations that faster and less expensive travel make more accessible. However, the same caveat also applies: transportation, labor, and product markets need to be adequately competitive and generate no significant externalities for benefits measured from changes in the costs and use of transportation infrastructure to accurately convey the economic benefits from improving it.

2.4 How Wider Economic Impacts Can Arise

There are situations where part of the economic benefits generated by improvements in transportation infrastructure may not be reflected in consumer surplus gains to travelers and shippers, and thus will not be captured in conventional benefit-cost analysis of proposed investments. These situations create the potential for wider economic

[18] This is a special case of the general result that the welfare consequences of changes in the price of factors of production can be measured in either the markets for those factors or in the markets for products they are used to produce. This principle was the subject of a prolonged exchange among Schmalensee (1971,1976), Wisecarver (1974), Anderson (1976) and Jacobsen (1979), with the participants ultimately agreeing that it held in the absence of market failures in both input and product markets. More recently, Rouwendal (2013) notes that it was originally asserted by Hicks (1946), using the example of measuring benefits from a subsidy to producers for using a specific input, developed much later in the context of transportation infrastructure improvements by Sugden and Williams (1978), and still later proven formally by Blackbory and Donaldson (1999). Other than Hicks, however, the references Rouwendal cites do not seem to be well known to benefit-cost analysts in the U.S. Just, Hueth and Schmitz (2004) provide a rigorous graphical and mathematical demonstration of the general result and argue that it applies regardless of the complexity of linkages among markets for intermediate and final products.

[19] As before, they do not purchase infrastructure services explicitly, because those services are not sold in conventional markets.

impacts. They arise where externalities, less-than-perfect competition, or other market failures prevent measures derived from transportation markets from reflecting the true economic costs and benefits of producing and consuming products and services that utilize transportation.[20] Such complications can arise in markets for transportation services, in markets for products that rely on transportation for their production and distribution, or in labor and land markets, where transportation affects access to employment opportunities and to favorable sites for development.

If transportation activity itself generates externalities such as congestion or air pollution, for example, investments in transportation infrastructure can cause changes in the economic cost of those externalities that partially offset the benefits measured by increased consumer surplus to users of the improved facilities. Similarly, if externalities arise in markets for transported products, or in labor or land markets, some economic costs or benefits that infrastructure improvements provide indirectly to suppliers and consumers in those markets may not be reliably transmitted back to markets for transportation services or infrastructure use. Where this occurs, they will not be reflected in the associated changes in consumer surplus to users of transportation services or infrastructure that analysts normally rely on to estimate benefits from those improvements.

The same result can occur if competition in local markets for transported products is inadequate to force prices to accurately reflect production and transportation costs, or where scale economies in production enable suppliers' costs to decline with increasing output and thus permit a few suppliers to dominate the market. In either case, while cost savings to users of improved infrastructure will be accurately reflected in lower costs to product suppliers, limited competition may prevent those savings from being fully translated into lower product prices and increases in consumption, so the resulting benefits to consumers will be smaller than if competition were more vigorous. As a consequence, some fraction of benefits from infrastructure improvements that reduce transportation costs may not be reflected in increased transportation activity and consumer surplus gains to infrastructure users and is thus likely to be overlooked in cost-benefit analysis of proposed investments.

The following section outlines categories and specific sources of these potential wider economic impacts, organizing them by the type of market in which they arise and the nature of the market distortion that causes them. Sections 4 through 8 explore in more detail the specific situations where benefits from infrastructure improvements may be

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[20] Schmalensee (1971) and Jacobsen (1979) consider how one specific market failure – imperfect competition – could require the computation of additional benefits from changes in the price of a production input beyond the usual consumer and producer surplus measures.

measured inaccurately in transportation markets. Each section illustrates why this can occur in a specific market context, identifies the types of investments where supplemental benefit measures may be necessary for accurate economic evaluation, and outlines possible methods and data requirements for measuring them.

3. Categories of Wider Economic Impacts

There are many different ways to organize and classify the various wider economic impacts that investments in transportation infrastructure can potentially generate, including by the markets in which they arise, the specific market failures that give rise to them (externalities, imperfect competition, tax distortions, etc.), the frequency with which they are likely to occur, their potential dollar magnitude, or the types of infrastructure investments that seem likely to generate them. Originally, both Graham (2006) and Venables (2007) organized potential wider economic impacts into the four categories of employment agglomeration, heightened competition, increased output in imperfectly competitive markets, and expanded labor supply, but the distinction between the second and third of these is subtle and can seem arbitrary. Reflecting this, Legaspi *et al*. (2015) recognize only agglomeration economies, increased output in imperfectly competitive markets, and “improved labor markets” as sources of wider economic impacts. Other studies (e.g., Rothengatter, 2017) use still different taxonomies, sometimes adding flaws in the operation or regulation of urban land markets as another potential source of Wider Economic Impacts.

Interestingly, none of these analyses classifies changes in congestion, environmental, or other externalities from transportation activity *itself* as wider economic impacts, even though they result from market failures and are not likely to be reflected in changes in consumer surplus measured in transportation markets, so they meet the usual definition of Wider Economic Impacts. Some authors (e.g., Laird and Venables, 2017) acknowledge that changes in these externalities would represent costs or benefits beyond those experienced directly by infrastructure users but seem to distinguish them from “true” wider economic impacts. This may be because reductions in these externalities arise in markets for transportation services (as consequences of vehicle use), rather than in “downstream” markets that are indirectly affected by improvements to transportation infrastructure (those for transported products, labor, or urban land). Nevertheless, they meet the conventional definition of wider economic impacts, so this report considers them as such.

While each approach to organizing potential wider impacts has advantages and drawbacks, this report classifies them by the market in which they can arise and the specific market failure that introduces the potential for wider impacts. The specific markets considered include those for transportation infrastructure (highways, public transportation facilities, rail lines, inland waterways, etc.), urban labor and land markets, and markets for manufactured products that utilize transportation for their production and distribution.[21] This taxonomy clearly identifies the source of each potential wider economic impact and the mechanism that generates it. Although this way of organizing wider economic impacts requires a larger number of categories than some previous research uses, it has the advantage of grouping impacts that originate in the same market together, while at the same time distinguishing between those that arise from different causes.

Table 1 shows the organization of wider economic impacts used in this study. As it indicates, they can originate in markets for transportation infrastructure, the market for skilled or specialized labor, markets for products whose production and distribution requires transportation (of raw materials, intermediate inputs, or the finished products themselves), and urban land markets. In markets for infrastructure, wider economic impacts can arise where its routine use generates environmental externalities such as air pollution or emissions of climate-altering greenhouse gases, or where particularly heavy use at certain times causes congestion and users impose delays on one another as a result. Wider economic impacts can also arise because building or expanding infrastructure influences users' choices among alternative routes, modes, or travel times, and by doing so affect the magnitude of these externalities.

As Table 1 also shows, labor market failures that introduce the potential for wider benefits include productivity spillovers occurring in large employment agglomerations or where firms in related industries cluster, as well as distortions of labor supply caused by income taxation. New infrastructure investments that increase the capacity of transportation systems often enable larger employment agglomerations and encourage commuting to jobs where employees are more productive, which can accentuate productivity spillovers and increase taxable incomes, both of which represent wider

[21] Markets for the use of infrastructure are rarely formally organized in the same sense that markets for manufactured products, services, labor, or land are. Except where tolls or fees are charged to vehicles using transportation facilities (bridges, highways, rail lines, airports, tunnels, etc.), the services provided by infrastructure are rarely priced explicitly, and the main costs users incur are expenses for operating vehicles and the value of their drivers' and passengers' time. Another distinguishing characteristic is that "producers" of infrastructure services are usually government (or quasi-government) agencies that own and operate public facilities, rather than traditional private firms producing goods or services for commercial sale. Nevertheless, it is useful to think of infrastructure users as consumers of the services it provides, and of the agencies that own transportation facilities as producers of infrastructure services. The normal market interaction between demand and supply results in an equilibrium price for infrastructure services (including vehicle operating costs, the economic value of travel time, and tolls or other user charges) and quantity of services produced and consumed, as measured by the level of facility use.

economic benefits.

Limited competition in markets for transportation-using products offers the potential for infrastructure improvements to cause wider impacts, either by reducing costs for incumbent suppliers or enabling new competitors to enter. Both responses can result in lower product prices to customers and expanded output and consumption, which provide additional benefits to consumers that are unlikely to be incorporated in the increases in consumer surplus that benefit-cost evaluation relies upon to capture benefits from proposed infrastructure expansions.

Finally, in urban land markets, spillovers that result from an increased variety of living, shopping, or recreational opportunities introduce the potential for infrastructure investments that improve access to advantageous sites to generate wider economic impacts, by stimulating new development and expanding the array of opportunities available at such sites. In addition, if those investments help to overcome economic or legal impediments to development, the added private capital investment in more intensive development that often results can also generate wider economic impacts.

Table 1. Situations where Wider Economic Impacts are Likely to Arise

Affected Market	Nature of Market Failure or Distortion	Mechanism for Wider Economic Impacts
Transportation infrastructure[22]	Congestion, safety, and environmental externalities from infrastructure and vehicle use	Changes in externalities are not reflected in transportation consumer surplus measures used in benefit-cost analysis
Urban labor	Productivity spillovers from employment agglomeration	Productivity effects of changes in employment density are not captured in transportation consumer surplus
	Income tax burden on earnings from increased labor supply and improved matching of worker and job skills	Increased tax revenue to governments not reflected in transportation consumer surplus
Transported products[23]	Limited competition in product markets	Consumer surplus from reduced prices and increased output due to transportation cost savings are not captured in transportation consumer surplus

[22] Including household and other private use of transportation infrastructure for personal travel, as well as use of infrastructure by operators of commercial transportation services.

[23] Products requiring transportation of materials used in their production, or for distribution to final markets.

Affected Market	Nature of Market Failure or Distortion	Mechanism for Wider Economic Impacts
		Consumer surplus from reduced prices and increased output due to new entry into product markets not captured in transportation consumer surplus
Urban land	Spillovers from increased range of shopping or living opportunities	Increase in attractiveness of sites made more accessible by infrastructure investments due to increased variety
	Barriers or restrictions on land development	Increases in development where infrastructure investments help to overcome barriers

To summarize, recent research has pointed to a limited number of situations where market failures prevent the usual measure of transportation consumer surplus that benefit-cost analysis relies upon from capturing the full range of benefits from investments that improve transportation infrastructure. These market failures in the four markets identified in column 1 of Table 1 above can create the wider economic impacts summarized in column 2 of the table. The following list reiterates these seven potential sources of wider economic benefits, and identifies an eighth situation that is often asserted to be an additional source:

- Where savings in transportation costs on improved facilities attract new users from competing routes, travel modes, or carriers, changes in externalities such as congestion, noise, and air pollution can result in additional economic benefits (or costs) beyond increases in consumer surplus to users of the improved facilities.

- Larger agglomerations of employment enabled by investments that increase the capacity of transportation service to locations where highly specialized or knowledge-intensive firms cluster together may promote interactions that mutually improve firms' productivity, generating benefits from increased output that benefit-cost evaluation of such investments is likely to overlook.

- Increases in labor force participation, longer working hours, and higher productivity from improved matching of worker and job skills requirements can occur where improving transportation infrastructure shortens commuting times, but the fraction of increased earnings that is taxed will not be reflected in increased consumer surplus to infrastructure users (commuters).

- Improvements to transportation networks reduce shipping costs and lower the delivered prices of products and can also expand the geographic area that suppliers serve, but the resulting gains in consumer surplus to buyers of their products will not be reflected in the benefits from increased shipping activity using the improved infrastructure.

- Infrastructure investments that improve access to underserved regions and enable new competitors to deliver products there can also lead to lower prices and increased consumption, which create additional benefits beyond those to shippers using the new infrastructure.

- Land-use changes or development impacts triggered by improving accessibility to desirable sites may expand the variety of living, shopping, or entertainment opportunities available there, thus generating benefits beyond those measured by reductions in transportation costs and increased travel activity, the yardsticks normally relied on in benefit-cost analysis.

- Where infrastructure investments improve a site's accessibility and the resulting pressure for more intensive development there helps to overcome institutional or legal barriers to private investment, benefits beyond those from increased use of the improved infrastructure can also arise.

- Finally, it is often argued that when infrastructure improvements enable faster or more reliable shipments, they can lead shippers to reorganize their supply and distribution networks to economize on inventory and storage by relying on more frequent shipments, and the resulting savings in firms' logistics costs may not be reflected in the usual measure of benefits.

The following sections examine each of these situations in detail, focusing on why each one has the potential to generate wider economic impacts and assessing the likelihood that they are likely to be significant. Where wider economic impacts seem likely to arise, the discussion outlines possible methods and data sources for measuring them and assesses the prospect for developing reliable dollar estimates of their value. Finally, the specific types of investments in transportation infrastructure that appear most likely to generate each category of wider economic impacts are identified. This assessment focuses on the U.S., where transportation networks are already well-developed in most geographic areas and vigorous competition characterizes most industries and markets, particularly those for products that rely heavily on transportation for production, distribution, and access.

4. Changes in Externalities from Transportation Activity

Benefit-cost analysis of investments in transportation infrastructure now routinely includes the value of changes in congestion and environmental externalities resulting from the response of transportation activity to investments that increase capacity and lower transportation costs. The economic value of reductions in those externalities are treated as additional benefits from such investments beyond the increase in consumer surplus to users of improved facilities, while any increase in the costs they impose are treated as "dis-benefits" or additional costs of proposed investments.

Because they are by now routinely included in economic evaluation, changes in these externalities are not widely cited as examples of wider economic impacts. Nevertheless, they are included in this discussion because they meet the definition of wider impacts: benefits or costs that are not included in the usual measures of changes in consumer and producer surplus to users of new or expanded transportation infrastructure. They also provide a clear illustration of how those impacts can arise, using an example that is already familiar to most analysts.[24]

4.1 Why Changes in Externalities are Wider Economic Impacts

Figure 2 above illustrated the conventional measure of benefits from an investment that expands or otherwise improves a transportation facility such as a highway, bridge, rail line, or waterway, which is the increase in consumer surplus to both its previous users and those newly attracted by the improvement.[25] As it showed, the investment shifts the cost function for facility users downward, because it can now accommodate a larger volume of travel at the same travel speed and resulting user cost.[26] In response, use of

[24] The only distinction between impacts arising from changes in congestion and environmental externalities and other effects that are included in most lists of wider economic impacts is that the former are attributable to failures in markets for transportation services *themselves*, whereas other effects commonly classified as wider economic impacts result from failures in markets for products that *use* or depend on transportation services – specifically, in labor, product, and land markets. Otherwise, their origins are identical: the presence of market failures prevents some benefits or costs resulting from infrastructure investments from being fully captured in gains or losses in consumer surplus measured in the market for infrastructure use, which are the core benefits and costs recognized in benefit-cost evaluation.

[25] This discussion refers to a specific infrastructure facility, but it also applies to measuring benefits from improving a transportation mode or service, such as by building a new rail transit line or increasing the frequency of an existing service.

[26] The generalized cost function shown in Figure 3 measures only private costs to facility users. For freight carriers, these include driver (and crew member) wages, vehicle ownership and operating costs, and the inventory value of the cargo being carried. For passenger travel, it includes vehicle operating expenses or fares, plus the economic value of travelers' time.

the improved facility – as measured by the number of ton-miles moved over it – increases from its pre-improvement level T_1 to T_2 in Figure 2, while the cost per ton-mile shipped declines from C_1 to C_2. Benefits from the improvement include the increase in consumer surplus on pre-improvement use of the facility, which is equal to the reduction in cost ($C_1 – C_2$) times their number (T_1), or the rectangular area C_1fgC_2 in Figure 2. They also include the consumer surplus from increased use of the improved facility ($T_2 – T_1$) prompted by the lower cost of traveling on it, the triangular area hjk in the figure.

Some (or even most) of these new users may be drawn from alternative routes or modes that do not involve the improved facility, and Figure 3 illustrates the resulting change in the use of one such alternative. Because the newly improved facility now offers a better substitute for this alternative, demand for its use shifts inward from D_1 to D_2 in response to the reduction in cost for using the newly improved route. However, users of the alternative facility consider only the costs they incur and disregard any externalities they generate, so equilibrium in the “market” for its use occurs where the user cost function intersects the demand curve; thus, use of the alternative facility or route declines from A_1 to A_2 as its demand curve shifts inward. The decline in its use forms part of the increase in travel on the improved facility, as these former users of the alternative facility re-route their trips to take advantage of the faster speed or lower cost of traveling via the improved route.

If travel on the alternative facility generates externalities – for example, if congestion occurs at certain times and users delay one another, vehicles emit air pollutants or greenhouse gases, and trucks cause objectionable noise or damage the roadway surface – the decline in its use will reduce the total costs of those externalities. For simplicity, the cost of externalities other than congestion is shown as constant on a ton-mile basis in Figure 3, and the reduction in the total economic cost of externalities generated by its users is equal to the trapezoidal area abcd. Because the reduction in external costs measured by this area represents a benefit from the improvement *in addition to* the gains in consumer surplus to previous and newly attracted users of the improved route or facility shown previously in Figure 2, it is thus an example of a wider economic impact.

