Does Benefit-Cost Analysis 'Miss All the Important Stuff?' Wider Economic Impacts from Investing in Infrastructure

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Abstract

Investing in transportation infrastructure can generate economic consequences that will not be reflected in the conventional measures of benefits and costs used in economic evaluation of proposed investments. This paper offers a unifying theoretical framework to explain how such "wider economic impacts" of infrastructure investment can originate, which has been a critical omission from previous research on the subject. It uses this framework to identify situations where conventional economic evaluation of infrastructure investments may overlook certain benefits or costs, identifies the types of investments where this is most likely to occur, outlines possible methods for measuring wider benefits and costs, and assesses their potential empirical significance.

Wider economic impacts can arise where producing and distributing products – including transportation services themselves – generates unintentional but harmful by-products ("externalities"), where building new infrastructure permits larger employment agglomerations, expands access to job opportunities, enables more vigorous competition, or spurs more intensive land development, and possibly where firms reorganize supply chains to take advantage of lower-cost or more reliable transportation. In these situations, 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.

While negative externalities from transportation activity are a likely source of overlooked costs, these are well understood and already commonly included in benefit-cost evaluation of proposed infrastructure projects. Enabling larger spatial concentrations of employment can be a source of potentially significant overlooked benefits (and possibly costs as well), but I argue that other alleged sources of such wider benefits are either likely to be comparatively modest or already treated correctly in economic evaluation. Finally, I explore whether measuring changes in GDP is likely to provide a more comprehensive measure of benefits and costs from infrastructure investments than is augmenting the usual consumer and producer surplus measures on which benefit-cost evaluation relies to incorporate any wider benefits or costs they overlook.

1. What are Wider Economic Impacts?

Economic evaluation of proposed investments in public infrastructure relies on measuring benefits and costs experienced by users of the services it would provide, including households, operators and customers of commercial services that use infrastructure, and public agencies that invest in and operate it. Where externalities generated by the use of infrastructure and by producing and consuming products that rely on it as an input are rare and markets for those products are competitive, benefits from expanding infrastructure will usually be fully reflected in the customary measures of consumer and producer surplus gains to its users and operators, and cost-benefit analysis of proposed investments will yield dependable assessments of their desirability.

Externalities, market failures, or inadequate competition, however, can prevent benefits or costs originating from changes market prices and output of products that rely on infrastructure for their production and distribution from being accurately transmitted to markets for infrastructure services themselves or for commercial services that use infrastructure as an input, where benefits and costs from new or expanded infrastructure are typically measured.[1] In their presence, investing in infrastructure can generate benefits or costs that may not be reflected in conventional measures of users' surpluses, and these need to be estimated separately and added to conventional benefit and cost measures to ensure reliable evaluation of proposed improvements.

These potentially overlooked benefits and costs are usually referred to as wider economic impacts – recognizing their potential to include missing costs as well as overlooked benefits – from infrastructure investments. This paper explores their origin, outlines methods for measuring them, and assesses their potential economic significance using the example of public investments in transportation infrastructure, particularly roads and highways. It first presents a unifying theoretical framework to explain how such wider economic impacts can originate, a feature conspicuously absent from previous research on the subject.

Although there is now an extensive literature on measuring supplemental (or "spillover") benefits from the larger or more dense spatial concentrations of firms and employment that some investments in transportation infrastructure enable – see Graham and Gibbons (2017) for an overview – even general treatments of the subject lack an overarching perspective on how and why wider economic impacts originate. As one example, Rothengatter (2017) begins by asserting that wider economic impacts are generated by market imperfections and thus likely to arise frequently, but turns immediately to a typology of measurement schemes and potentially useful models for estimating their value. Laird and Venables' (2017) more systematic survey does present an overarching framework to classify and evaluate potential wider economic impacts, but

[1] I say "markets" because neither private nor commercial users of infrastructure services typically purchase them in conventional market transactions; instead, they are most often rationed on a first-come, first-served basis and funded indirectly via taxes or government-imposed fees. Nevertheless, measuring the benefits they provide usually assumes the presence of hypothetical markets where their equilibrium use and associated user costs are determined. For a detailed example, see footnote 8 below.

appears to treat each category as arising from independent and "contextual" sources, seemingly without a common foundation.

I develop this unifying framework in some detail before using it to identify situations where conventional economic evaluation of infrastructure investments is likely to overlook certain benefits or costs. Briefly, wider economic impacts arise where market failures such as externalities or inadequate competition arise in markets for products that are transported for sale, or in input markets where transportation plays an important role, such as those for raw materials, labor, or urban land. Departures from efficient markets can prevent benefits or costs from improvements to transportation infrastructure – which originate from their impacts on production costs, market prices, and economic output of transportation-using goods and services – from being fully or accurately reflected in benefits and costs experienced by infrastructure users themselves, which are the common currency of economic evaluation.

Specifically, benefit-cost analysis of proposed infrastructure investments will 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.[2] After identifying the types of investments where this situation is most likely to occur, I outline possible methods for measuring the wider benefits and costs that can result, and assess their potential empirical significance. Finally, I show why measuring benefits and costs from major investments in infrastructure using changes in GDP – an approach that some analysts recommend as an alternative to relying on consumer and producer surplus measures of economic benefits and costs – is unlikely to produce more comprehensive assessment of proposed investments.

Section 2 of this paper briefly explores the intellectual origins of wider economic benefits, while section 3 illustrates why and how they can arise. Sections 4 through 8 focus on specific sources of wider economic benefits and costs from investments in transportation infrastructure, including externalities generated by transportation activity itself, enabling larger concentrations of employment, improving access and competition, promoting new land development, and facilitating reorganization of firms' product distribution networks. Each section also outlines procedures for measuring that category of wider benefits, and briefly assesses their likely empirical significance. Section 9 contrasts the likely outcome of including wider benefits in benefit-cost analysis of infrastructure projects with resorting to macroeconomic measures of their costs and benefits to evaluate proposed investments. Finally, section 10 addresses the question of how concerned analysts should be with the potential for wider economic costs or benefits when analyzing and evaluating proposed investments in public infrastructure.

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[2] I believe – but admittedly do not demonstrate in this paper – that this same result applies to economic evaluation of investments in other forms of public infrastructure such as water supply and distribution, utility services, etc.

