Freight Benefit/Cost Study

White Paper

Benefit-Cost Analysis of Highway Improvements in Relation to Freight Transportation: Microeconomic Framework

(Final Report)

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1. INTRODUCTION

This study develops the micro-economic framework within which to measure the freight-related economic benefits and costs of transportation improvements. A key objective is to ensure that the Benefit-Cost Analysis framework recognizes the gains in economic welfare (efficiency) that follow from the propensity of industry to adopt productivity-enhancing "advanced logistics" in response to transportation infrastructure improvements. Whether the conventional Benefit-Cost Analysis framework already recognizes these so-called "reorganization" effects has been debated for some time. This paper seeks to put the matter to rest.

This technical paper is presented in five sections. Section 2 gives an overview of industrial organization in relation to freight logistics. Section 3 outlines previous efforts to expand the micro-economic foundations of Benefit-Cost Analysis so as to capture the effects of industry reorganization. Section 4 builds on past efforts to develop the complete framework. Section 5 concludes with a discussion of related measurement issues and information requirements.

2. OVERVIEW OF LOGISTICS AND INDUSTRY RE-ORGANIZATION

2.1 Framing the Problem

The term logistics pertains to the way firms organization themselves in relation to transportation, warehousing, inventories, customer service and information processing. The phrase "advanced logistics" is shorthand for technologies and business processes that permit firms to reduce costs by substituting transportation, e-commerce and just-in-time deliveries for large inventories, multiple warehouses and customer service outlets. Firms can and do re-organize in response to transportation infrastructure improvements so as to reap the rewards of advanced logistics [1]. However, the effect of such re-organization on the economic benefits of freight and highway investment is not well understood.

Prior to formulating the micro-economic framework, we present a "meta-analysis" -- an influence diagram that maps the key variables and the various relationships that exist between them. An arrow is used from input to output with a sign indicating the effect of a change in input, either positive or negative. Relationships that have notable delayed effects are labeled by the letter "D" accordingly. Positive and negative feedback loops are identified such that positive feedback occurs when increases in one variable generates net increases throughout the chain feeding back to the original variable. This type of loop often results in exponential growth. Negative feedback occurs when positive response in a variable results in a negative effect feeding back to itself when seen through the cause and effect chain. This type of link results in asymptotic behavior towards some limiting value. The combination of positive and negative feedback loops generates time dependent system behavior that is often counter-intuitive at first sight.

2.1.1 Meta-Analysis of Freight Economic Relationships

Investment in highway improvement projects will affect attributes of links within the US transportation system. In particular, flow capacity may be increased by the addition of additional lanes, increases in speed limits from wider and safer roads, limited access highways, and operational/ITS improvements. There may also be fewer restrictions on truck weights, improved bridge clearances etc. Further improvements could be made to ports/customs thereby smoothing and increasing net system traffic flow. All these improvements result potentially in travel time savings and increased reliability. These and other downstream effects are shown diagrammatically at Exhibit 1.

As previously discussed, reductions in travel time and travel time variability have a direct and indirect effect on logistic costs. NCHRP 2-17(4) [2] developed an approach to quantify these relationships based on individual case studies, reviewed in section 3.5. The previous NCHRP 342 [3] study took a different view. Assuming logistics cost savings were known, it quantified benefits due to increased use of transportation while keeping output fixed.

Productivity gains occur within industries at the level of the firm. The potential for firms to re-organize their logistics systems and policies will occur according to specific trade-offs between logistics components. The 2-17(4) study examined the firm's change in logistics cost as a function of changes in transport times. Based on a sample of case studies, an aggregate of the sensitivity of industry logistics cost savings to travel time savings was estimated. This study limited its analysis to situations in which output remained fixed.

The present study develops a general framework and economic theory for the economics of freight while at the same time being empirically practical. The empirical estimation is the subject of a later research paper although comments shall be made as to the framework's applicability.

The goal is to develop a theoretical framework that is sound and can quantify the true benefits of infrastructure investment while at the same time being practicable in terms of available information and research efficiency. The approach will need to be strategic in nature while at the same time being sensitive to changes at the level of the firm according to various transportation services used.