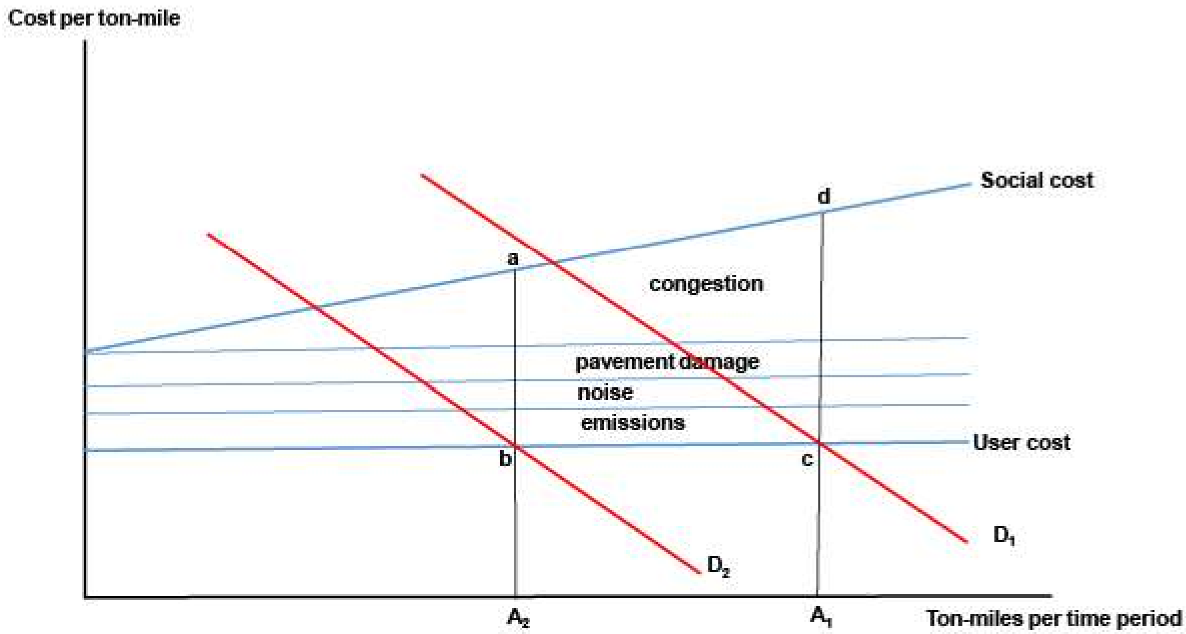

Figure 3. Reduction in Externalities from Transportation Activity when Travel is Diverted to a New or Improved Alternative

Of course, increased travel on the improved facility is likely to generate additional externalities of the same types that were reduced on alternative routes or services. Although these were not shown in Figure 2, the economic value of any increase in their magnitude that results from additional travel on the improved route represents a dis-benefit or additional cost of improving it, which *offsets* part of the gain in consumer surplus to users. This is another example of a wider economic impact from investing in improved infrastructure, and its negative economic value clearly illustrates why that terminology is more appropriate than the earlier term wider economic *benefits*.[27]

Thus, reductions in externalities caused by transportation activity – congestion, noise, or environmental spillovers – that result from investments in improved or expanded transportation infrastructure should be treated as additional benefits from those investments, beyond the direct benefits they provide to original and newly-attracted infrastructure users. Current benefit-cost practice almost universally measures and includes these benefits, although it sometimes fails to account for increases in those

[27] In the more likely case where the generalized cost curves for both the improved facility and competing alternatives slope upward, reflecting slowing in travel speeds or increases in operating costs with increasing travel volumes, Wider Economic Impacts are more complex to illustrate. However, the conclusion that they occur and the graphic illustration of their magnitude remain unchanged, so the simpler case is illustrated here.

same externalities that result from increased use of improved facilities. The value of reductions in externalities on facilities from which new users of expanded infrastructure are drawn is not captured in the gains in consumer surplus they experience, so measuring it separately entails no risk of double-counting investment benefits.

Similarly, any increase in the economic costs of externalities associated with increased transportation activity that occurs where infrastructure is improved should be treated as a cost over and above the initial capital outlays and higher operating or maintenance expenses those investments require. Again, there is little risk that doing so will double-count the costs of improving transportation infrastructure.

4.2 Are Changes in Transportation Externalities Likely to be Significant?

Congestion, noise, and environmental externalities – local air pollution and emissions that contribute to climate change – caused by the operation or use of many transportation modes can be significant. The nationwide average cost of congestion-related delays has been estimated at several cents per vehicle-mile (and to total billions of dollars annually), while incremental changes in traffic volumes on already-congested facilities can increase congestion costs by many times that figure.[28] While motor vehicles' emissions of ground-level air pollutants have declined significantly in recent decades as a result of strict controls on emissions from new vehicles, they still account for significant economic costs by contributing to the health damages suffered by those who are exposed to air pollution. Emissions of climate-altering greenhouse gases attributable to transportation activity are also important, and while estimates of the cost of future climate-related economic damages resulting from incremental emissions vary widely, the contribution of motor vehicle use to total climate-related damages is significant at any plausible unit (e.g., per ton) value.

Investments in improved transportation infrastructure that attract new users from congested alternative routes or travel modes can lead to significant reductions in the costs of delays to travelers and freight shipments, and the economic value of these reductions in delay represent additional benefits from such investments. Similarly, infrastructure projects that divert users from travel modes that emit air pollutants or greenhouse gases by improving service on lower-emitting modes can generate additional benefits beyond increases in consumer surplus to their users, in the form of

[28] For example, the National Highway Transportation Safety Administration and U.S. Environmental Protection Agency (2020, 1066-1067) recently estimated that each additional mile of travel by light-duty vehicles (including cars and light-duty trucks used as passenger vehicles) typically imposes costs of $0.14-0.15 in the form of congestion delays to occupants of other vehicles.

reductions in health and climate-related damages. Of course, any increases in congestion, air pollution, or climate externalities resulting from additional use of improved modes or facilities also need to be accounted for, since it is the *net* change in the cost of these externalities that represents a wider economic impact of such projects.

4.3 Measuring Changes in Externalities

Methods for measuring changes in congestion delays and their economic cost are well-established, and benefit-cost analyses of proposed transportation infrastructure projects frequently include these as supplemental benefits (or occasionally, dis-benefits). These include simplified queueing formulas, traffic simulation models, and network-wide traffic assignment models that incorporate empirical relationships between speed and traffic volume (or vehicle density) on individual links.

Values of travel time and estimates of vehicle occupancy, which are used to convert vehicle delays into economic costs of occupants' travel time, are well-established, and U.S. DOT guidance reports recent estimates of both (U.S. Department of Transportation, 2023). In contrast, estimates of damage costs imposed by vehicle noise are typically much smaller and display considerable variability, so these are much less frequently included in estimates of changes in externalities resulting from transportation infrastructure projects.

Similarly, the U.S. Environmental Protection Administration (EPA) maintains detailed models that estimate emissions of air pollutants and greenhouse gases by different types of highway vehicles, and publishes estimates of emissions for aircraft, locomotives, and other "non-road" vehicles. EPA regularly updates its estimates of the economic costs of health damages resulting from population exposure to air pollution, and these can be combined with estimates of vehicles' emissions to calculate changes in health damage costs that result from the effects of infrastructure investments on vehicle use, both for the improved facilities themselves and those from which they attract new users. As indicated previously, the economic costs of future climate-related damages caused by greenhouse gases – including those emitted by transportation vehicles – are challenging to estimate and the resulting values are controversial, but all plausible estimates imply significant damages from motor vehicle use, and reducing these emissions can also add significantly to benefits from investment in improved infrastructure.

5. Agglomeration Benefits from Investing in Transportation Infrastructure

The most widely discussed category of potential wider economic impacts from investments in new or expanded transportation infrastructure is increases in labor productivity that result from increased clustering of firms and employment. Such clustering can occur in traditional central business districts of large cities, satellite employment centers outside downtowns, and where firms in related industries cluster in lower-density suburban areas. Large concentrations of firms in related manufacturing industries can increase productivity by enabling larger-scale production and greater specialization of firms and their products, such as where automobile producers and components suppliers, or clothing designers, manufacturers, and fabric suppliers locate in close proximity.

In knowledge-intensive industries such as finance, media, or technology, interactions among employees of neighboring firms in densely developed centers are likely to generate "knowledge spillovers," particularly where firms in closely related sectors co-locate. The increased scale of production, more rapid diffusion of technological innovations, greater specialization of products and skills, and more intensive interaction among workers and firms that larger concentrations of economic activity permit can lead to higher productivity of workers, firms, and even entire industries.

Part of the value of increased productivity in dense employment clusters is likely to be captured by neighboring firms, rather than being limited to the firms whose specialized production expertise or employees' sharing of technical knowledge generates productivity gains, so increased agglomeration can create positive externalities. These "knowledge spillovers" are generally thought to arise from the close interactions among employees of neighboring firms that occur where firms – especially those in related industries – cluster tightly together. By enabling urban centers to accommodate larger concentrations of firms and workers without generating extreme congestion, investments in high-capacity transportation facilities or services can thus generate productivity benefits by promoting clustering of specialized firms and closer interactions among employees with advanced or specialized knowledge. Because these partly spill over to neighboring firms and are not fully captured by the firms who generate them, however, they are unlikely to be reflected in the usual measures of consumer surplus to users of improved transportation infrastructure – primarily workers commuting to the area – and thus create potential wider economic impacts.

5.1 The Basis for Agglomeration Benefits

Figure 4 helps to illustrate why some benefits from increased agglomerations of employment that investing in expanded transportation facilities enables may not be fully accounted for by increases in consumer surplus to users of those improved facilities. Its horizontal axis measures the quantity of labor a firm employs (measured in, say, labor-hours), while its vertical axis measures the hourly wage rate its workers earn. The firm's demand for labor, shown as the solid red line in the figure, reflects the value it receives from the increased output it can produce by employing additional workers (the "marginal value product of labor" in economic theory). The supply of labor is shown as the upward-sloping blue line, and the firm hires additional workers up to the point where the hourly wage it offers them – which reflects the value of the additional output they produce – is just sufficient to induce them to accept employment and commute to the firm's location.

In manufacturing, the increased scale or specialization that employing additional workers allows not only makes larger firms more productive, but also makes it more profitable for their suppliers or users of their products to locate nearby. In knowledge-intensive sectors, locating close to other firms that supply complementary products or services enables firms to take advantage of informally shared knowledge or technology, and thus become more productive than if they operated in geographic isolation. In either case, the value of hiring additional labor to an individual firm will reflect only its own increase in productivity and output, but will overlook the increase in productivity that expanding its scale and using more skilled or knowledgeable workers contributes to neighboring firms in its industry as they share knowledge or technology and become increasingly specialized.

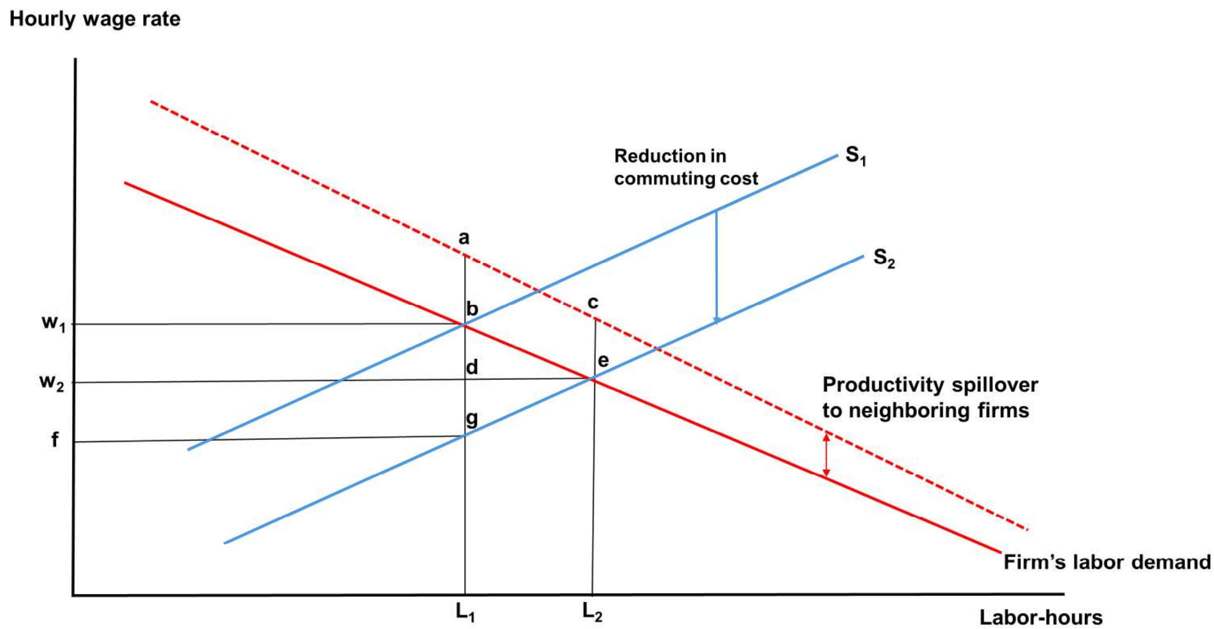

Figure 4. Benefits from Increased Agglomeration Measured in the Labor Market

The value of these productivity spillovers is shown in Figure 4 by the dashed line lying above the firm's labor demand curve. While the firm's labor demand curve (the solid line) reflects only the value *it* receives from employing more – or more skilled, or specialized – workers, the dashed line measures the additional value this provides to nearby firms by increasing their employees' productivity as well. Its distance above the firm's labor demand curve reflects the extent of the productivity spillover the firm provides to neighboring firms by hiring each additional employee, and that distance declines at higher employment levels to reflect the likelihood that the incremental productivity spillover from hiring successive additional employees declines gradually.

When improving transportation service to the site where they co-locate shortens commuting times from surrounding residential areas, the supply of labor at that location shifts outward, since more workers are willing to commute there to work for any given wage.[29] In response, the firm increases its employment from L_1 to L_2, and the wage it pays workers declines from w_1 to w_2 as the savings in commuting costs is shared between workers and their employers.

[29] This increase in labor supply occurs because the net wage they receive after accounting for commuting costs increases when commuting costs, including the value of travel time, decline.

As in Figure 1 above, the benefits to the firm resulting from improved transportation service to the area measured in the labor market consist of the entire area $w_1$begf in Figure 4, which is divided between benefits to the firm itself and those to workers. The firm saves $(w_1 – w_2)*L_1$ in wage payments to workers it previously employed, or area $w_1$bdw_2, and earns a net return equal to area bde on the additional $(L_2 – L_1)$ employees it hires.[30] Previously-employed workers each see their wage rate decline by $(w_1 – w_2)$ but save the larger amount $(w_1 – f)$ in commuting costs, so each one is better off by $(w_2 – f)$. In total, they lose the area $w_1$bdw_2 in wages but save the area $w_1$bgf in commuting costs, so on balance they benefit by the area $w_2$dgf. Newly hired workers benefit by the amount of area deg, which measures the difference between the wages they receive and the compensation they demand to sacrifice other valuable uses of their time (including working at other jobs).

Following the same logic that connected Figure 1 and Figure 2 above, the entire area $w_1$begf in Figure 4 will be captured by increased consumer surplus to users of the improved transportation facilities or service, as measured in the market for transportation services rather than in the labor market. Area $w_1$bgf corresponds to the increase in consumer surplus to commuters originally using the facility or service, who save travel time as well as monetary costs for commuting (and may endure less crowded travel conditions) after it is improved. Again as in Figure 1 above, the triangular area beg in Figure 4 equals the increase in consumer surplus to the $(L_2 – L_1)$ additional workers who commute to the site using the expanded transportation infrastructure or improved service the investment provides.

However, there is an additional benefit from improving the transportation service or infrastructure that is *not* reflected in increased consumer surplus to its users. This added benefit is the value of the added productivity spillovers from increased employment that is experienced indirectly by other firms located at the same site, shown as the area abec in Figure 4. Because it represents a productivity spillover that accrues to *other* nearby firms, however, this value is *not* reflected in the gains to firms who hire new workers, so they hire fewer additional workers than they would if they captured the value of the productivity spillover their own hiring creates. Consequently, it is not included in the gain in consumer surplus to new users of the improved transportation facilities or services that make the site more accessible. Instead, it represents a wider economic impact resulting from the investment in improved infrastructure, which stems from the larger agglomeration of firms and workers it enables at the location it serves.

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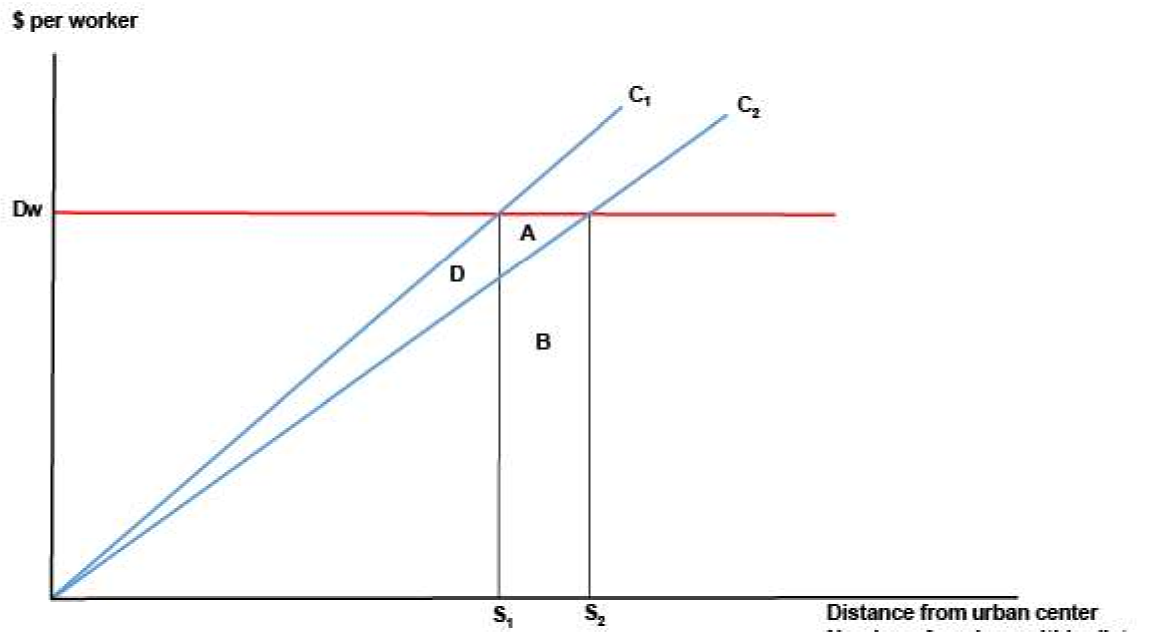
[30] Area abc is equal to the gross value to the firm of the additional output the newly hired workers produce, area acL2L1, minus the wages it pays them, area bcL2L1.