2. Intellectual Foundations

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 were likely to foster major increases in the usage of the facilities they added or expanded. 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, which incorporated both cost savings to users of existing facilities and a measure of gains from their expanded use.[3]

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.[4] 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. Although Marshall's consumer surplus measure ultimately became the norm in benefit-cost analysis, this distinction seems to have 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.

3. How Wider Economic Impacts Can Originate

Investments that expand the coverage or increase the capacity of transportation facilities reduce costs for shipping freight by increasing travel speeds for trucks, trains, or waterborne vessels, enabling their operators to economize on labor and vehicle capital inputs and reducing shippers' inventory costs for cargo in transit.[5] Where products that utilize freight transportation in their production and distribution are sold in competitive markets, reductions in shipping 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. The resulting increases in

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[3] 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.

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

[5] 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.

consumer and producer surplus in product markets will normally be reflected in consumer surplus gains from use of the transportation services that firms depend on to produce and deliver their products, whether those firms utilize for-hire 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 households to "produce" transportation services and by commercial operators of transportation services will be reflected in faster travel and lower vehicle operating costs. In turn, these reduce users' travel costs and spur increased use of the services that transportation infrastructure provides.[6] In the absence of market failures, benefits from faster travel, lower costs, and increased use will all be translated accurately into gains in consumer surplus from households' and transportation service operators' use of improved infrastructure.

The Ideal Situation

Figure 1 and Figure 2 illustrate the measurement of benefits from an investment in transportation infrastructure that enables faster shipping times and lower costs for raw materials and products.[7] 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 lower costs for producers who 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 reflects the reduction in transportation costs to produce and deliver the product.

In response, the delivered price of the product declines from P_1 to P_2 while its consumption increases from Q_1 to Q_2. As Figure 1 suggests, the decline in price is smaller than the savings in shipping costs because the supply or marginal cost curve slopes upward, reflecting producers' increasing costs to supply more of the product.[8] Both consumers and producers benefit from the reduction in price and the resulting increase in the quantity 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 buyers who are attracted by its lower delivered price.

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[6] The user cost of personal travel is usually defined to include both monetary costs such as vehicle ownership and operating expenses or fares charged to passengers, plus the economic value of travelers' time.

[7] 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.

[8] 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.

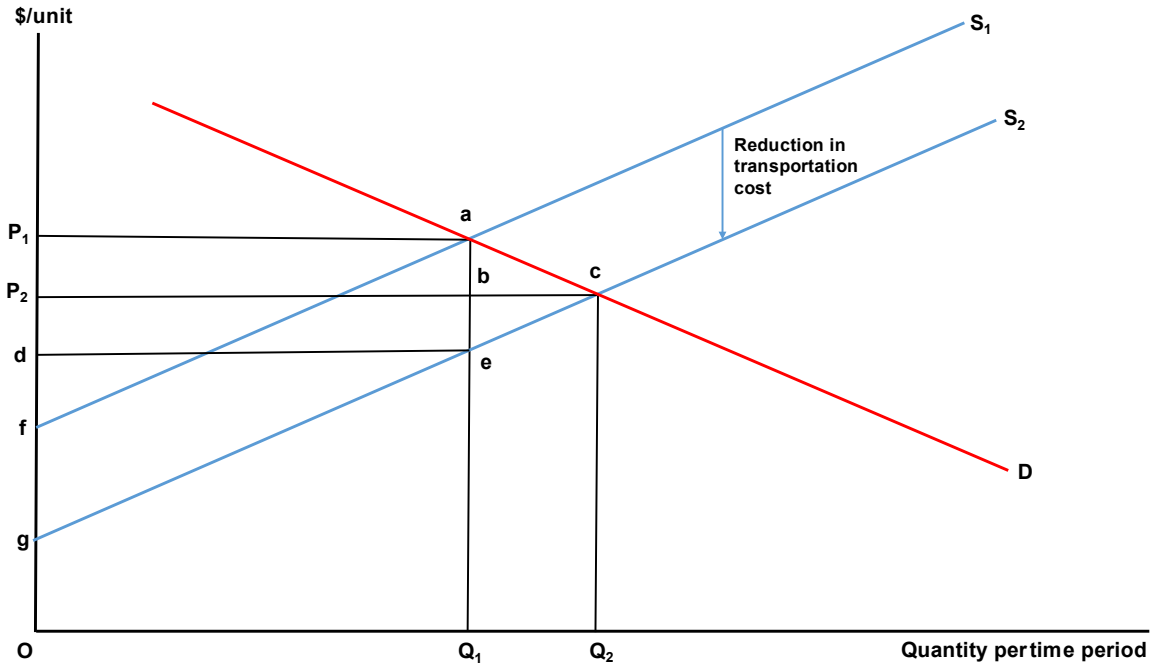


Figure 1. Benefits from Reduced Transportation Costs in the Product Market

Producers also benefit, in part because the product's price declines by less than their savings in transportation costs to produce and deliver each unit, increasing 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, so the producer surplus they earn from producing and distributing the previous quantity Q_1 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, the rectangular area Q_1bcQ_2, minus their incremental costs to produce and deliver that additional quantity, area Q_1ecQ_2; the difference is their gain in producer surplus on the increased quantity they sell, 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, 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. 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.[9] Because freight vehicles utilize the capacity that highway, rail, or water infrastructure provides, the horizontal axis of Figure 2 can also be interpreted as measuring freight carriers' increased use of the services that the new or expanded infrastructure provides.[10]

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 time-related 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, and in the cost to shippers who use trucking services. Where for-hire trucking companies operate in a competitive market, these savings in their operating costs will be reflected in lower freight rates, while firms that operate their own shipping subsidiaries will experience the cost reduction directly. In either case, lower shipping costs will ultimately be reflected in the reduction in delivered prices for transported products illustrated in Figure 1.

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[9] 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.

[10] Operators of commercial transportation services such as trucking firms or barge operators do not explicitly purchase the services that publicly provided infrastructure (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 (which often produces congestion and increases time-related costs). 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 typically measured as if markets for their transportation services existed, rather than attempting to measure those benefits in a theoretical market for infrastructure services.