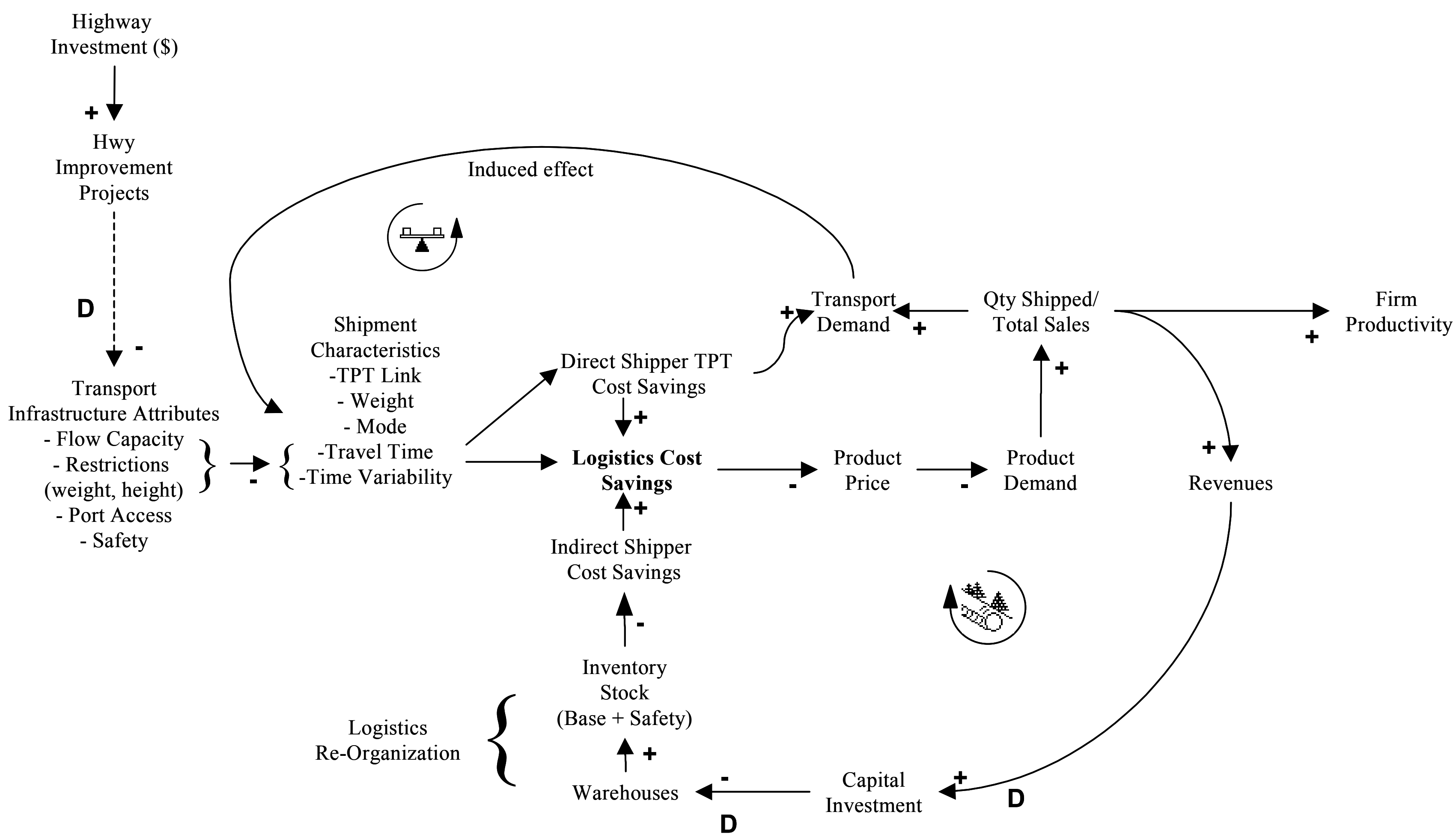

Exhibit 1: Freight Economics Influence Diagram

2.2 Integrating Re-organization Effects

In considering the substance of the issues being addressed in this paper, it is useful to refer back to the broad classification of benefits set out in the proposal.

Table 1: Effects of Improved Freight Transportation	
First-order Benefits	Immediate cost reductions to carriers and shippers, including gains to shippers from reduced transit times[1] and increased reliability.
Second-order Benefits	Reorganization-effect gains from improvements in logistics[2]. Quantity of firms' outputs changes; quality of output does not change.
Third-order Benefits	Gains from additional reorganization effects such as improved products, new products, or some other change.
Other Effects	Effects that are not considered as benefits according to the strict rules of benefit-cost analysis, but may still be of considerable interest to policy-makers. These could include, among other things, increases in regional employment or increases in rate of growth of regional income.