5.2 Venables' Model of City Size and Agglomeration Spillovers

Figures 5, 6, and 7 below represent a graphic version of Venables' (2007) original model of wider economic impacts resulting from agglomeration, which is often cited as a foundation of efforts to understand and measure such impacts. Their horizontal axes measure urban area size in terms of distance from the city center, where employment is assumed to be concentrated; because the total area within the urban perimeter increases with its radius, the total number of workers living there also increases along the horizontal axis of each figure. The vertical axis in each figure measures wages and commuting costs per time period (day, week, etc.), in dollars per worker.

In Venables' model, workers are assumed to be more productive in the central area because the high density of employment there creates productivity spillovers among firms, so they are offered higher wages to commute to the central area rather than work at outlying locations. Individual workers choose whether to commute to the city center or instead take jobs nearer where they live by comparing the higher wage they could receive by working in the center to their additional costs – including the value they attach to travel time – for commuting there.

Figure 5 shows the simplest version of the model, where the gap between center-city and suburban wages is assumed to be the same regardless of city size, shown as the horizontal line Δw. Commuting costs from suburban locations to central city jobs increase linearly with city size, as shown by the upward-sloping line C_1. Equilibrium in the urban labor market occurs at a city size that equates the wage premium for working in the center to the added cost of commuting there, shown as S_1 in Figure 5. At that size and level of employment, the value of the city's total economic output is the area under Δw up to the city's size S_1, and workers' total commuting costs are the area under C_1 up to S_1.



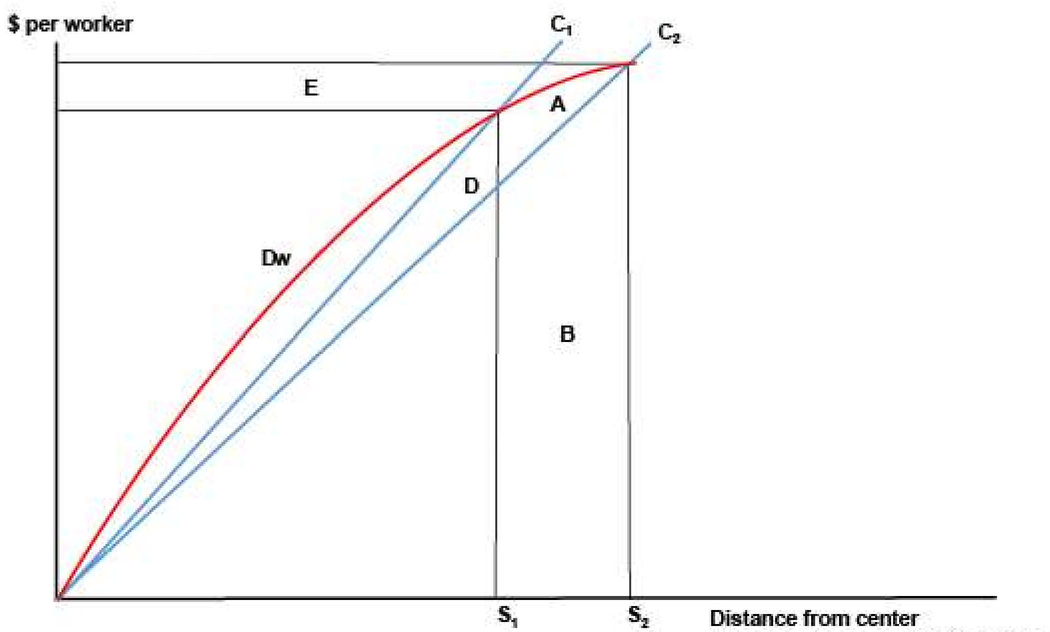
Source: Venables (2007), Figure 1b.

Figure 5. Benefits from Improving Transportation Infrastructure without Agglomeration Effects

If an improvement in transportation service reduces the cost of commuting to the center, say by increasing travel speeds and thus reducing the time it requires, the line C_1 rotates clockwise to C_2 in Figure 5, and the geographic size of the labor market expands to reflect the longer maximum commuting distance S_2. As a consequence, the value of total output produced by firms in the urban area expands by the area (A + B). Previously-employed workers – those located within distance S_1 of the central area – save the area D in commuting costs, but workers in the newly-annexed suburban ring between S_1 and S_2 now incur commuting costs equal to area B. Benefits from the investment in improved transportation are equal to the increase in the value of area-wide economic output, area (A + B), minus the net increase in commuting costs, which is equal to area (B – D). Thus, net benefits from the improvement are equal to (A + B) – (B – D), or the area (A + D).

Of this, area D represents the savings in commuting costs to previously employed workers, while area A corresponds to the net benefit experienced by workers in the newly added suburban ring. Area A is equal to the increased wages those new workers receive for now commuting to the city center (instead of working locally), which reflect the value of the additional output they contribute, minus their commuting costs. Thus, the benefits from the investment consist of exactly the same two components of increased consumer surplus to commuters shown originally in Figure 2, and they are captured in their entirety by the increase in consumer surplus experienced by users of the improved infrastructure.

Figure 6 illustrates the more complex – but also more realistic – version of Venables' (2007) model, in which workers are not only more productive in the central area than at suburban locations, but the productivity differential between suburban and central city workers also grows with city size rather than being fixed. This is assumed to occur because the extent of productivity spillovers among workers and their firms increases as the urban area expands, its total employment increases, and an increasing share of jobs is concentrated at the employment center. Thus, the wage gap between centrally located and suburban jobs is no longer constant, but instead grows with city size, following the curve labeled ∆w in Figure 6. That curve is convex because the rate at which the productivity differential between centrally-located and suburban firms grows – and thus the wage gap between central and suburban jobs expands – slows as city size continues to grow. As before, commuting costs from the edge of the urban area to the center increase linearly with city size along the straight line C_1.



Source, Venables (2007), Figure 1c.

Figure 6. Benefits with Agglomeration Effects

Investments that improve transportation infrastructure or service and make the city center more easily accessible again reduce commuting costs and rotate the line showing commuting costs from C_1 to C_2, which produces the same benefits to workers as in Figure 5, namely (A + B) – (B – D) = (A + D). Because Δw is no longer fixed but instead rises as the city and its labor market grow, however, both the distance by which the urban area expands ($S_2 - S_1$) and the increase in the number of workers it encompasses are slightly larger than was the case in Figure 5. Areas A and D again correspond to the two components of increased consumer surplus to transportation users, so they comprise the usual consumer surplus measure of benefits to infrastructure users normally employed in economic evaluation.

In Figure 6, however, the investment generates an additional benefit equal to area E, which measures the economic value of the higher productivity of central-city workers (reflected in the higher wages they receive) resulting from the increase in overall city size and the larger concentration of employment at its center. Again, this increase in workers' productivity is a spillover or externality resulting from the growing concentration of firms and employment at the city center, and the closer and more frequent interactions among workers, sharing of technology and knowledge, and specialization of products and services it enables.

This additional benefit initially accrues to firms located there in the form of increases in their productivity and the value of the higher output they produce, but in a competitive labor market will ultimately be shared (or even captured completely) with their workers in the form of higher wages. Whatever the case, the important point is that if there are productivity spillovers that depend on the scale of employment agglomeration, an investment in new or expanded infrastructure or improved transportation service can generate a wider economic impact that will *not* be measured by the increase in consumer surplus to its users and needs to be accounted for separately.

5.3 Taxes and Increased Earnings from Agglomeration

Finally, one additional wider economic impact can arise from agglomeration in the presence of income or payroll taxes. As previously, the gap between wages that workers earn in the central area and at suburban employment sites increases with city size, because as the city grows more workers and firms cluster together in its central area, workers' productivity and wages increase, and the extent of productivity spillovers among neighboring firms grows. However, workers select their residential locations and choose where to work – and thus how far to commute to reach their jobs – by comparing the increase in their *take-home or after-tax* earnings to the higher costs they would incur by commuting to the urban center.

This means that the full or gross value of the higher productivity they generate by commuting to centrally located jobs exceeds their commuting costs for two reasons: as above, some of it spills over and is captured by firms other than their employers; and second, some of it flows to government agencies in the form of higher tax payments on their increased earnings. Neither of these "wedges" between workers' enhanced productivity and the increase in their take-home earnings will be reflected in their willingness to commute from more distant locations, so neither will be reflected in the increased consumer surplus they experience because of an investment in transportation infrastructure that reduces commuting costs and spurs additional commuting travel.

Figure 7 illustrates this situation, again drawing on Venables' original model. As in Figure 6, the urban boundary is established where higher costs for commuting to centrally located jobs from more distant residential locations offsets the wage premium paid to central-city workers to compensate for their higher productivity. However, the presence of income taxation means that workers will compare increased commuting costs to higher *after-tax* earnings in deciding whether to commute to job locations where they are more productive – the city center in this simple model.

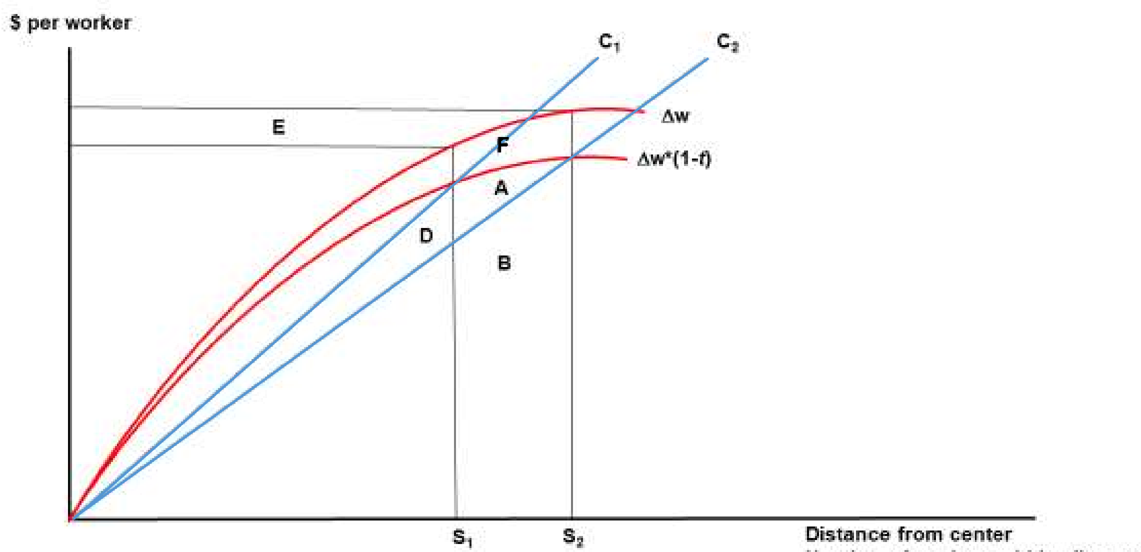
For workers who choose to commute there, the economic value of their increased productivity to their employers (and to the economy as a whole) will exceed the increase in their take-home earnings by the amount they pay in additional taxes.[31] In Figure 7, the before- and after-tax wage premiums from working in the center are shown by the curves Δw and $\Delta w^*(1-t)$, where t is the marginal tax rate on their higher earnings. The pre-investment urban boundary S_1 will be established where original commuting costs C_1 equal the take-home wage premium earned by central-area workers, $\Delta w^*(1-t)$.

Again as in Figure 6, an investment in transportation infrastructure that improves commuting speeds (or otherwise reduces commuting costs) rotates the commuting cost schedule clockwise from C_1 to C_2, because it reduces commuting costs at any distance from the center. Consequently, the urban boundary – where the higher costs of commuting to a centrally-located job exactly offset the higher *take-home* earnings it offers – moves outward to S_2, where C_2 intersects the curve $\Delta w^*(1-t)$. Productivity spillovers among centrally located firms still occur, so benefits from the investment once again include area E as well as areas A and D. But as Figure 7 illustrates, part of the value of workers' higher productivity to their own employers – area F in the figure – now accrues to government agencies in the form of higher tax revenues, rather than to

[31] Income taxation generally does not affect personal travel choices for purposes other than commuting, since those involve tradeoffs between travel time valued on the basis of after-tax earnings and consumption decisions, which are also based on after-tax earnings. Nor does it influence employers' and workers' decisions about on-the-clock business travel, since those entail tradeoffs between working time and the benefits of business interactions that require travel time, both of which firms value in pre-income tax terms.

workers themselves in the form of higher take-home earnings.

Comparing Figure 6 to Figure 7 shows two differences: first, adding income taxation results in a larger expansion of the urban labor market (reflected in the distance $S_2 - S_1$), the number of workers it includes, and the gain in productivity from increased agglomeration of employment in the central city, all as compared to the no-tax situation shown in Figure 6. Thus, the wider economic impact represented by productivity spillovers among firms – area E in Figure 6 and Figure 7 – increases in the presence of income taxation, growing as the marginal tax rate on wage earnings rises. Second, income taxation partitions the gain in workers' earnings resulting from their higher productivity at central city locations between workers and tax-collecting government agencies. Although the entire gain in productivity remains a wider economic impact, some fraction of it is revealed in the form of increased tax revenue rather than by gains in workers' take-home earnings, and this fraction is shown as area F in Figure 7.



Source, Venables (2007), Figure 1d.

Figure 7. Benefits with Agglomeration Effects and Taxes

Like area E in both Figure 6 and Figure 7, area F in Figure 7 represents a wider economic impact resulting from an investment in transportation infrastructure that reduces commuting costs and expands the labor market, because its value will not be reflected in the increased consumer surplus experienced by commuters using the improved infrastructure. Of course, if some of the new workers attracted to the city by improved transportation and lower commuting costs have relocated there from other urban areas rather than being absorbed from previously rural locations as the city expands, the reverse of the process shown in Figures 6 and 7 may produce partly offsetting losses in productivity due to shrinkage in the agglomerations of employment in those other cities. The challenge this introduces is that analysts ideally need to know the "curvature" of Δw – that is, how its slope changes with increasing distance from the city center (or another concentration of employment) – to produce complete estimates of wider economic impacts over a n entire region.[32]

5.4 Static vs. Dynamic Agglomeration Effects

Investments in transportation infrastructure can create two types of agglomeration effects. First, even if the geographic distributions of population and employment remain fixed and do not respond to the reduction in generalized transportation costs that an investment causes, the lower cost of travel will make interactions among workers, firms, and consumers easier, exactly as if they had become more concentrated in space. This result is usually termed an increase in the "effective density" of workers and firms, since its consequences are much like those of moving them physically closer together and increasing their actual density. The frequency or intensity of those interactions will presumably increase as they become easier – that is, less costly or time-consuming to initiate – thus improving the likelihood that beneficial spillovers will result.

The specific microeconomic mechanisms that produce agglomeration externalities include sharing of critical knowledge or other "human capital" inputs (entrepreneurship, for example) among employees and firms, increased specialization of workers' skills, products, or production processes, and closer matching of the specialized skills workers offer with the capabilities that specific jobs require.[33] These mechanisms are likely to be triggered to some extent even if households and firms do not relocate in response to the reduction in transportation costs and travel times that improving infrastructure generates, because interactions among firms, their employees, and customers will presumably occur more frequently when transportation costs are reduced.

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[32] Mathematically, this requires evaluating both the first and second derivatives of the Δw function.

[33] Duranton and Puga (2004) for a detailed analyses of the mechanisms that generate such spillovers. More recently, Eliasson and Fosgerau (2019) argue that agglomeration benefits arising from knowledge sharing are unlikely to affect workers' choices of employment locations, but economic gains resulting from improved matching of workers' skills and the skill demands of specific jobs *will* affect their commuting decisions. This is because when travel times are reduced, some workers will commute to more distant locations to obtain the higher wage that a job whose demands more closely match their skills is likely to offer. The benefits they receive from the additional commuting travel will be reflected in the increased consumer surplus they receive, and thus will not represent a wider economic impact. In contrast, any increase in productivity that results from increased sharing of specialized knowledge among workers does represent a wider economic impact of investments that enable it.

Since this process can occur even where households and firms do not move to become more concentrated in space and their physical density remains unchanged, its results are usually referred to as 'static' agglomeration effects. The productivity increases that can arise from these static agglomeration effects represent a potential wider economic impact from investing in transportation infrastructure, and to date have been the focus of researchers' efforts to measure and include their value as a supplemental source of benefits in economic evaluation of proposed infrastructure projects.

At the same time, the improved access to specific locations that lower transportation costs and faster travel speeds create makes them more attractive places to live and work, so infrastructure investments can prompt some households and firms to relocate to places where access has been improved. Where this occurs, it increases the actual physical density – not just the "virtual" or effective density – of firms, jobs, and workers. This sets the mechanisms that create agglomerations and generate productivity spillovers in motion, creating what are usually referred to as "dynamic" agglomeration effects.

Because they arise where firms, their employees, and consumers relocate from one place to another, dynamic agglomeration effects can be both positive and negative, depending on the specific locations where they are examined. As indicated above, if productivity gains occur within one urban labor market because workers relocate there from others, offsetting losses in productivity can occur as concentrations of employment shrink in the latter. The exact shape of the relationship between employment density and productivity affects their relative magnitude and the net change in productivity within the entire region.

Sophisticated models of households' and firms' location choices and their consequences for the geographic distributions of employment in specific industries are thus required to project the pattern and scale of dynamic agglomeration effects likely to result from proposed investments in new or expanded infrastructure. Mainly for this reason, they have not yet been extensively analyzed and are difficult to measure reliably, so to date they have rarely been estimated or included among potential wider economic impacts as part of benefit-cost evaluations of proposed infrastructure investments.