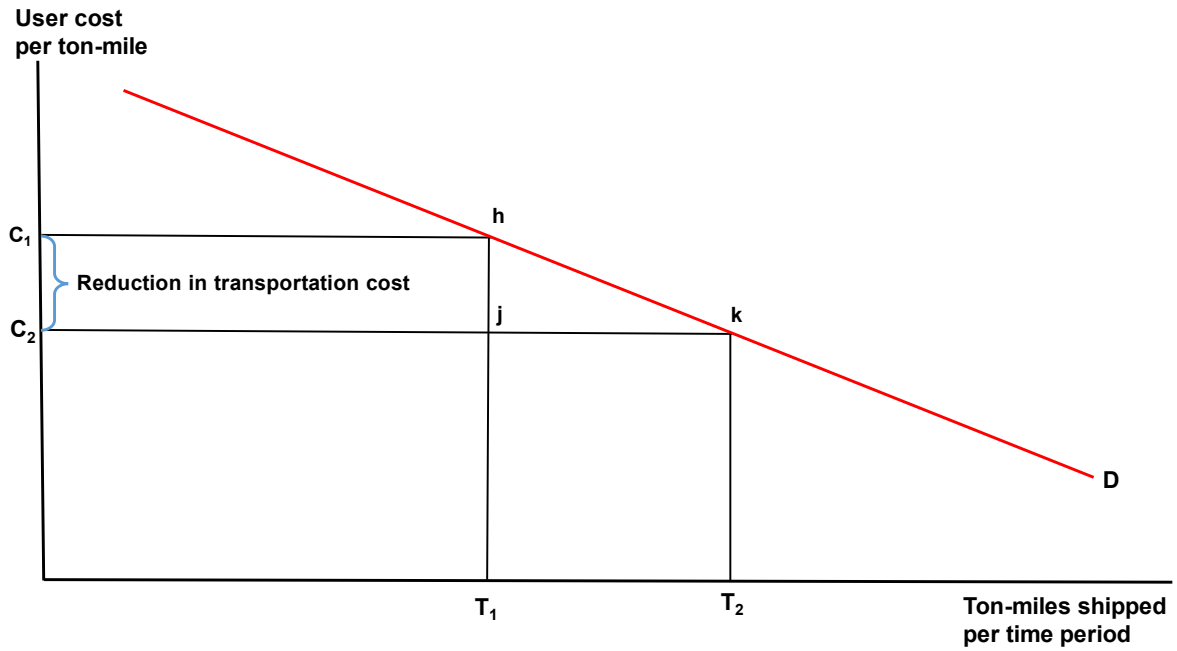


Figure 2. Benefits from Reduced Transportation Costs in the Transportation Market

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.[11]

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; 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

[11] 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. 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.

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 sold (Q_1 in Figure 1).

Triangle hjk in Figure 2 reflects the benefits to product suppliers – acting in their role as consumers of trucking services – from purchasing the *additional* services necessary to produce and distribute the increased amount of the good they can 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 ($T_2 – T_1$), which is exactly the same as the area of triangle aec in Figure 1.[12] 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.[13]

Thus where markets for transportation services and for the products they are used to produce and deliver are competitive, and neither the production of transportation services nor the goods they carry generates 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*.[14] Again, the logic can seem more complicated in the case of personal transportation, but it is exactly analogous: travelers using public (or "com-

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[12] 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.

[13] 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.

[14] 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.

mon 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.[15] Where households produce transportation services for their members' use, 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 not generate significant externalities for benefits measured from changes in users' costs and "consumption" of transportation infrastructure to accurately convey the economic benefits from improving it.

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. 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.[16] 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 increases 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), the economic benefits of infrastructure improvements to their suppliers and consumers that are transmitted back to markets for transportation or infrastructure services will not incorporate the spillover cost or value of those externalities. Where this occurs,

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

[16] 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.

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. Savings to users of improved infrastructure will be accurately reflected in lower product costs, but limited competition may prevent those savings from being fully translated into reduced product prices and increases in consumption. Consequently, some fraction of benefits from infrastructure improvements may not be reflected in increased transportation activity and consumer surplus gains to users of transportation or infrastructure services and is likely to be overlooked in cost-benefit analysis of proposed investments. The following sections expand on each of these situations.

4. 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 shifts in transportation activity in response to investments that increase the capacity of selected facilities and lower transportation costs. Because they are now commonly included as part of economic evaluation, changes in these externalities are not often described as wider economic benefits, although they do meet its definition: benefits that are not included in the usual measures of changes in consumer and producer surplus to users of new or expanded infrastructure.[17]

Some (or even most) new users of an improved facility may be drawn from alternative routes or travel modes, and Figure 3 illustrates the resulting change in the use of one such alternative. Because the newly improved facility now offers a better substitute, demand for its use shifts inward from D_1 to D_2 in response to the reduction in users' costs for travel on 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, and the benefits they experience by doing so are reflected in the gain in consumer surplus from its increased use.

[17] 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.

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. This benefit, however, is *not* captured in the gain in consumer surplus from increased use of the improved facility, and because it represents a benefit from the improvement *in addition to* the gains in consumer surplus to newly attracted users of the improved route or facility shown previously in Figure 2, it is an example of a wider economic benefit.[18]