The central question posed here is whether benefits categorized in Table 1 as "second-order" and "third-order" are captured in the conventional micro-economic foundations and measurement framework of Benefit-Cost Analysis. Before addressing the question directly, we examine the nature of the re-organization effects at-issue.

2.3 Nature of Re-Organization

Logistics systems are key enablers of economic development. Governments can adopt policies that will encourage overall logistics efficiency. In some instances, logistics costs can amount to 30% of delivered costs. In efficient economies, these costs can be as low as 9.5% [4]. Transportation charges account for nearly 40% of all logistics costs.

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[1] Carrier effects include reduced vehicle operating times and reduced costs through optimal routing and fleet configuration. Transit times may affect shipper in-transit costs such as for spoilage, and scheduling costs such as for inter-modal transfer delays and port clearance. These effects are non-linear and may vary by commodity and mode of transport.

[2] Improvements include rationalized inventory, stock location, network, and service levels for shippers.

Freight transport continues to evolve. According to work done for the World Bank [4], truck trips of less than 50 miles account for:

- 80% of trips made,
- 74% of tons carried,
- 66% of revenues earned,
- 36% of vehicle miles travelled.

Trucks also serve as the access and egress mode for maritime, air, intermodal, and many rail trips. Short haul trips are therefore an essential component of the economy.

Logistics costs are driven by activities that support the logistics process. Trade-offs are possible among the elements of logistics costs in order to minimize total costs given customer service level objectives. The main components of logistics costs are:

- Transportation costs
- Warehousing costs
- Order processing/Information systems costs
- Lot quantity costs
- Inventory carrying costs

These elements are inter-related and various trade-offs exist. It is worth noting that some of these trade-offs are not realized in a continuous way. Consolidation of warehouses occurs at a discrete point in time and this will be different for various firms based on their decision to invest in new logistics systems. The primary goal of the firm in developing its logistics strategy is to provide customer service while reducing costs thereby increasing its profits and being competitive.

Any framework for quantifying the benefits of freight productivity from highway improvements must be able to account for firm-level adaptation of its logistics. Although case studies will be useful to quantify firms' response to infrastructure improvements, methods must be able to aggregate benefits at the market or commodity level[3]. The objective of this White Paper is to delineate the scope of the study and to establish a

[3] Given the recent total supply chain management phenomenon, it may be possible to group SICs which are related to the supply chain.

theoretical framework on which to base further work. Considerations of parameter estimation are also discussed.

2.3.1 Changes in Logistics Network Infrastructure

A firm could re-organize its logistics in many ways as a result of lower transportation costs. For one, it could reduce the number of warehouses and thereby increase the use of transportation services. Four factors influence the number of warehouses a firm chooses to maintain: cost of lost sales, inventory costs, warehousing costs, and transportation costs.

Cost of Lost Sales. The cost of lost sales is the most difficult to quantify. It would generally decrease with number of warehouses and would vary by industry, company, product, and customer. The remaining cost components are more consistent across firms and industries.

Inventory Costs. Inventory costs increase with the number of warehouses because firm maintain a safety stock of all (or most) products at each facility. More total space is required overall.

Warehousing Costs. More warehouses mean more space to be owned, leased or rented. Fixed costs across many facilities are larger than the marginal variable costs of fewer locations.

Transportation Costs. Transportation costs initially decline as the number of facilities increases due to proximity. Costs eventually increase for too many warehouses due to the combination of inbound and outbound transport costs.

A firm seeking to minimize total costs, the sum of the above components, could balance all cost components by solving a multi-facility location problem. As transportation costs decline however – possibly due to highway infrastructure investment, the minimum total cost will in general occur for fewer warehouses. The nature and timing of re-organization will occur at different points for each firm. Sufficient potential gains will need to be realized before an investment hurdle rate is exceeded.