5.5 Measuring Agglomeration Benefits

5.5.1 Productivity Gains

The economic value of productivity gains generated by increased agglomeration that is enabled by investments in transportation infrastructure is surprisingly straightforward to estimate, at least in concept. Their magnitude depends on four main factors:

- The initial density and geographic distribution of employment in an area, usually represented by the number of jobs in each of a set of small geographic zones.
- Changes in travel costs (including both travel time and money outlays) between each pair of zones resulting from an expansion or improvement to transportation infrastructure serving the area.
- The response of productivity to changes in employment density.
- The baseline level of economic output likely to be affected by increased productivity.

Graham and Gibbons (2019) describe a detailed process (originally outlined by Graham (2007)) for estimating agglomeration effects that result from infrastructure investments and imputing their economic value. This process measures the effective density of employment within a geographic region using a gravity-type index of the initial distribution of jobs among sub-zones of the region, with the interaction between employment in each pair of zones weighted inversely by the "impedance" to traveling between them.

Improvements to local transportation infrastructure initially change the value of effective employment density in each zone by increasing travel speeds and lowering the impedance of traveling to adjacent (and possibly more distant) zones, producing static agglomeration benefits.[34] In the longer term, they can change the actual density of employment by triggering relocation and expansion of firms, thus altering the geographic distribution of employment in specific industries and producing dynamic agglomeration benefits.

The U.K. Department for Transport's guidance for incorporating wider economic impacts in economic evaluation (2020) outlines a sequence of steps for quantifying the effects of proposed investments in transportation infrastructure on employment agglomeration and productivity, identifies specific data sources required to measure them, and describes the required calculations. Briefly, these steps are:

1. Calculate the average user cost for all travel modes (public and private) and journey purposes (excluding leisure trips) between each pair of geographic zones

[34] Abelson (2019) seems extremely skeptical about the legitimacy of static agglomeration benefits, arguing that the number of new business trips using improved or expanded infrastructure is typically small and they are likely to be of marginal importance in expanding interactions among workers.

comprising the area served by a proposed infrastructure expansion, weighted by the number of trips for each purpose using each travel mode.

2. Calculate the "effective density" of industry-specific employment within each zone by dividing employment in the same industry in each other zone by the distance, time, or generalized cost of traveling there (from step 1) raised to a specified power, summing the results, and dividing by the number of zones. (Employment within the zone being considered is weighted by the inverse of distance or generalized cost of trips within it, raised to the same power.) The recommended measure is:

$$\mathbf{D_{ik} = [\Sigma_{=1,\ldots,n} (E_{jk} / C_{ij}^{\alpha})]/n}$$

where $\mathbf{D_i}$ is the effective density of employment in industry **k** within geographic zone **i**,

n is the number of geographic zones into which the area is divided,

$\mathbf{E_{jk}}$ is employment in industry **k** in zone **j**,

$\mathbf{C_{ij}}$ is some measure of the "impedance" of traveling between zones **i** and **j**, such as the distance, travel time, or transportation cost (usually a share-weighted average of their values for alternative travel modes), and

α is a "decay parameter" that translates this impedance into a measure of the strength of interaction between zones.

3. Calculate the change in effective density of employment in each industry and zone resulting from the changes in inter- and intra-zonal travel times (changes in the values of $\mathbf{C_{ij}}$ in the formula above) for different travel modes and purposes anticipated to result from a proposed investment.

4. Estimate the proportional increase in economic productivity in each industry and zone from the proportional increase in its effective employment density and an empirical estimate of the elasticity of productivity with respect to effective density in each industry. The proportional increase in economic productivity is:

$$\mathbf{\Delta P_{ik}/P_{ik} = \Delta D_{ik}/D_{ik} * \varepsilon_k}$$

where $\mathbf{P_{ik}}$ is the value of output per worker in industry **k** in zone **i**, and

$\boldsymbol{\varepsilon_k}$ is the elasticity of productivity in industry **k** with respect to the effective density of employment.

5. Scale the increase in productivity in each industry and zone to produce a dollar-denominated estimate of increased economic output. The increase in output is:

$$\Delta Y_{ik} = \Delta P_{ik} * E_{ik} = \Delta D_{ik}/D_{ik} * \varepsilon_k * P_{ik} * E_{ik}$$

where ΔY_{ik} is the increase in economic output of industry **k** in zone **i**, and E_{ik} is the number of employees in industry **k** within zone **i.**

6. Sum these increases in economic output over all industries and zones in the urban area to estimate the aggregate, area-wide increase in economic output resulting from agglomeration-induced productivity increases.

The U.K. Guidance suggests repeating these calculations for each industry for which employment data and separate estimates of productivity elasticities are available, as well as for various future time periods. This process estimates only the static agglomeration benefits associated with a proposed infrastructure project, and the guidance cautions that detailed models capable of simulating the interactions among transportation costs, firms' location choices, and the geographic distribution of employment are necessary to estimate a project's potential dynamic agglomeration benefits. Future changes in industry- and zone-specific employment generated using this process would appear as changes in the values of E_{jk} in step 2 above, and would produce changes in effective density in addition to those resulting from changes in travel times or costs (the values of C_{ij} in step 2).

The main challenge in measuring agglomeration benefits of proposed infrastructure projects is assembling the data necessary to implement the required calculations. As outlined above, these include detailed data on the geographic location of employment within the affected area, including the distribution of jobs by industry if industry-specific estimates of agglomeration effects are to be calculated. These data are normally compiled for a set of small geographic zones that together cover the entire area likely to be affected by a proposed investment, typically using GIS methods.

Estimates of zone-to-travel times or generalized transportation costs are also necessary, both before and after the proposed infrastructure investment is completed. These are usually obtained from a detailed model of the transportation network interconnecting the zones, with travel times or costs on one or more links in the network reduced as a consequence of the investment. Transportation planning agencies in urban areas typically maintain detailed network models that can be used to estimate inter-zonal travel times before and after improvements are made to one or more links in the network, allowing for initial changes in trip routings and traffic flows in response to reduced travel times and convergence to new network-wide equilibrium speeds and travel flows.

Several details are important to consider when calculating agglomeration benefits. These include the size and number of geographic zones to use, whether to measure effective density using employment, population, or some other measure of a zone's "economic mass," and the form of the transportation cost function to employ. Other important considerations include whether changes in transportation costs should be evaluated separately for different modes or as some multi-modal composite, the form of the "decay function" that translates generalized transportation costs into a measure of impedance or resistance to interactions between zones (the denominator of the calculation described in Step 2 above), and the values of its parameters. Graham and Gibbons (2019, pp. 6-10) provide a concise and useful discussion of these details and illustrate how alternative choices about how to treat them can affect empirical estimates of agglomeration benefits.

If investing in new or improved transportation infrastructure causes employment to relocate from some areas to others, there may also be reductions in agglomeration spillovers and resulting *declines* in productivity at locations that lose employment. In theory, the resulting losses in earnings represent negative economic impacts that should be regarded as wider economic costs of proposed investments. These should be calculated using exactly the reverse method from estimating agglomeration benefits, and their dollar value included as an economic cost (or "dis-benefit") resulting from such an investment.

This means that it may also be important to know whether the elasticity of productivity with respect to employment density is constant – which seems unlikely given the nature of agglomeration spillovers – or varies with employment density itself. Unfortunately, few estimates of its magnitude seem to consider potential variation with employment density, so this appears to be an area where more needs to be known to enable complete and credible estimates of agglomeration impacts.

5.5.2 Increases in Tax Revenue

The remaining component of wider economic impacts from increased agglomeration, the increase in tax revenues collected by governments that levy income or payroll taxes, should in principle be easier to estimate by relying on accounting records. However, if tax revenue estimates are not publicly available and marginal tax rates are graduated with income, estimating it may require knowledge of the baseline or pre-investment distribution of wages, as well as that of increased earnings due to larger agglomerations of employment.

Because multiple levels of government often levy income or payroll taxes, measuring this component also requires accounting for these multiple sources of taxation and how they interact. It may also require accounting for losses in tax revenue in jurisdictions where infrastructure investments lead to reduced agglomerations of employment and productivity declines as a consequence.

5.6 How Large are Agglomeration Effects on Productivity?

A key determinant of the magnitude of agglomeration benefits is the response of productivity to increased employment density, usually summarized by the elasticity of productivity with respect to the effective density of employment (the parameter ε_k in Step 4 above). A substantial body of research conducted over the past several decades finds that larger concentrations of economic activity do lead to higher productivity, but analysts arrive at this conclusion using differing approaches and empirical estimates of this relationship vary. Early research examined the relationship between city size, usually measured by population or employment, and productivity measured at the scale of entire urban areas or regions, either by total factor productivity or wage rates.[35] More recent analyses usually relate productivity measures for individual firms, plant locations, or even workers to the density of employment in the immediate areas where they are located.

Most estimates of the elasticity of productivity with respect to employment density are small (below 0.1 in magnitude), with higher values for business services such as law and financial services and for advanced-technology sectors such as electronic communications and information systems. Graham and Gibbons (2019, Table 1) present an extensive survey of research over the past several decades, which shows a mean elasticity of productivity with respect to employment density of 0.046. This value suggests that doubling the number of jobs located in a fixed geographic area would increase workers' and firms' productivity by less than 5%. Almost 90% of the estimates included in Graham and Gibbons' survey fall in the range from zero to 0.1, so there appears to be a surprising degree of consensus about its magnitude.

5.7 U.S. Estimates of Agglomeration Effects

Of the 47 empirical studies of agglomeration effects included in Graham and Gibbons' survey, 9 apply to the U.S. These include 152 of the 1,043 different estimates of the elasticity of productivity with respect to employment density reported in the 47 studies, although 78 of those 152 come from only 2 of the 9 U.S. studies, and those studies are among the most dated. Table 2 summarizes the findings from U.S. studies; as it shows,

[35] In the usual marginal productivity theory of wage determination, more productive workers earn higher wages.

their estimates of the elasticity of productivity with respect to employment density range from small negative values to as high as 0.319, averaging 0.038. The average estimate implies that doubling population or employment density in an urban area would increase the productivity of firms and workers there by almost 4%. Typical increases in density resulting from even the largest investments in transportation infrastructure seem likely to be a few percent at most, meaning that the resulting productivity increase would be measured in hundredths of a percent. However, this would apply to a very large initial dollar value of output, so it could still imply large benefits from increased agglomeration.

Table 2. Estimates of Agglomeration Effects for the U.S.

Author(s)	Date	Period Covered	Units of Analysis	Agglomeration Measure	Estimated Elasticity		
					No.	Range	Mean
Ciccone and Hall	1996	1988	Regions	Total employment	8	0.03 to 0.084	0.053
Henderson	2003	1982	Firms	Employment density	4	-0.127 to 0.189	0.024
Moomaw	1981	1967	Regions	Total population	18	0.006 to 0.319	0.060
	1983	1977	Regions	Total population	26	-0.052 to 0.182	0.038
	1985	1972	Regions	Population density	36	-0.104 to 0.270	0.040
Rosenthal and Strange	2008	2000	Workers	Total employment	9	0.025 to 0.058	0.042
Sveikauskas	1975	1967	Regions	Total population	42	0.012 to 0.124	0.057
Sveikauskas *et al.*	1988	1977	Regions	Total population	6	0.007 to 0.017	0.013
Wheeler	2001	1980	Workers	Total employment	3	0.000 to 0.030	0.017
All	--	1967-2000	Various	Various	152	-0.127 to 0.319	0.038

Source: Graham and Gibbons (2019), Table 1, p. 2.

5.8 What Investments Are Likely to Generate Agglomeration Benefits?

It seems likely that agglomeration benefits will be limited to infrastructure investments that increase travel speeds or reduce transportation costs significantly, since those will be required to produce measurable increases in effective employment density over a widespread geographic area. This is because most investments are likely to produce important changes in travel times or costs – and thus in effective employment density – over only a limited area, so the resulting increases in productivity seem likely to be modest in both geographic scope and magnitude. However, the implied changes in productivity in some zones may be applied to large initial values of output, which would magnify the resulting benefits.

Thus, it appears that significant wider economic impacts from agglomeration are most likely to arise from infrastructure investments that generate major increases in travel speeds (or savings in transportation costs) across many commuting routes, whose destinations already feature large concentrations of employment and high economic output. Such investments will tend to produce larger changes in effective density and thus larger productivity increases, and the latter will be applied to higher baseline values of economic output, so the resulting estimates of agglomeration benefits will be larger for all these reasons. In contrast, improvements to a transportation network that are isolated, localized, or modest in scale are likely to produce small changes in productivity over a limited area, and thus to produce similarly modest agglomeration benefits. These situations also raise the question of whether the underlying data used to estimate agglomeration benefits are sufficiently precise and reliable to support credible estimates of benefits at locations where they are likely to be limited.

5.9 Empirical Estimates of Agglomeration Benefits

To date, empirical estimates of wider economic benefits from increased agglomeration have been reported for only a handful of proposed infrastructure investments. In his early study of how agglomeration effects arise, Venables (2007) used a spatial computable general equilibrium (SCGE) model of a stylized urban area to simulate the effects of an infrastructure investment that reduces commuting times on employment, productivity, wages, and land rents across the region. Benefits from savings in commuting costs and gains in central-area employment were captured by the usual consumer surplus gains measured in the transportation market, but the larger agglomeration of workers there raises productivity, and the resulting gains in output and income represented additional benefits that BCA would normally overlook.

Venables showed that with plausible (but only illustrative) productivity elasticities, these wider economic benefits could exceed the investment's conventionally measured transportation benefits. Graham (2007) reported that the U.K. Department for Transport (DfT) combined his earlier empirical estimates of productivity elasticities in conjunction with Venables' model to calculate that productivity gains from increased employment in central London enabled by a proposed major addition to rail service would add 24% to the project's estimated time-saving benefits for users.

Feldman *et al.* (2007) used the procedure outlined in the original DfT Guidance on estimating Wider Economic Impacts (DFT 2005) in conjunction with Graham's estimates of productivity elasticities to calculate agglomeration benefits for a sample of proposed transportation improvements across the U.K., including investments in both expanded highway and transit infrastructure. The impedance measures these authors used to calculate changes in effective density was generalized travel cost (including monetary outlays plus the value of travel time), and the value of the distance decay parameter – the parameter α in the formula given in Step 2 above – was assumed to be 1.0.

The analysis utilized a land use-transportation interaction (LUTI) model to estimate changes in employment within individual geographic zones, and the calculated changes in effective density reflected the redistribution of jobs projected to occur in response to the proposed infrastructure improvements, so the estimated impacts represent dynamic agglomeration benefits. As Table 3 indicates, the authors' estimates of benefits from increased employment agglomeration ranged from 11% to 31% of conventional user benefits (mainly travel time savings) for the five infrastructure projects studied.

Table 3. Estimates of Agglomeration Benefits for U.K. Infrastructure Projects

Project Description (1)	User Benefits (million pounds, 2002)	Agglomeration WEI (million pounds, 2002)	% of User Benefits
Leeds to Sheffield Highway Improvements	1,213	287	24%
Leeds Urban Area Highway Improvements	3,319	1,030	31%
Leeds to Bradford Improved Highway Connections	1,243	369	30%
Leeds Urban Area Major Public Transport Investment	8,396	884	11%
Leeds to Bradford Public Transport Improvements	577	104	18%

(1) See Feldman *et al.* (2007), p. 12 for project descriptions. Infrastructure component of transit improvements appears to be minor.

Source : Feldman *et al.* (2007), Table 2.

Hensher *et al.* (2012) used detailed information on geographic variation in wages among occupations and industries within the Sydney (Australia) metropolitan area to estimate elasticities of labor productivity with respect to employment density for 17 industry groups. The authors combined these estimates with a model that simulated the response of residential and employment locations to changes in travel times over the area's transportation network to estimate dynamic agglomeration benefits from a proposed new commuter rail line connecting downtown Sydney with its northwestern suburbs. Despite the inclusiveness of their measure, these authors estimated that the project's agglomeration benefits were likely to represent only about 2.5% of its conventional transportation benefits.

Legaspi *et al.* (2015) later used the process recommended by U.K. Guidance to estimate agglomeration-related benefits – among other categories of benefits they included as wider economic impacts – for the same Sydney-area commuter rail project. Like the previous analysis of this same project by Hensher *et al.*, this more recent study focused on dynamic agglomeration increases projected to result from changes in employment locations prompted by the proposed new rail line. Using the estimates of labor productivity gains from increased agglomeration for Sydney-area industries reported in Hensher *et al.* (2012), Legaspi *et al.* (2015) estimated that labor productivity gains from increased employment agglomeration enabled by the project would amount to 5% of the project's anticipated travel time savings and other conventional benefits, double the fraction estimated in the earlier study.

The Swedish Transport Administration (STA) analyzed agglomeration-related benefits that could result from implementing its ten-year, EUR 62 billion plan for nationwide improvements in transportation infrastructure between 2018 and 2029 (Isacsson, 2018). STA's analysis generally followed the steps outlined above, using a single estimate of the elasticity of productivity – which was measured by wage earnings – with respect to accessibility to estimate localized increases in wages throughout Sweden, and aggregating these to a national total. Not surprisingly, improvements in accessibility and resulting wage gains were estimated to be largest outside the nation's three major cities. Because the analysis assumed fixed employment locations and did not consider potential relocation of firms, the resulting increases in productivity and wages capture purely static agglomeration effects. STA estimated that wage gains would increase direct benefits to users of improved infrastructure by 5-14%, depending on whether they were consequences of productivity spillovers alone or also included the effects of improved matching of workers' skills to specialized jobs.[36]

Most recently, the Norwegian Public Roads Administration (2020) analyzed potential agglomeration benefits as part of its benefit-cost evaluation of six proposed road improvement projects. Some of these projects would replace current ferry service with highways on bridges or in tunnels, resulting in significant savings in travel time and increases in the calculated effective density of employment in outlying regions of the nation. Two different methods were used to estimate benefits, one of which followed closely the procedure recommended by the U.K. guidance and described above, including using its recommended values for productivity elasticities and the distance decay parameter to calculate changes in effective employment density. The resulting estimates of Wider Economic Impacts for these six projects ranged from 2% to 23% of their projected time savings and other direct benefits to road users, but proved to be quite sensitive to the size of the geographic zones used in the analysis.