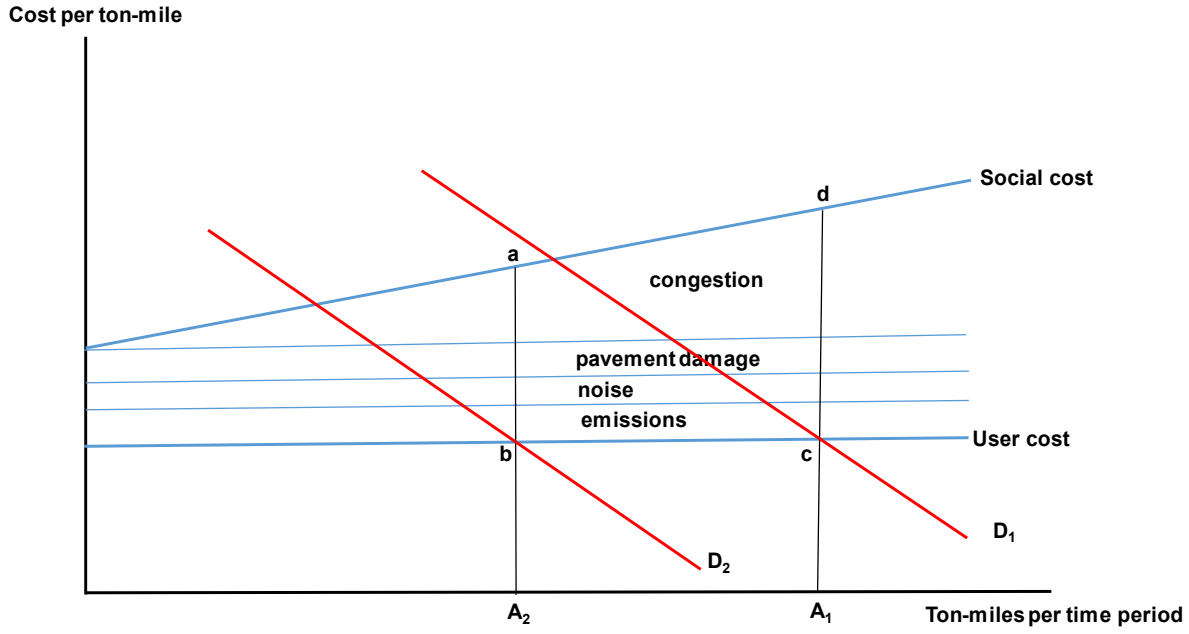


Figure 3. Reduction in Externalities from Transportation Activity on Competing Route or Mode

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 several billion dollars annually), and while motor vehicles' emissions of ground-level air pollutants have declined significantly in recent decades,

[18] 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.

they still account for significant economic costs by contributing to the health damages suffered by those who are exposed to air pollution.[19] 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 value.

The economic value of reduced externalities can be readily estimated and included as a supplemental benefit in economic evaluation of proposed infrastructure projects.[20] Methods for measuring changes in congestion delays and their economic cost are well developed, and include simplified queueing formulas, detailed traffic simulation models, and network-wide traffic assignment models that incorporate empirical relationships between speed and traffic volumes on individual network links. Values of travel time and estimates of vehicle occupancy, which are necessary to convert vehicle delays into economic costs of occupants' travel time, are also well-established, and U.S. Department of Transportation guidance presents representative estimates of both (U.S. Department of Transportation, 2023).

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 also publishes estimates of emissions for aircraft, locomotives, and other non-highway forms of transportation. 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, so reducing these emissions can also add significantly to benefits from investment in improved infrastructure.

5. Agglomeration Benefits

The most widely analyzed category of wider economic benefits from investing in new or expanded transportation infrastructure is gains in labor productivity from the increased clustering of firms and employment that high-capacity transportation services or facilities enable. Such clustering can occur in traditional central business districts of large cities, satellite employment centers outside downtowns, or where firms in related industries co-locate in lower-density suburban areas. The increased scale of production and more intensive interaction among workers

[19] 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 $0.10-0.11 in the form of congestion delays to occupants of other vehicles.

[20] Of course, it is also important to account any increase in the costs of these externalities resulting from additional use of new or expanded infrastructure.

and firms that larger concentrations of economic activity permit can lead to more rapid diffusion of technological innovations, greater specialization of products and skills, and higher productivity of workers, firms, and even entire industries.

As one example, 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 more likely to generate "knowledge spillovers," particularly where firms in closely related sectors co-locate.

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. If these productivity gains are shared with neighboring firms and not fully captured by the firms who generate them, 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.

The Basis for Agglomeration Benefits[21]

Figure 4 illustrates 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

[21] This analysis focuses on the firm-level origin of agglomeration benefits; Venables (2207) develops the case for such benefits at the scale of an entire metropolitan area, where major investments in transportation infrastructure facilitate larger central employment concentrations by expanding the geographic scope of the local labor market.

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.

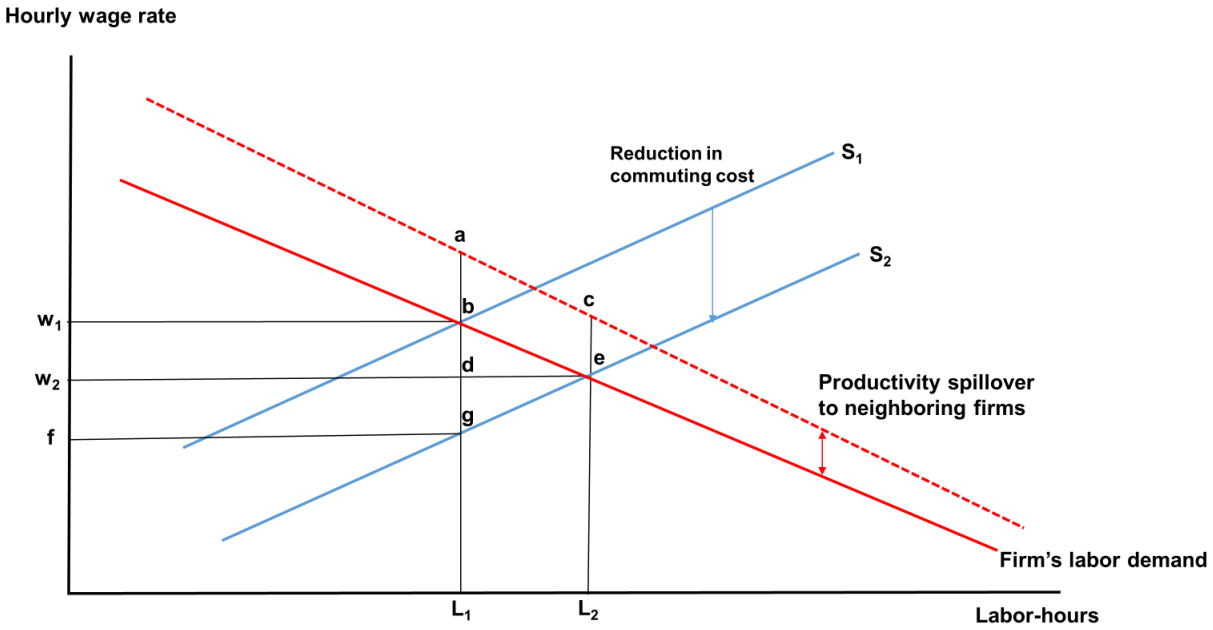


Figure 4. Benefits from Increased Agglomeration Measured in the Labor Market

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 the figure shows that distance declining at higher employment levels to reflect the likelihood that the incremental productivity spillover from hiring successive additional employees diminishes gradually.