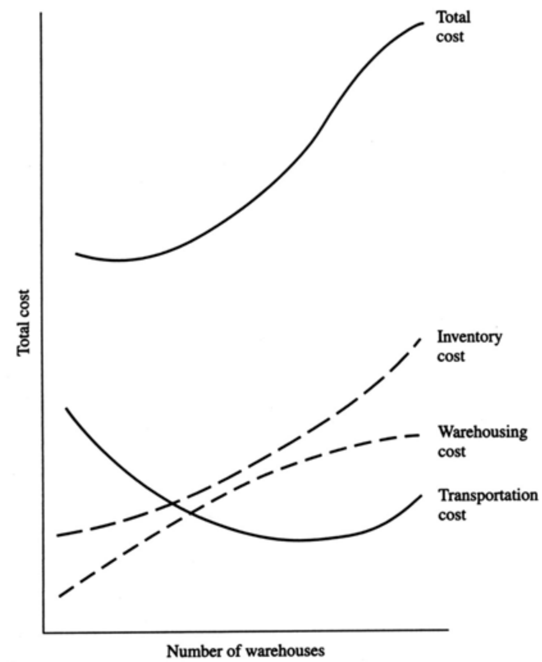

Exhibit 2: Relationship between total logistics cost and number of warehouses.

2.3.2 Changes in Inventory Policy

A simpler more rapid response to lower transportation costs, improved transit times and reduced delivery time variability is a change in a firm's inventory policy. To demonstrate the direct relevance of travel time and travel time variability on total logistics costs, consider a simple example where a firm has a central production plant and a single warehouse located within its market area.

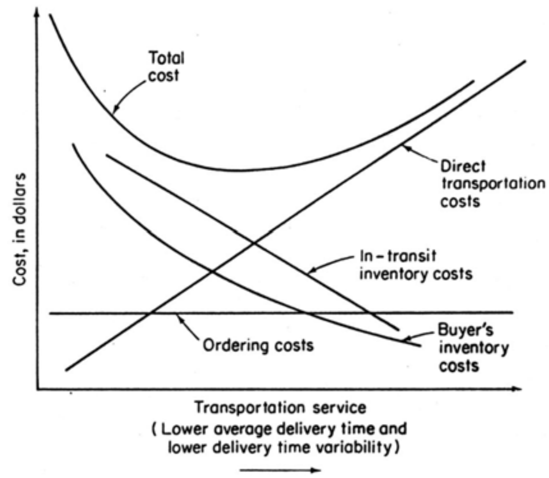

Exhibit 3: Generalized cost trade-offs for transportation services.

As direct transportation costs decrease, the minimum total logistics cost point moves to the right. A profit-maximizing firm would increase the demand for transportation services.

An increase in travel time and variability can be costly. Most obviously, money tied up in inventory isn't earning interest. The longer it takes to ship perishable goods (e.g., fresh fruit and vegetables, newspapers and magazines, high fashion clothing), the more they depreciate. It's the near elimination of travel-time variability that makes just-in-time inventory management possible.

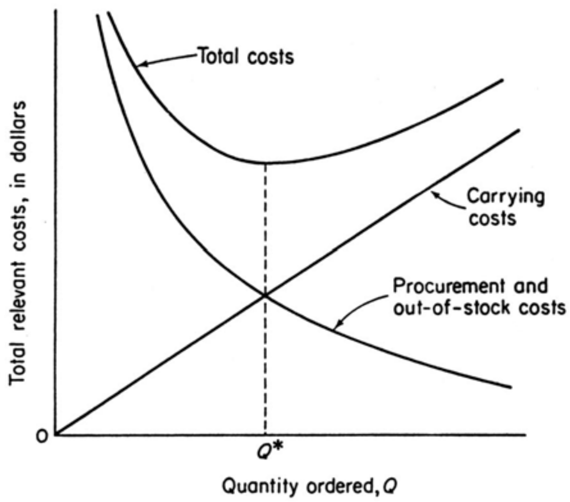

Exhibit 4: Basic inventory cost trade-offs.

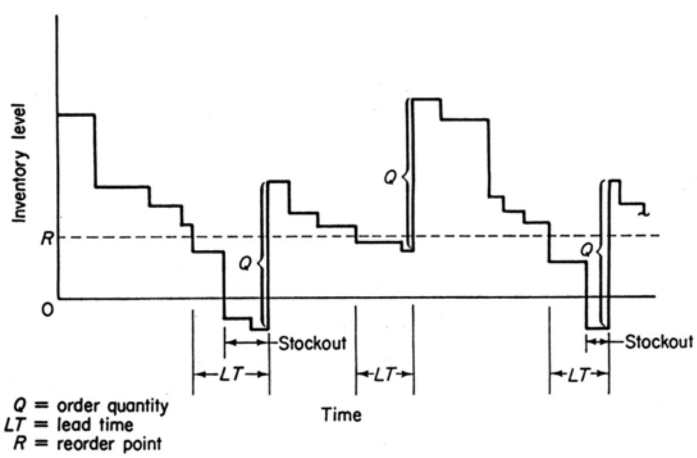

Exhibit 5: Inventory levels under a fixed order quantity-variable order interval policy.