6. Wider Economic Impacts Where Competition is Limited

Another situation where investing in transportation infrastructure can generate wider economic impacts arises where competition in markets for products that rely on transportation for their production and distribution is limited. When suppliers face limited competition and have market power over the prices they can charge customers, their most profitable strategy will be to restrict output compared to the levels they would supply to a competitive market, and to raise prices above competitive levels. Under these circumstances, some benefits from investments in transportation infrastructure that reduce costs for shipping raw materials and finished products can be "hidden" by suppliers' market power and will not be captured by the usual measure of benefits from those investments relied on for benefit-cost analysis, as they would be with competitive markets.

Where product markets are not fully competitive, infrastructure improvements will still generate benefits to producers in the form of transportation cost savings and increased profits, and these will be reflected in corresponding welfare gains measured in the transportation market. However, producers' savings in transportation costs may not be

[36] This range reflects Eliasson and Fosgerau's (2019) caution that only wage gains resulting from agglomeration and productivity spillovers represent wider economic benefits, while with fixed employment locations, improved matching of workers' skills and the demands of specialized jobs are likely to be reflected in increased commuting distances and thus registered as gains in consumer surplus to users of improved infrastructure (see footnote 32 above).

fully reflected in lower delivered prices for their products when they face limited competition, and if so, welfare gains to consumers will be smaller than where markets are fully competitive.

More important, the gain to consumers from increased product supply and consumption is unlikely to be captured in the benefits from increased activity in the transportation market, so it must be estimated separately to ensure accurate benefit-cost evaluation of proposed investments. Improvements to transportation infrastructure can generate such wider impacts through the usual mechanism of reducing transportation costs and delivered prices for products, even *without* necessarily increasing the extent of competition, as well as by facilitating access to previously isolated markets by new suppliers and increasing competition there.

6.1 Benefits from Lower Transportation Costs with Limited Competition

Figure 8 below depicts the market for a product that requires transportation to assemble the materials used to produce it or to deliver the product to customers; as usual, its horizontal axis measures the quantity produced, delivered, and sold during some time period, while its vertical axis measures the production cost, transportation cost, and delivered price of each unit sold. Suppliers face increasing marginal costs for producing their product, as shown by the blue line in the figure labeled Marginal Production Cost, and constant costs for assembling the materials they use to manufacture each unit of their product and deliver it to customers. This combination of production and distribution costs initially results in the supply curve labeled S_1 in the figure.

When only a single firm supplies a product and has a monopoly in the market, it can sell more only by lowering the price it charges, so it faces a downward-sloping demand curve like that shown in Figure 8. Because it must reduce its price to sell additional output, the additional revenue it receives for selling each additional unit is less than the price it can charge by the amount it loses from also having to charge the new lower price on its previous sales. Thus, the incremental revenue it receives from producing and selling each additional unit lies below the demand curve – which shows how the maximum price it can charge declines as it continues to increase production – and also slopes downward, as shown by the line labeled Marginal Revenue in the figure.

A supplier with the power to set prices will produce and sell more – even though this requires lowering the price it charges – as long as the increased revenue it earns by doing so exceeds its costs for producing and delivering more. At the initial level of transportation costs, the producer elects to supply Q_1 per time period, for which it incurs per-unit production and transportation costs totaling C_1, and charges the maximum that customers are willing to pay to purchase Q_1, which is the price P_1. At this combination of price and sales, the supplier collects total revenue equal to (P_1 x Q_1), or the rectangular area OP_1aQ_1 in Figure 8, and incurs the area $OedQ_1$ in production and transportation costs (remember that the blue lines show the *incremental or marginal* costs of production and shipping). Thus, it initially earns the area eP_1ad in profits (the difference between its revenue and costs), the maximum it is able to earn given its production cost structure, the transportation costs it faces for assembling materials and shipping its finished products, and the elasticity of market demand for its output.

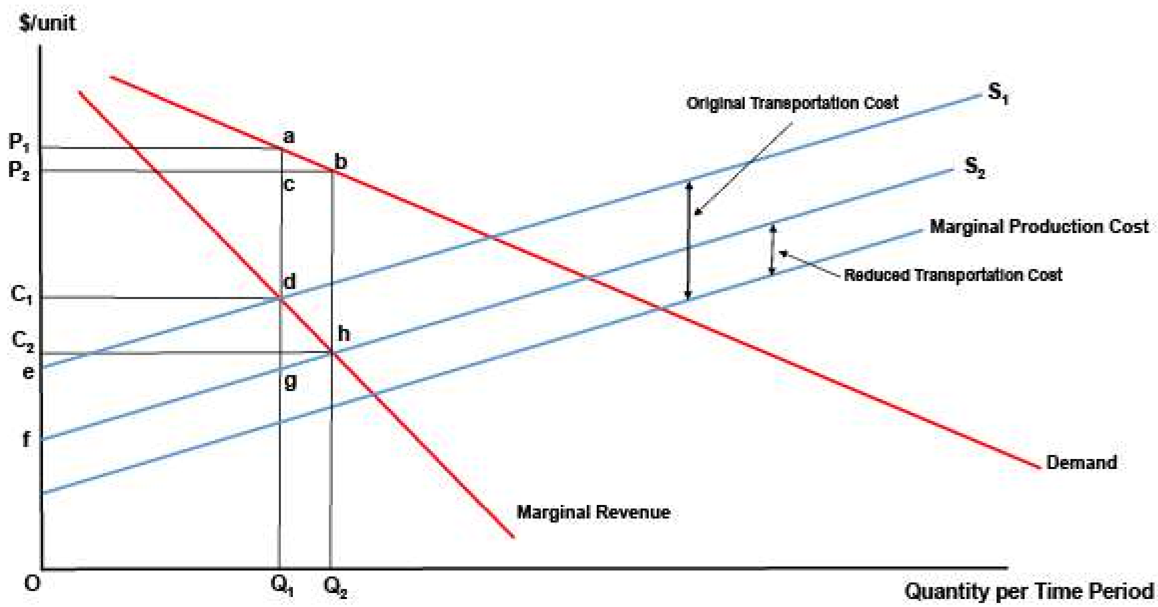


Figure 8. Benefits from Reduced Transportation Costs when Producers Have Market Power

When an improvement to transportation infrastructure reduces the supplier's transportation costs for producing and delivering its product, its supply curve shifts downward to S_2, as shown in Figure 8. This changes its highest-profit strategy to producing Q_2 units per time period, since producing and selling each additional unit between Q_1 and Q_2 contributes more in incremental revenue than it now does in additional costs, despite the fact that selling that additional output requires it to reduce the price it charges – including the price it charges for the Q_1 units it sold previously – from P_1 to P_2. With this new strategy, the supplier collects (P_2 x Q_2) in revenue, or the rectangle OP_2bQ_2, and incurs production plus transportation costs of $OfhQ_2$, so it now earns profits equal to the area fP_2bh.

Thus its profits have increased by the area (fP_2bh – eP_1ad), and this measures the benefit the monopoly supplier receives from an infrastructure investment that allows it to produce and deliver its original output at a lower cost and to sell more, even though it has to reduce its price to do the latter.[37] Part of the increase in the producer's profit results from savings in transportation costs on the quantity it previously supplied, area edgf in Figure 8. As in the competitive case, this savings will be measured as a gain in consumer surplus to infrastructure users – freight carriers who deliver raw materials to the producer and carry its product to customers, or the producer itself if it operates its own shipping subsidiary and experiences the cost saving directly – on the pre-improvement level of transportation activity associated with its original output Q_1. Again as in the competitive case, this full savings in transportation costs resulting from an infrastructure improvement represents an economic benefit, even though some of this savings is ultimately "shared" with consumers via lower product prices.

What differs in the case where competition is limited is that the gain to consumers of the product from purchasing more will *not* be incorporated in the increase in consumer surplus recorded in the transportation market, as it is with a competitive product market. The triangular area dhg in Figure 8, the difference between the producer's increased revenue (area Q_1dhQ_2) and its additional costs (area Q_1ghQ_2) measures the producer's net gain in profit (or producer surplus) from producing and selling the additional output ($Q_2 - Q_1$), and this area will be translated into the usual gain in consumer surplus from additional shipping activity that is measured in the transportation market.[38] Unlike in a competitive market, however, the gain in consumer surplus from increased consumption of the product – triangle abc in Figure 8 – will be omitted from the gain in consumer surplus on increased shipping activity when it is measured in the transportation market.

[37] Another way to view the net gain in the producer's profit is as the sum of three components: (1) its additional profit on the increased output ($Q_2 - Q_1$), or area gcbh in the figure (equal to the difference between its revenue from selling the additional quantity, area Q_1cbQ_2, and its costs to produce and deliver it, area Q_1ghQ_2); (2) the savings in transportation costs on the quantity Q_1 it previously produced (fedg); and (3) the loss in revenue on that previous quantity when its price must be reduced (P_1acP_2) in order to sell the additional output.

[38] The *net* change in the producer's revenue from reducing its price and selling more can be measured directly by the area under the marginal revenue line, which reflects *both* the revenue gain from producing and selling the additional output ($Q_2 - Q_1$) and the loss from having to reduce its price on its original sales Q_1 in order to do so; this is the area Q_1dhQ_2 in Figure 8. Similarly, its increased costs for producing the added output correspond to the area under its newly reduced supply or marginal cost line S_2 between Q_1 and Q_2, or the area Q_1ghQ_2. Its gain in profit on the increased output is the difference between its net gain in revenue and its increased costs, which is the triangle dhg. Because this net gain in profit incorporates the loss in revenue from charging a lower price for the original level of output, it reflects the sharing of transportation cost savings between producers and consumers, although limited competition causes suppliers to share less of those savings with consumers than where competition is more vigorous.

This omission occurs because the "wedge" between the demand and marginal revenue curves that limited competition introduces separates the gains in consumer and producer surplus that result from the effect of transportation cost savings on product output and consumption. By doing so, it prevents the former from being incorporated in the gain in consumer surplus on increased shipping activity as measured in the transportation market. It is thus an additional welfare gain or wider economic impact from the project that must be measured separately and added to the usual measure of benefits calculated in the transportation market.

Authors who classify this omission as a potential wider economic impact from investing in transportation infrastructure include Legaspi at al. (2015), Rothengatter (2017), and U.K. DfT (2019). Interestingly, this additional benefit occurs even if no new competitors enter the market, and the original supplier retains its monopoly position and power to set prices. Further, if there are economies of scale in producing the product – which would be reflected in downward-sloping marginal production cost and supply curves in Figure 8 – the decline in the product's price, the increase in consumption, and the resulting gain in consumer surplus would all be larger than shown there.[39]

6.2 Benefits from Increased Competition

A related situation occurs where an investment in new transportation infrastructure provides new competitors with access to a market that was previously served by only one or a limited number of local suppliers. It is likely to arise mainly where infrastructure investment takes the form of building a new access route (or improving an existing one) to a remote region, thus enabling suppliers located outside the region to serve customers within the region and increasing competition there. Although this situation seems closely related to the previous case, where infrastructure investment reduced transportation costs for a single (or few) supplier(s) serving a market, it differs subtly because there is not necessarily a reduction in transportation costs for local suppliers (those located within the region). This situation does not seem to be discussed frequently in recent analysis of wider economic impacts.[40]

Competition from new sources of supply originating outside a region can force incumbent local suppliers to lower prices they charge to customers within the region, increasing their consumption and providing benefits that may not be measured in

[39] The existence of scale economies is sometimes cited as a separate source of wider economic impacts. This is because an investment that reduces transportation costs, lowers the delivered prices of products, and increases their demand and output as a consequence will generate benefits to consumers beyond those from increased use of the improved infrastructure even if markets for those products are competitive.

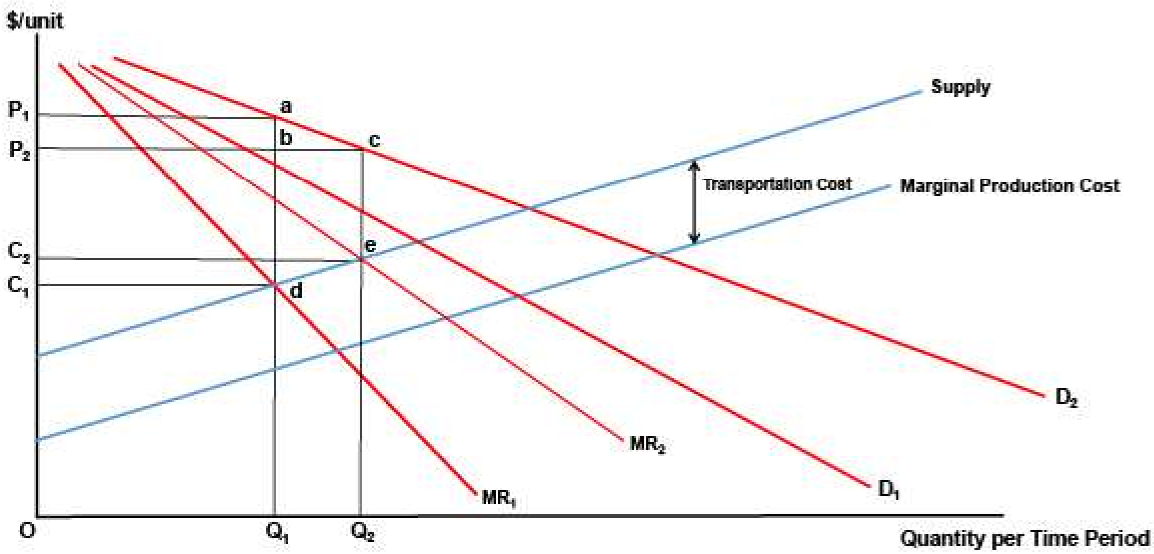
[40] An exception that provides a clear and succinct explanation of this potential source of wider economic impacts is Commonwealth of Australia (2021, Section 5, p. 29).

conventional economic evaluation of proposed investments. These additional benefits can arise even if constructing a new transportation route does not reduce transportation costs within the region; they occur because the increase in competition enabled by the new access route will lead to a reduction in product prices within the region, as well as possibly to lower production costs or improved product quality.

The reduction in product prices has two effects: first, some of the producer surplus previously earned by local suppliers is in effect transferred to consumers, but this transfer results in no change in their total. Second, the resulting increase in output and consumption generates gains in consumer and producer surplus, so consequently there is a net gain in their total. This gain will not be captured in the associated gain in transportation consumer surplus when it is measured in the transportation market, so it represents a source of wider economic benefits as defined here.

Figure 9 depicts this situation. As in Figure 8, when only a single local supplier initially serves the market and demand is shown by D_1, its profit-maximizing strategy will be to supply Q_1 units of its product and charge the maximum price that customers in the region are willing to pay for it, namely P_1. If constructing new infrastructure connects the region to another supplier who can now deliver the same product there at a competitive price, the elasticity of demand faced by both producers will increase. That is, customers' purchases will become more sensitive to potential changes in the product's price, which is shown in Figure 9 as a rotation of the market demand curve to D_2. This will in turn cause the marginal revenue curve to rotate outward to position MR_2, changing the incumbent supplier's maximum-profit strategy to producing an output of Q_2 and reducing its price to P_2 in order to sell the increased quantity.

The reduction in the product's price will reduce the incumbent supplier's profits by area P_1abP_2, the loss in revenue on the quantity originally sold (Q_1), but this results in an exactly offsetting gain in consumer surplus to buyers of the original quantity. The resulting increase in the quantity produced and sold will increase short-term profits or consumer surplus by the gain in revenue Q_1bcQ_2 minus the cost of producing the additional output Q_1deQ_2, or by the area bced. This gain in profits measures the value of the investment to suppliers, and as previously, this is the benefit that will be captured by users of the new access route – either producers outside the region who transport their products to the region themselves, or freight carriers who deliver them from producers outside the region to customers within it – and measured as increased transportation consumer surplus in benefit-cost evaluation of the new infrastructure.



Source: see text.

Figure 9. Benefits from an Investment in Transportation Infrastructutre that Enables Increased Competition

However, neither the area P_1abP_2, which is in effect transferred from producers' short-term profits to become additional consumer surplus to continuing buyers of the product, nor the area abc, the gain in consumer surplus to its new buyers, will be reflected in benefits to users of the new infrastructure when those are measured as usual in the market for transportation services that are produced utilizing the improved infrastructure. Both gains will instead represent wider economic impacts that should be estimated separately and added to the conventional transportation consumer surplus measures included in benefit-cost evaluation of the investment.

6.3 Measuring Wider Economic Benefits where Competition is Limited

Measuring wider economic benefits from improved transportation access where suppliers exercise market power over supply and pricing is likely to be challenging, because it requires empirical estimates of the extent of price markups over suppliers' production and distribution costs, and these margins are likely to vary significantly among both industries and geographic market areas. Anticipating how improved transportation access and lower shipping costs would affect price-cost margins would also be important, because as the preceding discussion indicates, the extent of any wider economic benefits also depends on how savings in transportation costs affect the delivered prices of products to markets that are less than fully competitive. Finally, estimating the resulting increase in consumption would also require knowledge of demand elasticities for those products within the relevant geographic market areas.