When improving transportation service to a site where firms 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.[22] In response, a single 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.

As in Figure 1 above, benefits 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_1bdw_2, and earns a net return equal to area bde on the additional $(L_2 – L_1)$ employees it hires.[23] 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_1bdw_2 in wages but save the area w_1bgf in commuting costs, so on balance they benefit by the area w_2dgf. Newly hired workers benefit by the amount of area deg, which measures the difference between the wages they receive and the (now reduced) 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 as measured in the market for transportation services. Area w_1bgf corresponds to the increase in consumer surplus to commuters originally using the facility or service, who save travel time and monetary costs for commuting (and may endure less onerous 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 internalized the value of this productivity spillover. 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 benefit

[22] 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.

[23] Area abc is equal to the gross value to the firm of the additional output the newly hired workers produce, area acL_2L_1, minus the wages it pays them, area bcL_2L_1.

from the investment in improved infrastructure, which stems from the larger agglomeration of firms and workers it enables.

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 and time burden 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.[24] 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.

Since this process can occur even where households and firms do not actually 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

[24] 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.

and include their value as a supplemental source of benefits in economic evaluation of proposed infrastructure projects.[25]

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 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 response also 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 thus affects their relative magnitude and the net change in productivity within the entire region.

Measuring Agglomeration Benefits

The economic value of productivity gains enabled by investments in transportation infrastructure that promote larger employment agglomerations is surprisingly straightforward to estimate, at least in concept. Graham and Gibbons (2019) describe a detailed process (dating originally to Graham (2007)) for estimating agglomeration effects from infrastructure investments and imputing their economic value.[26] 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 within the region, with the interaction between employment in each pair of zones weighted inversely by users' cost or the transportation system's "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 to more distant) zones, producing static agglomeration benefits. In the longer term, they can also 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. In either case, an elasticity of productivity with

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[25] 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.

[26] The U.K. Department for Transport's guidance for incorporating wider economic impacts in economic evaluation (2020) follows this process, outlining a sequence of steps for quantifying the effects of proposed investments in transportation infrastructure on employment agglomeration and productivity. It also identifies specific data sources required to measure them and describes the required calculations in detail.

respect to employment density is applied to the increase to estimate the proportional increase in output per worker, which is in turn scaled by the initial wage rate and employment level to produce a dollar-denominated estimate of increased economic output. This calculation is usually performed for specific industries and geographic zones and the results summed to produce a total increase output within the area served by improved infrastructure.[27]

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 it is also 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.

Empirical Estimates

A key determinant of the magnitude of agglomeration benefits is the response of productivity to increased employment density, summarized by the elasticity of productivity with respect to the effective density of employment. Most recent empirical 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%.

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. Most investments are likely to produce important changes in travel times or costs – and thus in effective employment density – over only a very limited geographic 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.

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[27] 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 or some other measure of a zone's "economic mass," the specific transportation cost function to employ, and the value of the "decay parameter" that translates transportation costs into a measure of impedance or resistance to interactions between zones. 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.

To date, empirical estimates of wider economic benefits from increased agglomeration have been reported for only a handful of proposed infrastructure investments, but some of these have suggested they could add substantially to conventionally measured project benefits. 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. He showed that with plausible productivity elasticities, the value of productivity gains stemming from larger employment concentrations might even *exceed* the investment's conventionally measured transportation benefits. Graham (2007) reported that the U.K. Department for Transport (DfT) used his 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 new subway line could add 24% to the project's estimated time-saving benefits for users.

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) subsequently estimated that agglomeration-related benefits for the same Sydney-area commuter rail project. would amount to 5% of the project's anticipated travel time savings and other conventional benefits, double the fraction estimated in Hensher's 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 relied on 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 aggregated these to a national total. 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.[28]

[28] 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

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 effective density of employment in outlying regions of the nation. The method used to estimate benefits followed the procedure recommended by U.K. guidance, including using its recommended values for productivity elasticities and the distance decay parameter to calculate changes in effective employment density. The resulting estimates of agglomeration-related benefits 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 that reduce costs for shipping raw materials and finished products can be "hidden" by suppliers' market power and not transmitted to the market for transportation services, so the usual measure of benefits in the transportation market will miss them.

Benefits from Lower Transportation Costs with Limited Competition

Figure 5 below depicts a non-competitive market for a product that requires transportation to produce and distribute. The sole producer faces increasing marginal production costs and constant transportation costs for assembling raw materials and delivering its product to customers, yielding the initial supply curve labeled S_1 in the figure. The firm faces a downward-sloping demand curve and can sell more only by lowering its price, so the marginal 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.

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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 24 above).

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 to produce and deliver more. At its initial level of transportation costs, this producer elects to supply Q_1 per time period and charges P_1, the maximum price that customers are willing to pay. The firm collects total revenue equal to area OP_1aQ_1, incurs area $OedQ_1$ in production and transportation costs, and earns area eP_1ad in profits or producer surplus. When improving local infrastructure reduces the supplier's transportation costs, its supply curve shifts downward to S_2, changing its highest-profit strategy to producing Q_2 and selling at a lower price P_2. With this new strategy, the supplier collects OP_2bQ_2 in revenue and incurs production plus transportation costs of $OfhQ_2$, leaving it with fP_2bh in profits.

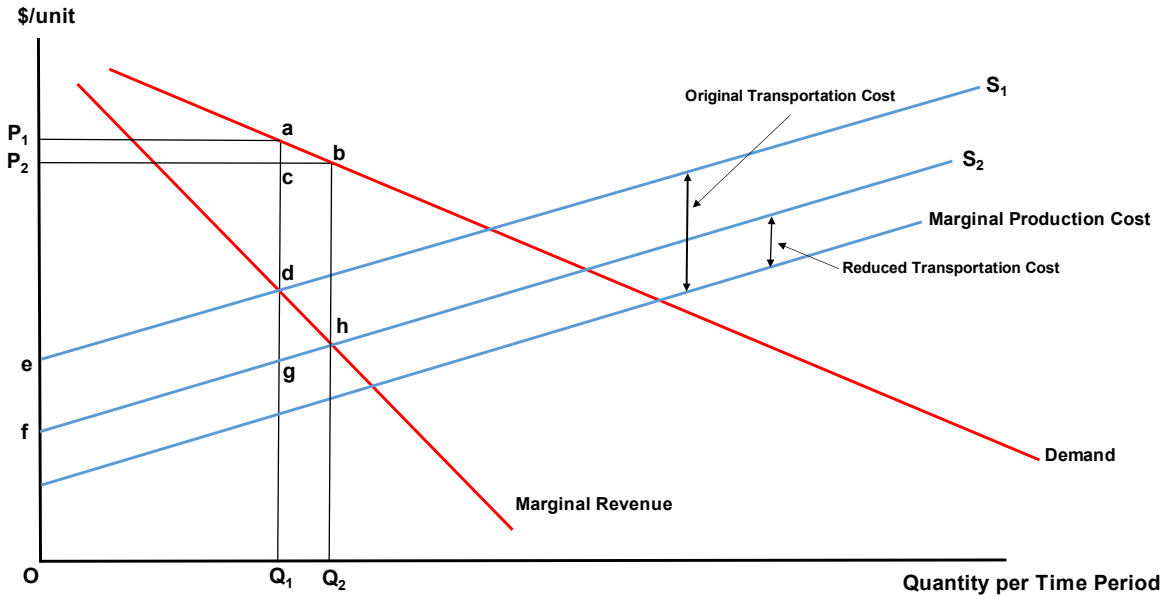


Figure 5. Effect of Reduced Transportation Costs when Producers Have Market Power

Thus its profits have increased by ($fP_2bh - eP_1ad$), of which $fedg$ represents savings in transportation costs on the quantity it previously supplied; as in the competitive case, this savings will be measured in the transportation market as a gain in consumer surplus to freight carriers (or to the producer itself, if it operates its own shipping subsidiary).[29] The triangular area dhg in Figure 5, the difference between the producer's increased revenue (area Q_1dhQ_2) and its additional costs (area Q_1ghQ_2), measures the producer's gain in profit (or producer surplus) from producing and

[29] Less of the savings in transportation costs will be shared with consumers via a reduction in the product's delivered price than in the competitive case shown in Figure 1, but the important point is that all of it will be recorded as an increase in consumer surplus measured in the transportation market.

selling the additional output ($Q_2 – Q_1$). Its value equals one-half of the reduction in transportation costs times the increase in output, and will be reflected as the usual gain in consumer surplus from additional shipping activity measured in the transportation market.[30]

Unlike in a competitive market, however, the gain in consumer surplus from increased consumption of the product – triangle abc in Figure 5 – will be omitted from the gain in consumer surplus on increased shipping activity when it is measured in the transportation market. 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 transportation cost savings. By doing so, it prevents the resulting gain in consumer surplus from increased consumption from being incorporated in the gain in consumer surplus on increased shipping activity measured in the transportation market. Although arguably modest, 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). How frequently these situations occur seems likely to depend on the geographic scope and coverage of transportation networks and the effectiveness of government policies in limiting market power. Where infrastructure investments reduce transportation costs for multiple less-than-competitive industries, wider economic impacts from increased output and lower prices for their products could be significant in total. In highly competitive, spatially integrated economies, however, 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.

Measurement Challenges

Measuring wider economic benefits from improving transportation infrastructure where suppliers exercise market power 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. Estimating the resulting increase in consumption would also require knowledge of demand elasticities for those products within the relevant geographic market areas.

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%

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[30] 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 between Q_1 and Q_2, since it reflects *both* the revenue gain from producing and selling additional output and the loss from having to reduce its price on its original sales; this is the area Q_1dhQ_2 in Figure 5. 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.

markup ("uplift") to savings in business travel time and to costs and benefits to freight shippers, to account for potential wider benefits in imperfectly competitive markets. This allowance appears to be based on an 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 reduce product prices. An alternative approach would be to require analysts to base project-specific estimates of wider economic benefits 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 any supplemental benefits.

7. Wider Economic Impacts in the Urban Land Market

Public investment in new or expanded infrastructure can encourage complementary investments in private infrastructure, including in the form of more intensive land development at sites where improving access makes it more desirable for employers, retailers, or residents to locate. As the benefits from savings in users' costs and travel time that improved infrastructure provides are reflected in higher land values at sites it makes more accessible, economic returns to private development increase and attract new investment there. Where 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. But if land market outcomes are distorted by spillovers, limited competition, or other sources of inefficiency, 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.[31]

Some analysts assert that such situations can occur where agglomeration-type spillovers in commercial development generate external benefits that are not fully reflected in economic returns that private developers realize, and where infrastructure investment acts as a catalyst for overcoming market or regulatory barriers to land development.[32] The former parallels the situation where increased agglomeration of employment generates productivity spillovers that create benefits the firms whose location decisions generate them cannot capture themselves, while in

[31] A more important problem seems likely to be that such market failures will inhibit optimal investment in new development, so that both new infrastructure and the sites it makes more accessible remain underutilized.

[32] The clearest statement of this view appears in Laird and Venables (2017), Section 2.4.2.

the latter case infrastructure investments could "unlock" the previously restricted development value of sites it makes more accessible or desirable.

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 it 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.[33] 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 might 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 consumer surplus from using the improved infrastructure, and would need to be measured separately and added to the conventional measure of welfare gains.[34]

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 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

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[33] 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.

[34] As always, 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.

other extreme, 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 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. Nevertheless, there seem likely to be more direct and effective mechanisms to overcome these barriers than making costly investments in new transportation infrastructure.

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 incomplete. 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.[35] 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.