Even where current limits on suppliers' access to markets raise the potential that investments in new transportation facilities could expand product distribution networks and enhance competition, estimating the magnitude of the resulting wider economic benefits to include in economic evaluation would thus present a formidable challenge. In lieu of requiring analysts to assemble detailed data on price-cost differentials and estimate price and quantity changes, the U.K. Department for Transport (U.K. DfT Transport Analysis Guidance Unit 2.2 [2020], Section 4.3.2, p. 17), recommends applying an across-the-board 10% markup ("uplift") to savings in business travel time and costs and benefits to freight shippers to account for potential wider benefits in imperfectly competitive markets. This allowance appears to be based on a much earlier survey of econometric estimates of price-cost relationships for industries in the U.K. (U.K. DfT 2005).

However, resorting to standard "markup factors" to account for this source of potential wider benefits seems like a poor strategy for U.S. practice of benefit-cost evaluation, as those could lead analysts to include unjustified benefits in cases where competition is already robust, and possibly to underestimate them for proposed investments that genuinely do enhance transportation access and improve competition. An alternative approach would be to require analysts to base project-specific estimates of wider economic benefits arising from imperfect competition on detailed evaluation of price-cost relationships and demand elasticities for products likely to be shipped via improved infrastructure facilities. While it would undoubtedly be more data-intensive and analytically demanding than applying standard markups, requiring project-specific quantification would provide more reliable and defensible estimates of these wider economic benefits.

6.4 What Investments are Likely to Generate these Benefits?

Wider benefits from increased supply and lower prices can occur wherever expanding transportation infrastructure reduces costs for supplying products to markets where competition is limited. How frequently these situations occur seems likely to depend on the prevalence and degree of scale economies in production, the geographic scope and coverage of transportation networks, and the effectiveness of government policies to limit market power and encourage competition.

The presence of significant scale economies in production can allow one or a few suppliers to dominate an industry – in the extreme, enabling "natural" monopoly – because they will be able to produce at lower costs than smaller-scale competitors. Thus where scale economies are common or pronounced, infrastructure investments may reduce transportation costs for several less-than-competitive industries, and wider economic impacts from increased output and lower prices for their products could be significant in total.

Similarly, where transportation networks are sparse or poorly interconnected, producers in some geographic regions may be insulated from competition; expanding those networks can reduce incumbent suppliers' costs or enable new competitors to enter, thus generating benefits that may not be captured fully in consumer surplus gains to transportation users. Finally, if government policies to protect and encourage competition are limited or ineffective, monopoly power can arise and persist, creating situations where expanding transportation infrastructure generates benefits beyond those that will normally be measured in benefit-cost evaluation of proposed investments.

In any of these situations, improving infrastructure that serves truck, rail, or waterborne freight shipping would seem to have the most potential to generate wider economic impacts. This could include regional or interstate highways, rail lines, capacity management systems, and loading facilities, and locks, dams, and loading facilities serving inland or coastal waterways.

6.5 How Important are Benefits from Increased Competition Likely to Be?

In highly competitive, spatially integrated economies, supplemental benefits from expanding output and reducing prices in markets where competition is limited seem likely to be rare, and modest where they do arise. They would occur only in markets for agricultural or manufactured products that require shipping by rail or truck to reach customers (as contrasted with services, which do not require physical distribution), and competition in markets for such products is generally robust throughout the U.S. The most common exceptions seem likely to be markets in remote regions or rural areas that are not well-served by highways or rail lines, and thus rely mainly on local suppliers or outside producers whose access is constrained by the sparseness of transportation networks serving those locations.

In these cases, wider benefits would be proportional to savings in travel time and costs for businesses, since it is the reductions in those variables that would be indirectly reflected in increased output and lower prices for goods that are produced or sold under non-competitive conditions. Savings in those categories typically account for a relatively small share of user benefits from proposed expansions of highway infrastructure, although they would undoubtedly constitute a much larger share of benefits from improvements to rail and waterway facilities, since those modes carry freight exclusively. This limits the potential magnitude of wider benefits from this source, but there may still be instances where these prove to be significant.

7. Wider Economic Impacts in the Urban Land Market

As indicated previously, public investment in new or expanded transportation infrastructure can encourage complementary investments in private infrastructure, often in the form of more intensive land development at sites where the improved access they provide makes it more desirable for employers, retailers, or residents to locate. As the benefits from savings in transportation costs and travel time that improved infrastructure provides to its users are transmitted through the urban economy, economic returns to private development increase at sites it makes more accessible and attract new investment there. If land markets function efficiently, benefits to users of improved infrastructure will accurately reflect the economic value of expanded housing, shopping, entertainment, or other opportunities these complementary private investments provide.

If land market outcomes are distorted by spillovers, limited competition, or other sources of inefficiency, however, the value of increased private investment may not be fully captured by the conventional user benefit measures that economic evaluation of proposed infrastructure projects relies on. Two situations where this can occur are where agglomeration-type spillovers in residential, retail, or supporting development (entertainment, recreation, etc.) generate benefits that private investors cannot fully realize, and where infrastructure investment acts as a catalyst for overcoming previous barriers to land development and "unlocks" the previously restricted value of sites it makes more desirable.[41] In many ways, the former closely parallels the situation where increased agglomeration of employment generates productivity spillovers that create benefits that firms whose location decisions generate them cannot capture themselves, so they represent wider economic benefits.

[41] The following discussion follows Laird and Venables (2017), Section 2.4.2.

7.1 Benefits from Increased Variety

If investing in new or expanded transportation infrastructure prompts complementary private investments that expand the variety or diversity of economic opportunities at sites that the new infrastructure makes more accessible, it can create benefits analogous to the productivity spillovers generated by the larger employment agglomerations these same investments enable. For example, expanding the variety of shopping opportunities available at a single destination by adding new stores whose products are differentiated from those offered in existing retail outlets can create spillover benefits – convenience, enjoyment, or other advantages – to shoppers, in the form of consumer surplus gains beyond those from increases in their retail spending.[42] New development that increases the range of entertainment or recreation opportunities that a more accessible location offers may have a similar effect, as visitors' collective enjoyment of the wider variety of opportunities at a destination can exceed the private value revealed by their increased spending.

However, the usual measures of benefits that visitors to more intensively developed sites experience from using the improved transportation infrastructure that makes their locations more readily accessible will be limited to visitors' savings in travel time and costs. Any additional benefits they collectively experience from having an expanded range of opportunities available at a single site seem unlikely to be captured by their gains in transportation consumer surplus from using the improved infrastructure to that makes it more accessible. This welfare gain will represent a wider economic benefit, which needs to be measured separately and added to the conventional measure of welfare gains.

A similar argument applies to new development that expands the variety of living opportunities, provides additional entertainment options, or introduces new recreational activities at sites that infrastructure investment makes more accessible. By offering a wider range of housing, entertainment, or recreation options among which residents and visitors can choose, new development can provide spillover-type benefits beyond those revealed by any increase in their collective spending they elicit. These expanded choices provide gains in welfare over and above the value of increased consumption, but again, the measured gains in consumer surplus to users of the improved infrastructure that makes a site more accessible will not reflect those added gains.

Thus, there may be additional benefits beyond the usual gains in consumer surplus to infrastructure users that need to be accounted for separately, so that they can be

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[42] In contrast, if more intensive development simply provides additional retail outlets without expanding the range of products they collectively offer, it will provide no additional benefit beyond the dollar value of increased retail activity.

properly incorporated in economic evaluation of proposed investments. As always with such wider economic benefits, however, there can be analogous welfare losses at other locations. If improvements to transportation facilities attract economic activity and development away from competing locations, the resulting losses in variety of retail and other opportunities there can partly or even completely offset gains from new development at sites they make more accessible.

7.2 Benefits from Overcoming Barriers to Development

Land development in urban areas can be constrained by government regulations such as limitations on building heights, ceilings on lot coverage or ratios of building floor area to land area, or required set-asides of land for parking or other ancillary uses. Private market failures such as consolidation of land ownership in one or a few hands can also restrict development, since limited competition requires developers to reduce rents on existing properties to ensure that new development is occupied, and may make them reluctant to invest in more intensive development. At the other extreme, or where land ownership is fragmented, interdependency among prospective returns to individual developers' investment decisions can make them individually hesitant to commit to new projects and also lead to suboptimal development intensity.

In these situations, investing in new transportation infrastructure may prompt local government agencies to reassess (and perhaps relax) restrictions on development, or signal the likelihood of favorable returns to additional development and catalyze individual landowners' investment decisions. By doing so, expanding transportation infrastructure may foster new development that would not otherwise occur, and potentially generate benefits beyond those that were anticipated in benefit-cost evaluations of proposed investment projects. Wider economic benefits would arise if the collective economic return to landowners on new commercial development exceeded the gains in transportation consumer surplus to visitors using the improved infrastructure to travel to the site. However, there may be more direct and less costly mechanisms to overcome these barriers to development than making costly investments in new transportation infrastructure.

7.3 How Would We Measure Wider Benefits in Land markets?

One obvious strategy for measuring wider economic impacts arising in urban land markets would be to use increases in land values at sites where investing in new or expanded transportation infrastructure improves access. As always, there are significant empirical challenges to measuring increases in property values, particularly where land ownership is fragmented, transactions are infrequent, or record-keeping is haphazard. Attributing increases in value unambiguously to specific infrastructure projects is likely to pose additional challenges, particularly where they are being planned in conjunction with other investments in public infrastructure serving the same area.

Evaluating proposed investments would also require projecting anticipated gains in land value in advance of actual investments, so locally-calibrated models that simulate the interaction of transportation activity and land uses at a high level of geographic resolution would be required.[43] In theory, land value increases would include the capitalized value of continuing benefits to users of the improved infrastructure that enables faster and less costly access, so it would also be important to avoid double-counting consumer surplus gains in the transportation market when resorting to land value increases to capture wider benefits.

7.4 What Types of Projects Would Generate Wider Economic Impacts in Land Markets?

New investments in transit or highway infrastructure that improve access to centrally located destinations could potentially generate wider economic benefits by spurring more intensive development there. Transit may offer some intrinsic advantage over highways in these situations because of its lesser requirements for land compared to that required by highway rights-of-way and parking facilities, since more land would remain available for development and distances separating adjacent land uses could be made shorter. In outlying areas, however, improving highway access to underdeveloped sites may be more likely to stimulate increased investment in commercial development, since the connectivity offered by interconnected highway networks often facilitates region-wide access.

7.5 Are these Benefits Likely to be Significant?

It is difficult to anticipate whether wider economic impacts arising in urban land markets are likely to be widespread or economically significant where they do occur. More intensive development is often associated with greater product differentiation and expanded variety in residential, shopping, and entertainment opportunities, such as in downtown areas, yet there are almost certainly diminishing returns to further intensification in the expanded choices it brings, and the marginal value of successive increases in variety also seems likely to be declining. In addition, measuring the value of shopping or entertainment choices seems likely to pose difficult challenges, and applying universal “markup factors” based on theoretical computations or isolated

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[43] An alternative would be to rely on land value increases measured for previous infrastructure improvements as guidelines for the scale of gains to be anticipated for similar projects in the planning and evaluation stages.

empirical studies seem likely to overstate the frequency and value of such benefits in many settings, and potentially even to invite abuse.[44]

8. "Logistics Reorganization" Benefits

Investments in highway, rail, or waterway infrastructure can speed freight shipments and increase the likelihood that they will be delivered on schedule. Some analysts argue that firms will reorganize their supply chains or delivery logistics in response to availability of faster and more reliable shipping, effectively substituting more frequent deliveries or shipments for inventory holdings of raw materials or finished products. These "reorganization effects" may even extend to firms relocating or consolidating warehousing facilities for materials or products in response to faster or more reliable shipment times.[45] The resulting savings in firms' costs for assembling raw materials and distributing their finished products are often asserted to be a wider economic benefit from investments in improved infrastructure, which will not be captured in conventional benefit-cost evaluation and must be calculated separately.

For example, a 2001 study conducted for FHWA asserts that "…'reorganization effects,' [are] the adjustments in their logistical arrangements that shippers make in response to lower costs of freight movement. Typically, these adjustments would involve fewer warehouses and more miles of truck movement as shippers take advantage of lower freight costs to consolidate storage facilities and reduce inventory costs. *These effects are the principal source of benefits not captured in the conventional approach to benefit-cost analysis*." (FHWA 2001, Section 2.3.2; emphasis added)

In other words, savings in firms' costs for assembling raw materials and shipping finished products for retail sale, including ordering and shipping costs, rental or ownership costs for warehouse facilities, inventory holding expenses, and costs of lost sales when products are unavailable – referred to collectively as "logistics costs" – are often asserted to be a wider economic impact resulting from investments in transportation infrastructure that make freight shipping faster or more reliable. Some studies even suggest that improvements in product quality or new product innovations

[44] For example, Laird and Venables (2017, 5) use an illustrative theoretical calculation and empirical estimates of demand elasticities that seem appropriate for highly differentiated products to show that increases in the variety of retail opportunities could generate benefits amounting to 10-20% of increases in retail sales at sites that investment makes more accessible.

[45] An early – if not the original – statement of the argument that cost savings and other benefits from logistics reorganization are likely to represent wider economic benefits is Quarmby (1989); a completer and more detailed version of this argument appears in FHWA (2001).

can result when firms reorganize their supply or distribution networks, thereby producing additional benefits that are unlikely to be measured in BCA (FHWA 2001, Section 2.2, Table 1).

8.1 Are Logistics Reorganization Benefits a Wider Economic Impact?

Despite assertions that savings in logistics costs represent a benefit from improved transportation infrastructure that is not reflected in the usual measure that benefit-cost evaluation relies upon, there is no clear market failure that would inhibit firms' increased shipments of materials and products as they substitute more frequent orders and deliveries for reduced inventory holdings and warehouse space from being reflected in their increased demand for shipping services. Thus any savings in their "supply chain" costs should be captured by the increase in consumer surplus measured in the transportation market and relied upon by benefit-cost analysis.[46] The same is true for increases in output and consumption of products supplied by firms whose reduced logistics costs enable them to reduce their delivered prices: unless some market failure prevents increases in their output from being reflected in increased demand for transportation services, all benefits they experience from lower logistics costs will be captured by increased consumer surplus from the use of additional shipping services measured in the market for freight transportation.[47]

Unless competition in either the goods-producing industries where savings in logistics costs occur or the freight shipping industries is inadequate to cause product prices and shipping rates to reflect marginal costs, consumer surplus gains from reduced freight rates and increased use of shipping services measured in the transportation market will convey the full value of logistics cost savings and benefits from lower product prices and increased consumption. Thus in most cases, savings in logistics costs will be fully incorporated in the normal measure of benefits from an infrastructure investment and will *not* represent a wider economic impact.

Mohring and Williamson (1969) offered a clear demonstration of this result more than 50 years ago, which was repeated in FHWA (2001, Section 3.2.3). More recently, Laird and Venables (2017, p. 4) argue that "…more reliable and faster transport may allow firms to change the way in which they organize their logistics or production (e.g., just-in-time

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[46] This is the triangular component of the increase in consumer surplus to transportation users shown in Figure 2.

[47] As discussed in detail above, if their products are sold in less-than-fully competitive markets, conventional BCA will overlook benefits to consumers from increased production and sales.

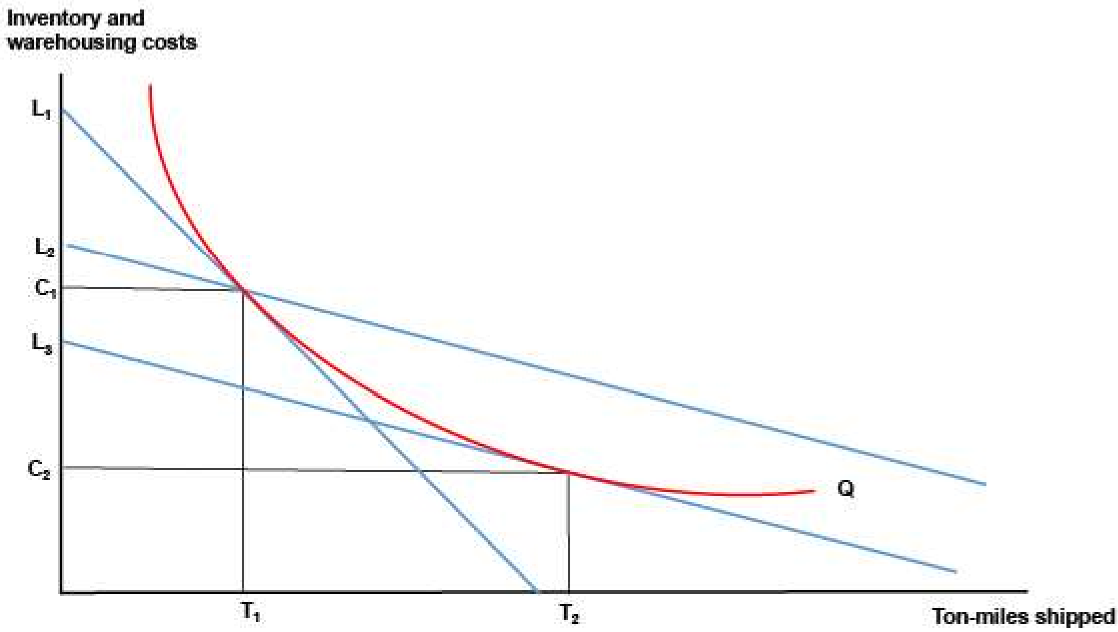
manufacturing technologies)," but they hasten to add "These gains are *user-benefits*, and are accounted for in calculation of those benefits. They should *not* be double-counted as a wider economic impact." [emphasis added]

8.2 Analysis of Reorganization Benefits

Figure 10, which is adapted from Mohring and Williamson (1969), illustrates why any cost savings that result when firms reorganize their shipping logistics in response to faster or more reliable delivery times will be reflected in the conventional measure of consumer surplus to users of improved transportation infrastructure, and thus do not represent wider economic impacts. Its horizontal axis measures a firm's use of freight shipping services, while the vertical axis measures the firm's spending on other components of its logistics costs, mainly those for holding inventories and renting or owning warehouse space to store them.