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 utility gains from further diversification of choices, so the marginal value of successive increases in variety seems likely to be declining. Measuring the value of shopping or

[35] 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.

entertainment choices also seems likely to pose difficult empirical challenges, and applying universal "markup factors" based on theoretical computations or isolated empirical studies seem likely to overstate the frequency and value of such benefits in many settings, and potentially even to invite abuse.[36]

8. "Logistics Reorganization" Benefits

Investments in highway, rail, or waterway infrastructure can speed up freight shipments and increase the likelihood that they will be delivered on schedule. Some firms may reorganize their production and distribution networks in response to availability of faster and more reliable shipping, effectively substituting more frequent deliveries or shipments for larger inventory holdings of raw materials or finished products. These "reorganization effects" may even extend to firms relocating or consolidating production facilities and warehousing locations in response to faster or more reliable shipment times.[37] The resulting savings in firms' costs for assembling raw materials and distributing their finished products are often asserted to represent wider economic benefits from investments in improved infrastructure, which will not be captured in conventional benefit-cost evaluation and must be calculated separately.

Despite these assertions, there is no clear market failure that would inhibit firms' inventory and production cost savings as they substitute more frequent orders and deliveries for reduced inventory holdings and warehouse space from being reflected in their savings in transportation costs and increased demand for shipping services. Thus, any reduction in their "supply chain" costs should be captured by the increases in consumer surplus measured in the transportation market and relied upon by benefit-cost analysis. The same is true for increases in output and consumption of products supplied by firms whose reduced logistics costs enable them to lower their delivered prices: no obvious market failure prevents the resulting increases in consumer and producer surplus in product markets from being conveyed to the market for transportation services. Hence all economic benefits from lower logistics costs and product prices enabled by improving infrastructure should be captured by increased consumer surplus from as measured in the market for freight transportation.[38]

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[36] 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.

[37] 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 complete and more detailed version of this argument appears in FHWA (2001).

[38] 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.

Mohring and Williamson (1969) demonstrated this result more than 50 years ago.[39] Figure 6, which is adapted from that source, illustrates why 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 benefits. 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 6 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 distance products travel to reach customers, or making more frequent shipments out of its smaller inventory.[40] 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 materials or products and of substitutes such as holding inventory or renting warehouse space.

[39] Their argument was repeated in FHWA (2001, Section 3.2.3), although later sections of that document appear to contradict it. 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 manufacturing technologies)," but 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]

[40] 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.

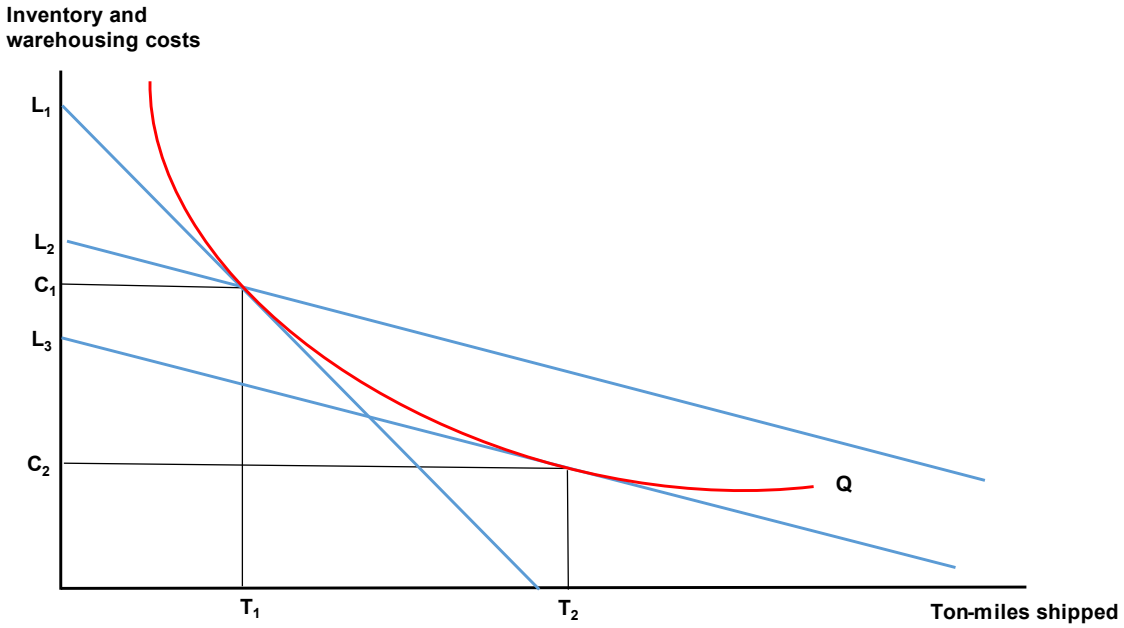


Figure 6. Logistics Reorganization Effects from Improved Transportation Infrastructure

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 6, 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 6, 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 addi-

tional benefit to the firm, 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.[41]

Figure 7– 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.[42] 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 6 increases its use of shipping from T_1 to T_2, exactly as shown originally in Figure 2.

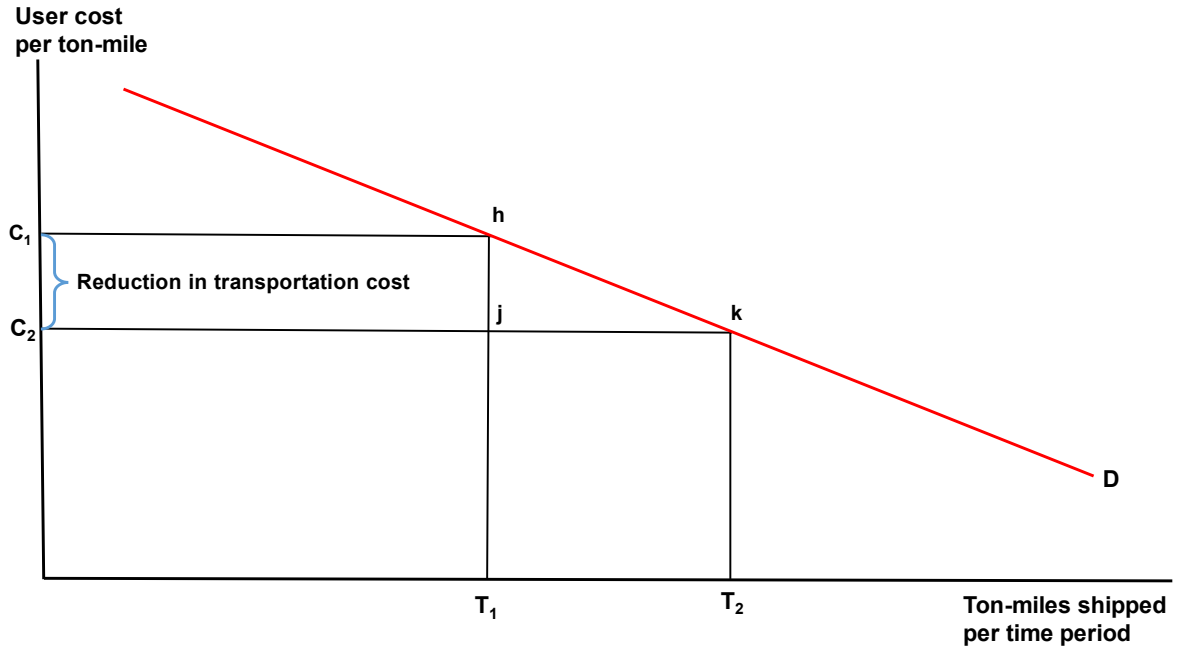


Figure 7. Logistics Reorganization Benefits Measured in the Transportation Market

The rectangle C_1hjC_2 in Figure 7 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 pre-

[41] 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.

[42] 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.

viously in Figure 6. 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 6. 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 recorded in the transportation market, and none of it represents a wider economic benefit resulting from the investment that would require separate quantification.[43]

9. Incorporating Wider Economic Impacts vs. Alternative Evaluation Methods

Some analysts advocate estimating changes in Gross Domestic Product (GDP) resulting from large investments in infrastructure as an alternative to measuring wider economic benefits and incorporating them in benefit-cost analysis. Some early approaches to evaluating infrastructure projects calculated changes in measures that closely resembled Gross Domestic Product or National Income 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 sometimes produced much larger benefits than today's 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.[44] 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

[43] 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 7 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.

[44] 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 an existing capital stock.

larger benefits than would have been estimated using conventional benefit-cost measures (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 of the benefits and costs they do include, while GDP accounting largely overlooks households, typically a major beneficiary of investments in new or expanded transportation infrastructure.

Figure 8 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 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.

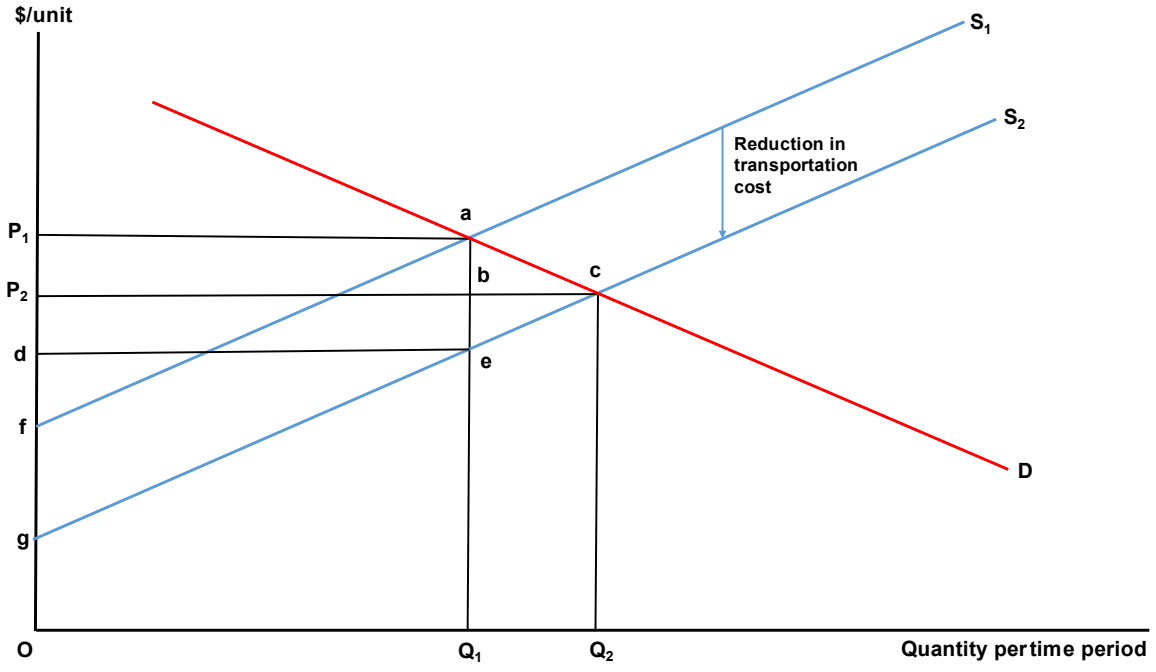


Figure 8. Benefits from Reduced Transportation Costs Measured as GDP Gains

As previously, 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 – 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 measures the additional 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 area P_1aed are no longer required to produce transportation services, they are "released" to be employed productively elsewhere in the economy. 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.[45]

The triangular area ace in Figure 8 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.[46]

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 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.

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[45] 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.

[46] 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).

If anything, benefit-cost analysis seems likely to produce *larger* estimates of benefits from such investments, since 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. In contrast, macroeconomic accounting seems likely to be more effective at capturing general-equilibrium or "downstream" increases in the value of economic output that are triggered indirectly by improved infrastructure than is the partial-equilibrium framework used in benefit-cost analysis, so this may explain the apparent tendency of changes in GDP to yield larger estimates of benefits.

10. Are Wider Economic Impacts an Important Concern?

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 where 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) 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…," but shortly thereafter asserts that "There are strong reasons to apply WEI [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." (pp. 131-132)

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 efforts to quantify wider economic impacts would have the largest payoff in terms of reliably identifying the most attractive investment opportunities. 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.

As the previous sections indicated, 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 step is to identify those cases and distinguish them from broader impacts that are unlikely to be large and challenging to measure, so that analysts can focus on understanding the most significant sources of wider economic impacts and developing their capability to measure and value them reliably.

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