The curve labeled Q in Figure 10 shows alternative combinations of inventory holdings (including stocks of both raw materials and finished products) and freight shipping the firm can use to produce its products and distribute them to retail locations or directly to customers. The concave shape of Q reflects the fact that as the firm consolidates its warehousing locations or reduces its inventory holdings, it must use progressively more transportation services to distribute its products, either by shipping them from fewer warehouse locations and thus increasing the average distance products travel to reach customers, or making more frequent shipments out of its smaller inventory.[48] The line originating at L_1 on the vertical axis shows alternative combinations of shipping and other logistics inputs the firm can purchase with a fixed budget for its "supply chain;" the slope of L_1 reflects the relative costs of shipping products and substitutes such as holding inventory or renting warehouse space.

[48] An analogous situation applies for the raw materials firms use to produce their products: consolidating the number of production facilities increases the average distance materials must be shipped and may increase the size or frequency of shipments.



Source: Mohring and Williamson (1969), Figure 2a.

Figure 10. "Logistics Reorganization" Effects from Improved Transportation Infrastructure and Lower Shipping Costs

At prevailing costs for these inputs, the firm's cost-minimizing strategy for distributing its products is to use a quantity T_1 of shipping (measured, say, in ton-miles carried) while spending C_1 to build or rent warehouse space and store inventories of products there while waiting to be shipped. Where an investment in transportation infrastructure such as a new rail line or faster highway route reduces the firm's cost of shipping, the slope of L_1 will "flatten" to that of the lines originating at L_2 and L_3 on the vertical axis, since it can now make more frequent deliveries of its products – in effect, using more transportation services – at the same cost.

If the firm retains its current shipping and inventory holding practices, thus continuing to use T_1 in shipping services while spending C_1 on inventory and storage, it will reduce its total logistics costs by the amount it saves in transportation costs, or from $(L_1 – C_1)$ to $(L_2 – C_1)$. The amount it saves is thus $(L_1 – C_1) – (L_2 – C_1)$, which is measured by the distance $(L_1 – L_2)$ on the vertical axis of Figure 10, and this savings represents a benefit to the firm from the investment in the form of reduced transportation costs.

Because the faster or more reliable shipping enabled by the improved infrastructure reduces its shipping costs, however, the firm's cost-minimizing logistics strategy will now be to hold less inventory and perhaps consolidate the number of locations where it does so, while shipping its products to customers over longer distances and possibly more frequently as well. In Figure 10, this new strategy is shown as a move to the point on curve Q that corresponds to an increased quantity of shipping T_2 and reduced outlays for holding and storing inventories C_2. Reorganizing its distribution network to use this new combination of shipping and inventory produces an additional benefit to the firm, which is equal to the further reduction in its logistics costs from L_2 to L_3. This reduction measures the "logistics reorganization" benefit to the firm resulting from an investment that improves the transportation infrastructure it relies on to produce and distribute its products.[49]

Figure 11 – which is nearly identical to the previous Figure 2– shows how these two components of savings in logistics costs are reflected in the market for shipping; its horizontal axis shows the quantity of shipping (again measured in, say, ton-miles), while its vertical axis measures the internal cost or commercial charges it faces for shipping each ton-mile.[50] The improvement in transportation infrastructure reduces this cost from C_1 to C_2, and the firm's reorganization of its logistics practices that was demonstrated in Figure 10 increases its use of shipping from T_1 to T_2, exactly as shown originally in Figure 2.

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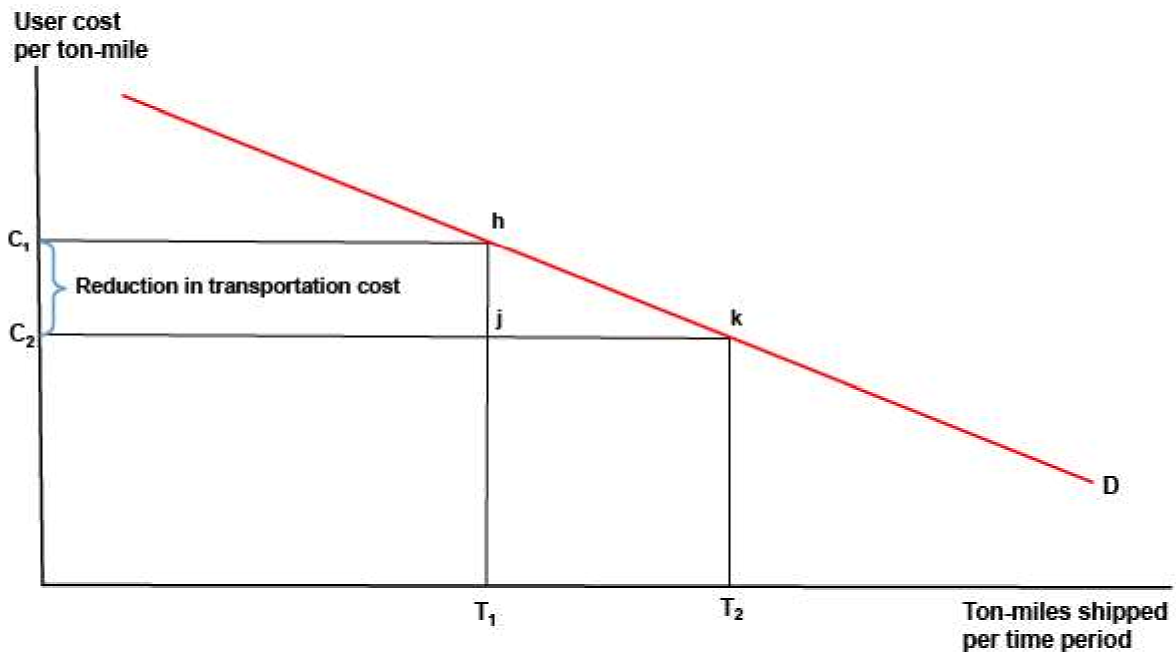
[49] The same savings will result if the firm uses for-hire freight carriers to distribute its products, as long as competition among them is sufficient to ensure that the cost savings they experience by using the improved infrastructure are reflected in the shipping rates they charge.

[50] This market will reflect a transaction internal to the firm if it operates its own shipping services and will describe an explicit transaction if it uses for-hire freight carriage.



Source: Mohring and Williamson, Figure 2b.

Figure 11 (repeats Figure 2). "Logistics Reorganization" Benefits as Measured in the Market for Transportation Service

The rectangle C_1hjC_2 in Figure 11 measures the firm's cost savings on its previous use of shipping; its area is (C_1 - C_2) times T_1, which corresponds exactly to the savings (L_1 – L_2) shown previously in Figure 11. The triangle abc measures the value to the firm of the increase in transportation services it uses by making longer, more frequent, or larger shipments, and this exactly equals the additional cost savings from reorganizing its logistics to take advantage of lower-cost, faster, or more reliable transportation, shown previously as (L_2 – L_3) in Figure 10. Thus, the *entire* benefit the firm experiences from the improved infrastructure used to transport its products is reflected in the usual measure of increased consumer surplus in the transportation market, and none of it represents a wider economic impact resulting from the investment.[51]

[51] The firm's cost savings enable it to sell its products at lower prices, so its sales and production may increase, thus further expanding its use of transportation. The area of triangle abc in Figure 9 will increase in exact proportion to the firm's increased shipping activity, so any additional benefits from this "output effect" of improved infrastructure will also be reflected in the usual measure of consumer surplus to transportation users.

9. Incorporating Wider Economic Impacts in Benefit-Cost Analysis vs. Alternative Evaluation Methods

As indicated previously, estimating wider economic impacts for the purpose of incorporating them into benefit-cost analysis of proposed infrastructure investments is often confused with using alternative evaluation methods that would replace rather than supplement benefit-cost analysis. Alternative evaluation methods that are commonly confused with estimating wider economic impacts include analyzing local or regional economic impacts of proposed infrastructure investments, estimating those investments' contributions to macroeconomic measures such as productivity, GDP, or national income, and "multi-criteria" evaluation. Each of these differs fundamentally from incorporating wider economic impacts into benefit-cost evaluation, and unlike estimating the value of wider economic impacts, they are intended to substitute for benefit-cost analysis rather than to expand its scope to include benefits that might be overlooked.

9.1 Wider Economic Impacts Contrasted with Economic Impact Analysis

Economic impact analysis refers to the process of estimating the economic consequences of infrastructure investments within a geographically delimited area, usually a metropolitan area, county, state, or region. This process differs fundamentally from benefit-cost evaluation, which typically adopts a broader – usually national – rather than a localized perspective for measuring and comparing benefits and costs, so it is important to avoid confusing measures of localized economic impact with wider economic impacts in benefit-cost evaluation.

Measures of local economic impact frequently represent gains or losses of economic value that occur within the delimited area of interest and are often partly or completely offset by corresponding losses or gains outside it; unlike benefit-cost analysis, economic impact analysis usually considers only localized gains and losses while ignoring those occurring elsewhere. In contrast, considering wider economic impacts refers to including *additional categories of economic benefits or costs that can arise from infrastructure investments* but are likely to be overlooked in conventional benefit-cost analysis evaluation, and thus need to be estimated separately and added to the conventional measures of proposed investments' benefits and costs.

Economic impact analysis typically focuses on measuring consequences of proposed investments such as increased local employment (particularly during their construction phase), retail sales, property values, or local tax revenues. While such impacts are often of central interest to local political officials and project advocates, they usually do not represent increases in economic welfare, and are thus excluded from benefit-cost evaluation of infrastructure projects. Although the practice of economic impact analysis is well-developed, widespread, and often plays an important role in local infrastructure planning, it is important not to confuse it with measurement of wider economic impacts in benefit-cost analysis.

9.2 Wider Economic Impacts vs. Macroeconomic Benefit Measures

As indicated previously, some early approaches to evaluating infrastructure projects calculated changes in measures that closely resembled Gross Domestic Product or National Income – before these became widely-reported measures of the value of an economy's total output and the income it generates – to measure benefits from proposed investments. Although their proponents were attempting to capture the *same* welfare effects of infrastructure investment that benefit-cost analysis measures using consumer surplus calculations for infrastructure users, these economy-wide measures often estimated much larger benefits than conventional benefit-cost analysis would have, particularly for new highways (Tinbergen 1957; Bos and Koyck 1961; Jara-Diaz 1986).

During the 1990s and early 2000s, an outpouring of studies attempted to measure increases in economic productivity, aggregate earnings, Gross Domestic Product, or other economy-wide indicators of output and income that were associated with recent investments in infrastructure, particularly highways.[52] These studies also seemed to suggest much larger benefits from infrastructure investment than would be measured by the gains in consumer surplus to transportation or infrastructure users that are featured in conventional benefit-cost analysis. More recent efforts to use national income and product accounting to measure benefits from infrastructure investment, such as those using econometric or computable general equilibrium (CGE) models of regional or national economies, have sometimes arrived at a similar result – that is, much larger benefits than would have been estimated using conventional benefit-cost measures

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[52] The earliest is Aschauer (1991); later influential later studies include Munnel (1992) and Fernald (1999). For a survey and critique, see Gramlich (1994). Most of this research measured infrastructure investment by accumulated stocks of transportation or other infrastructure capital, rather than by new investment that adds to existing capital stocks or accessibility-based measurres such as the effective density metric described previously (Section 5.5).

(see for example Hensher *et al*. 2012 and Legaspi *et al*. 2015).

The finding that macroeconomic approaches to measuring benefits from infrastructure investment seem to produce systematically larger estimates than traditional benefit-cost analysis has understandably led many analysts to assume that macroeconomic methods were able to capture some or all of the wider economic impacts that conventional benefit-cost evaluation methods are now recognized as having the potential to overlook. This result is somewhat surprising, however, as the economic theory underlying both benefit-cost evaluation and measurement of GDP impacts from investments in new or expanded transportation infrastructure suggests that they should arrive at identical valuations.

Figure 12 below reproduces Figure 1 above; as the discussion originally accompanying Figure 1 indicated, the benefits of an investment in new or improved infrastructure include the entire area P_1aced when they are measured in the market for products that rely on transportation services produced using the new or expanded facilities. As also argued previously, if there are no significant market failures in either the product markets or the market for transportation services used to produce and deliver those products, these benefits will be fully and accurately reflected in gains in consumer surplus measured in the market for transportation or infrastructure services.

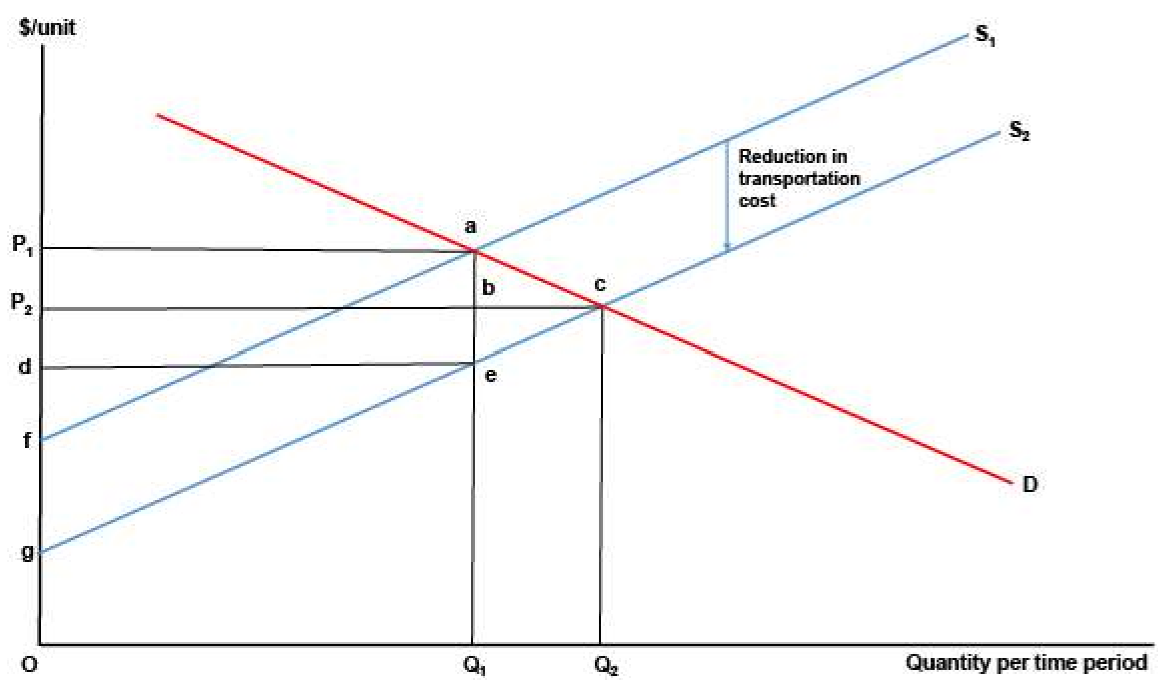

Figure 12 (repeats Figure 1). Benefits from Reduced Transportation Costs Measured as Gains in GDP

The rectangular area P_1aed – which is equal to the savings in transportation costs to produce and distribute the pre-improvement level of output Q_1 (that savings can also be measured by the area faeg) will be recorded as a gain in consumer surplus resulting from the reduced cost of shipping when benefits are measured in the transportation market. The triangular area ace will be measured as a gain in consumer surplus from the increased use of transportation services necessary to produce and distribute the increase in output from Q_1 to Q_2.

Examining the individual components of P_1aced in detail also suggests that their sum will equal the gain in GDP resulting from the investment in new infrastructure. First, when the resources represented in areas P_1aed and faeg (again, these are equal in the figure) are no longer required to produce transportation services, they are "released" to be employed productively elsewhere in the economy, where they will be used to produce goods or services other than transportation. Assuming that the resulting increases in output of those other products are sufficiently small as to leave their prices unaffected, these alternative outputs will be valued at the marginal cost of producing them, and GDP will increase by exactly the value of P_1aed.[53]

The triangular area ace in Figure 12 can be decomposed into a series of vertical "slices," each corresponding to an increase in one unit of output of the product depicted in the figure. The first such slice, which represents the increase in output from Q_1 to (Q_1+1), is valued at its original price P_1 but the resources necessary to produce it have a marginal cost of Od, so its contribution to increased GDP is equal to (P_1 – Od). The second one-unit wide vertical slice of triangle ace is valued at a slightly lower price than P_1 but requires resources whose value is slightly larger than Od to produce, so the gain in GDP from producing and consuming it is slightly smaller than (P_1 – Od). Extending this logic to each of the successive one-unit increases in output from Q_1 to Q_2 shows that their overall contribution to increased GDP is the entire triangular area ace.[54]

Thus, the total contribution to increased GDP from the savings in transportation costs that an investment in new or improved infrastructure enables is identical to the increase in economic welfare – the sum of increases in consumer and producer surplus – measured in either the market for transported products or the market for transportation

[53] This result is viewed from the value-of-output perspective on measuring GDP, but the same result holds when measuring GDP using the alternative methods of summing increases in final expenditures or factor income.

[54] Measuring the value of increased output using a Divisia price index gives an exact measure for the value of triangle ace, and using a chain-type price index provides a close approximation. A clear explanation is Moulton (2018), and more details on the underlying theory are available in Forsyth and Fowler (1981) and Diewert (2001).

services. Since the latter is the measure that benefit-cost evaluation of proposed investments in transportation infrastructure most commonly relies on, it should – at least in theory – produce the same result as measuring their benefits using increases in GDP.

If anything, benefit-cost analysis seems likely to produce *larger* estimates of benefits form such investments, since (as Figure 1 illustrated previously) it includes welfare gains from the production and use of transportation services by household members, whereas GDP accounting omits the value of household-produced services.
Several explanations for why macroeconomic or GDP-based measures of benefits from infrastructure investment might exceed welfare-based valuation of the same benefits are possible. Some of these include:

- The relationships of transportation activity to the "generalized cost" of transportation services – that is, the transportation demand curves – that are used to calculate consumer surplus benefits from infrastructure improvements in the transportation market may omit longer-run responses of prices and output in the markets for transported products that increase the elasticity of transportation demand to reduced generalized costs, causing consumer surplus gains to be underestimated.

- Measured gains in GDM may "automatically" incorporate some wider economic benefits from infrastructure investment that require separate measurement in benefit-cost evaluation, most likely including agglomeration effects from increased concentration of employment, the value of productivity gains from increased labor supply and improved matching of workers' skills to the skill demands of specific jobs, and gains from lower prices and increased consumption in imperfectly competitive markets.[55]

- Similarly, revenue from income taxes levied on the increased earnings that reward agglomeration-based productivity gains, increased labor supply, or better matching between employee skills and job demands are wider economic impacts that would not be captured in benefit-cost analysis, but would be included in GDP, since macroeconomic accounting values gains in labor productivity using increases in workers' pre-tax earnings.

There are also definitional distinctions between benefit-cost evaluation of infrastructure investment and measuring its benefits using GDP accounting – principally in their

[55] In contrast, savings in emergency service and medical care costs resulting from less frequent transportation incidents are reflected in macroeconomic measures (although ironically, these may reduce GDP rather than increasing it), while welfare gains from reduced pain and suffering caused by fatalities or injuries resulting from such incidents are not. These omissions seem likely to produce the opposite result.

treatment of household-produced services – that inevitably lead them to produce different estimates of benefits, and these are compounded by differences in the conventions they use to value changes in output and in the assumptions they make about the responses of labor and capital supplies to higher earnings.[56] Thus while macroeconomic methods for measuring benefits from proposed infrastructure investments can be informative and have the advantage of producing more familiar measures such as gains in GDP or income, they cannot exactly duplicate or substitute for benefit-cost evaluation. Nevertheless, in some – and maybe even many – cases, benefit-cost analysis needs to be supplemented with empirical estimates of wider economic impacts to arrive at a comprehensive and accurate evaluation of some proposed investments in transportation infrastructure.

9.3 Wider Economic Impacts vs. Multi-Criteria Evaluation

Multi-criteria evaluation typically evaluates proposed investments by estimating their likely performance on a combination of non-economic criteria and economic measures that are only loosely related to either welfare or the value of output, sometimes even combining these with conventional measures of economic benefits and costs. Examples of such criteria include changes in employment, the distribution of economic gains and losses among geographic areas or population sub-groups, difficult-to-quantify environmental or neighborhood quality impacts, property value increases, and improved accessibility to employment, shopping, or recreational opportunities.

Although multi-criteria evaluation shares with incorporating wider economic benefits the idea of expanding the range of benefits and costs beyond those considered in benefit-cost evaluation, they differ fundamentally. Multi-criteria evaluation expands the focus of evaluation beyond measurable economic costs and benefits and the changes in economic welfare they are intended to represent, to include social, aesthetic, and other non-economic considerations. Unlike benefit-cost analysis, it does not attempt to develop quantitative measures or monetary equivalents of all these consequences, instead treating many of them in qualitative and subjective terms. Again, this differs fundamentally from expanding the scope of benefit-cost analysis to incorporate economic impacts that it might otherwise overlook, which is the focus of considering wider economic impacts, so the two will inevitably yield very different assessments of the same proposed investment.

[56] For example, benefit-cost analysis values changes in output at the average of initial and final (or pre- and post-project) prices, while national income and product accounting may value small changes in output at initial prices unless chain-type indices are recomputed at high frequencies. Similarly, benefit-cost analysis typically undervalues savings in travel time that are redeployed into working time, while GDP accounting captures the full productivity value of redeployed time savings.

10. Are Wider Economic Impacts Worth Pursuing?

Even experts in the analysis of wider economic impacts appear to be uncertain about their potential significance or the value of efforts to quantify and monetize them, particularly in nations whose efficiently functioning economies and extensive transportation networks limit the potential for additional investments in transportation infrastructure to promote further agglomeration or more vigorous competition. As one illustration, Rothengatter (2017, 131-132) remarks “While one can assume that wider economic impacts play a big role in developing countries and emerging economies, it is doubtful whether such impacts occur in industrialized countries to a substantial order of magnitude…” Shortly thereafter, however, he asserts that “There are strong reasons to apply wider economic impacts [wider economic impacts] analysis to the assessment of transport infrastructure also in countries which are highly industrialized. It is an illusion to believe that the transportation system is approaching a stationary point of saturation or a steady-state equilibrium.”

One possible resolution of this uncertainty is that most experts would reserve the analysis of wider economic impacts for particularly large or costly projects, where their potential to add significantly to conventionally measured benefits seems largest, and extensive efforts at quantifying wider economic impacts would have the largest payoff in terms of reliably identifying the most attractive investment opportunities (and avoiding particularly risky ones). Other applications where efforts to quantify and monetize wider economic impacts to support investment decisions seem likely to be valuable include combinations of transportation infrastructure projects that would be jointly planned and evaluated, large-scale programs of infrastructure investment extending over prolonged periods, and deployment of advanced technologies that have the potential to alter travel behavior.

Table 4 summarizes the potential wider economic impacts reviewed here, gives summary assessments of their likely empirical significance and the prospects for measuring them reliably, and outlines the tools and data that would be required to do so. As it indicates, most conventional economic impacts that are routinely included in benefit-cost analysis of proposed infrastructure investments are both empirically significant and readily measurable, and these properties are reflected in the fact that such benefits already comprise the focus of most project evaluations. As discussed in detail above, wider economic impacts arising in transportation markets – such as changes in congestion levels, environmental and climate externalities, and transportation safety consequences – are also likely to be at least occasionally significant and readily measurable, again as reflected by the fact that they are now regularly included in benefit-cost evaluation of proposed investments.

Table 4. Summary of Conventional Benefits and Wider Economic Impacts

Nature of Impact	Category (1)		Potentially Significant?	Readily Measurable?	Required Tools
	CB	WEI			
Travel time	X		Yes	Yes	Transportation planning simulation models
Vehicle operating costs	X		Occasionally	Yes	Average values for different vehicle classes
Infrastructure operating and maintenance costs	X		Yes	Yes	Historical agency records, average values by facility type
Logistics reorganization effects	X		Occasionally	Yes	Already included in other benefit categories
Congestion impacts		X	Yes	Challenging	Traffic simulation models, speed-volume relationships
Environmental and climate externalities		X	Often	Yes	Air pollution and climate models, health damage functions
Safety impacts		X	Yes	Yes	Crash reduction factors, injury, and fatality costs
Agglomeration effects on productivity		X	Yes, for large projects	Somewhat	Transportation-land use models Effective density measures and productivity elasticities
Tax revenue on higher earnings		X	Probably not	Yes	Changes in productivity and earnings Marginal tax rates
Increased output in markets with limited competition		X	Probably rarely	No	Region- and market-specific supply and demand curves or elasticities
Lower prices in markets with limited competition		X	Probably rarely	No	Region- and market-specific supply and demand curves or elasticities
Increased variety of shopping, entertainment, or recreational opportunities		X	Potentially	No	Land-use simulation models Estimates of consumers' valuation of increased variety

Nature of Impact	Category (1)		Potentially Significant?	Readily Measurable?	Required Tools
	CB	WEI			
Reducing barriers to development		X	Probably not	No	Site-specific identification and analysis of development barriers

(1) CB indicates conventional economic benefit; WEI indicates wider economic impact.

Table 4 also indicates that agglomeration effects seem likely to be significant at least for some major investments in transportation facilities, although measuring them accurately continues to present the various empirical challenges detailed previously. In contrast, the table speculates that most other wider economic impacts reviewed in previous sections seem unlikely to be empirically significant in the U.S. context, difficult to measure reliably, or both. Of course, these assessments are highly subjective, and others may interpret their potential significance differently based on the theory and evidence presented previously in this review and reported in published research.

Recognizing this situation, a promising strategy for FHWA would be to refine – and correct, where necessary – the assessments of potential empirical significance and prospects for reliable measurement reported in Table 4 for those wider economic impacts that are not already commonly quantified and included in benefit-cost evaluation. These include potential agglomeration effects on productivity and economic output, tax revenue consequences of higher earnings, increased product supply and lower prices in markets where competition is now limited, expanding the variety of shopping, entertainment, or recreational opportunities at sites made more accessible by infrastructure improvements, and reducing barriers to development or redevelopment of urban land parcels.

11. What Additional Research Should FHWA Support?

As the previous section indicates, some wider economic impacts resulting from investments in new or expanded transportation infrastructure appear likely to be both potentially important sources of additional benefits or costs that should be included in economic evaluation, and measurable with approximately the same accuracy as infrastructure's more conventional impacts on travel time and costs. An important first step is to identify those cases and distinguish them from wider impacts that are unlikely to be large and also present difficult measurement challenges, so that FHWA can focus its resources on improving its understanding of the most significant sources of wider economic impacts developing its capability to measure and value them. This first step is likely to demand a serious commitment of resources by itself, but the payoff from a focused effort to understand and measure the specific wider impacts that appear likely to be most widespread and economically significant – and distinguish them from less important impacts – should justify that effort.

11.1 Research Related to Agglomeration Benefits

Virtually all estimates of agglomeration-based wider economic impacts reported to date in either published research or consulting studies for specific projects rely exclusively on static agglomeration effects, which as indicated previously arise from changes in the "effective density" of employment that result from the effect of improved infrastructure on travel times, regardless of whether firms or employees relocate in response. The underlying assumption that changes in travel times are likely to generate the same increases in the frequency of worker and firm interactions and resulting knowledge spillovers as actual physical increases in employment density seems questionable.

Research documenting measured increases in the frequency, duration, or closeness of interactions among workers or firms, and linking these increased interactions to growth in firm-level productivity would provide increased confidence that static agglomeration benefits are a reliable source of wider economic benefits. It could also demonstrate whether those benefits are comparable in magnitude to productivity increases resulting from actual increases in the density of firms or employment at sites that are made more accessible by past infrastructure improvements.

Separately, a detailed assessment of the availability of tools and data required to estimate agglomeration effects and the resulting wider economic impacts from large transportation projects seems potentially valuable. This should include identifying and evaluating models and data that can be used to estimate increases in employment agglomerations at locations where infrastructure improvements would improve access, as well as possible losses in productivity resulting from shifts in employment away from existing agglomerations.

As part of this assessment, identifying reliable measures of industry- or occupation-specific elasticities of productivity with respect to firm or employment density that are derived from analysis of U.S. data could help analysts to refine future estimates of resulting productivity increases for proposed infrastructure projects. More detailed and precise agglomeration elasticities could also enable more confident linkage of productivity increases in individual industries or occupations to specific infrastructure improvements, reducing the risk that economy-wide productivity growth might be mistakenly attributed to infrastructure improvements.

Finally, it would be useful to verify whether estimating increases in income or payroll tax revenues that result from agglomeration-induced changes in productivity and increased earnings is a simple extension of estimating agglomeration-related productivity effects, as appears to be the case. As indicated previously, part of any increase in productivity and earnings that results from increased agglomeration accrues to government in the form of additional tax revenue, so detailed knowledge about tax rates is likely to be necessary to estimate that component of wider economic benefits resulting from agglomeration. This should not require a new research effort, but it could require assembling information on marginal tax rates at both the federal and state levels, including how marginal rates vary with income across different jurisdictions.

11.2 Comparing Different Evaluation Methods

Table 5 compares the measures of benefits and costs on which these different approaches to evaluating infrastructure investments focus and identifies the models and other analytic tools that each approach commonly uses to estimate the impacts of alternative investments. As the table indicates, conventional benefit-cost analysis focuses on a limited set of very specific measures, often employs specialized travel demand and traffic analysis models to calculate them, and requires estimates of economic parameters such as values of travel time for different trip purposes and for reducing injuries of varying severity. To supplement these with estimates of the various wider economic impacts described above, additional specialized models and estimates of economic parameters such as productivity elasticities and health damage costs are also required.

Table 5. Key Measures and Tools Used in Alternative Evaluation Methods

Evaluation Method	Conventional Benefit-Cost Analysis	Benefit-Cost Analysis, Supplemented with Wider Economic Impacts	Local or Regional Economic Impact Evaluation	Macroeconomic Impact Measurement
Key Measures	Savings in travel and shipping times Improved reliability of travel and shipment times Savings in vehicle operating costs Value of reductions in fatalities, injuries, and property damage from crashes	Savings in travel and shipping times Improved reliability of travel and shipment times Savings in vehicle operating costs Value of reductions in fatalities, injuries, and property damage from crashes Reductions in congestion and environmental externalities Productivity increases from larger employment agglomerations Lower prices and increased output in imperfectly competitive markets Some land development impacts	Local and regional employment Consumer spending or retail sales Property values Local tax revenues	Labor and total factor productivity Gross Domestic Product Household and Personal Income

Evaluation Method	Conventional Benefit-Cost Analysis	Benefit-Cost Analysis, Supplemented with Wider Economic Impacts	Local or Regional Economic Impact Evaluation	Macroeconomic Impact Measurement
Common Tools	Travel demand, traffic, and network simulation models Vehicle fuel consumption and operating cost models Values of travel time and future fuel prices Unit values for reducing injuries, fatalities, and vehicle damage	Travel demand, traffic, and network simulation models Vehicle fuel consumption and emission models Values of travel time, future fuel prices, and emission damage costs Urban development and land use simulation models Econometric estimates of productivity elasticities with respect to employment density Product supply and demand elasticities	State, regional or county input-output models	Macroeconomic forecasting models Spatial computable general equilibrium (CGE) models

In contrast, evaluating the local or regional economic impacts of proposed investments in transportation infrastructure focuses on measures such as increases in local employment (sometimes by specific industry), retail sales, tax revenues, and property values. While these individual impacts are occasionally estimated on an ad hoc basis, more common practice is to use a local or regional input-output model to estimate a comprehensive, internally consistent set of these and other impacts. Macroeconomic measurement of costs and benefits from proposed investments typically focuses on their consequences for GDP, mean or median income at the household or individual level, and labor or other productivity measures. These estimates are usually measured using large-scale econometric models of a regional or national economy, or more recently, using computable general equilibrium (CGE) models, often those that include the capability to measure detailed spatial allocation of economic activities and changes in aggregate output and income measures.

The clear implication of the distinctions among the measures these different evaluation methods focus on that are highlighted in Table 5 is that they represent fundamentally different approaches to assessing the desirability of proposed projects. Although each approach attempts to measure economic benefits and costs associated with competing investment proposals, they define benefits and costs somewhat differently, measure them at varying geographic scales and from differing perspectives, and rely on different types of models and other analytic approaches to do so. The three approaches should be viewed as serving distinct purposes, and generally cannot substitute readily for one another. The emphasis of this report is on identifying and measuring potential wider economic impacts arising from investments in transportation infrastructure, rather than on comparing the advantages of supplementing benefit-cost analysis with wider economic impacts to adopting alternative evaluation methods.

11.3 Wider Economic Impacts from Increased Competition

As Section 6 previously indicated, limited competition can in theory be the source of two categories of wider economic benefits, but the empirical significance of both depends on whether competition in specific industries and regions of the U.S. is adequate to ensure that prices adhere closely to marginal costs for producing and transporting products. If wider economic impacts arising from increased competition are considered potentially significant – as benefit-cost guidance for the U.K. and other nations seems to treat them – it will be important to identify geographic regions of the U.S. where the limited extent of transportation infrastructure currently inhibits access and may restrict competition, and to pinpoint the specific products for which competition among suppliers is limited and price-cost margins are excessive. Equally important, government agencies funding infrastructure investments will need the capability to assess whether proposed projects include the types and levels of infrastructure investment that would improve supply routes to isolated regions sufficiently to enable new competitors to serve those markets.

11.4 Refining Our Understanding of Wider Economic Impacts from Land Development

Potential wider economic impacts created by development (or redevelopment and intensification) of sites where investing in new or improved transportation infrastructure improves accessibility and raises the value of land are perhaps the least well-understood and carefully researched source of wider economic impacts. As Section 7 previously discussed, their empirical significance relies on factors including regulatory barriers to land development, coordination or decision-related market failures in land markets and development decisions, and the magnitude of benefits from increased variety in adjacent land uses.

To assess the potential value of these "variety effects" from improving transportation access, it would be useful to review available research on consumers' valuation of increased product variety at shopping destinations, the market value of diversity in living opportunities within residential areas, and the utility provided by making a wider range of recreational opportunities available at desirable sites. Surveying local planning agencies and potential sponsors of infrastructure projects (such as state DOTs, MPOs, or transit agencies) to identify locations where regulatory barriers or market failures currently impede more intense development, and to assess where the project planning process provides opportunities to relax or overcome them, could also make a useful contribution to assessing potential wider benefits from accessibility-induced land development.

11.5 Resolving Whether "Logistics Reorganization" is a Potential Source of Wider Economic Benefits

Sponsors of proposed improvements to freight transportation infrastructure sometimes claim as part of their economic evaluations or funding applications that these projects will enable firms to improve supply chain operations and reduce logistics costs, but that the resulting benefits may be overlooked in conventional project assessment. Commercial software is even available to assist firms who are potential beneficiaries or project planners in estimating the dollar magnitude of such benefits, thus lending them apparent credibility.

Yet as Section 8 above described, many analysts classify these as conventional cost-saving benefits that arise from substitution of transportation services for other production inputs, which would be captured fully in normal benefit-cost evaluation of proposed infrastructure improvements. Although logistics reorganization benefits have previously been one of the sources of wider economic benefits addressed by at least two major studies, it would be extremely useful to conduct additional research to identify the specific conditions under which these benefits are unlikely to be captured in conventional economic evaluation and require separate measurement.[57]

[57] See NCHPR Report 786, *Assessing Productivity Impacts of Transportation Investments*, Chapters 3 and 5; and Strategic Highway Research Program-2 Report S2-C11-RW-1, *Development of Tools for Assessing Wider Economic Benefits of Transportation*.

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