Stockout and backorder costs[4] are a function of the lead time distribution for supply. Lead times are in turn a function of travel time and variability. Reductions in either

[4] Stockout periods occur when a product is not available. A key element of customer service, these periods can lead to out-of-stock costs incurred when an order is placed but cannot be filled from inventory. These costs can be classified as lost sales costs and back-order costs. Back-orders often generate additional order processing as well as transportation costs when they are not filled through the normal distribution channel.

travel time and/or travel time variability will directly impact various logistics cost components and may trigger re-organization at the level of the firm. Shorter and more predictable lead times can enable firms to reduce their reorder points and average stock levels while maintaining the same level of service. This in turn reduces logistics carrying costs.

A paper by Mohring and Williamson [5] is, to our knowledge, the first formal analysis of what Mohring refers to as "reorganization effects," the adjustments in their logistical arrangements that shippers make in response to lower costs of freight movement. Typically, these adjustments would involve fewer warehouses and more miles of truck movement as shippers take advantage of lower freight costs to consolidate storage facilities and reduce inventory costs. These effects are the principal source of benefits not captured in the conventional approach to benefit-cost analysis.

2.4 The New Supply Chain

Logistics management continues to evolve with the adoption of e-business practices and various forms of just in time (JIT) delivery. E-commerce and e-business won't reduce trade, it will increase it. Growing trade means more freight movements. The nature of these movements may evolve to more single package deliveries requiring additional transport services. New information technologies also enable JIT logistics systems that rely on dependable and inexpensive transportation. E-business may affect the nature and extent of transportation demand as well as the rate of industrial re-organization, but the logistics principles remain the same. Although they are to be included, isolating the direct effects of e-business are beyond the scope of this study.

3. DEVELOPMENTS TO-DATE FOR A BENEFITS MEASUREMENT FRAMEWORK

3.1 Introduction

Several papers have been identified as containing basic theoretical and conceptual discussions underlying the proposed approach to evaluating benefits of freight-transportation improvements. The number of key papers is small, because the great preponderance of the work on highway benefit-cost analysis does not give detailed attention to issue of improvements for freight carriage. And, even where benefits to freight carriage are addressed, the treatment is usually incomplete, since effects of shippers' longer-run responses to lower freight costs are not, in most of the literature, addressed.

There have been three strands of development since 1969 in the development of a cost-benefit analysis framework for transportation investment. Foundational work by Mohring [6] and others set the stage for cost-benefit analysis of transport projects. Two later HLB studies, NCHRP 342 [3] and NCHRP 2-17(4) [2] took these basic principles and applied them to quantify improvements in freight productivity. All three strands are reviewed briefly here. The proposed framework that is described in Section 4 builds on all these elements.

If only we could measure a business firm's short-, medium- and long-run demand schedules for a transport service, these would reveal all of the benefits it and (but with important qualifications) its customers would derive from cost-lowering transport improvements experienced by the carriers on which the firm relies. Indeed, if marginal-cost full prices[5] were charged users of an economy's transport facilities and if all of the economy's markets conformed to the competitive model of economics texts, all of the

[5] By "full price" in connection with roads, we mean the sum of whatever tolls users pay for trips and the time and other costs users directly incur in taking it.

benefits improvements confer on carriers and, indirectly, their customers could be determined from carriers' demand schedules for just the improved facility; examining the markets for other transport facilities and for commodities that are affected by the improved facility would be unnecessary.

In a world of universal marginal-cost prices and easily determined market demand schedules, benefit measurement would be a simple task. Section 3.2 justifies this assertion for a competitive world. While, for expositional brevity, we write there only about road improvement, this discussion applies without appreciable modification to any transport-facility improvement.

In Section 3.3, we relax Section 3.2's assumption of universal marginal-cost pricing. Without "price equals marginal cost," benefit estimation is much more complex than in 3.2's world.

If elements of monopoly exist in markets for transported commodities, transport demand schedules can yield distorted benefit measures. Section 3.3 shows that, with universal marginal-cost pricing, all of the net benefits that result from improving one of a pair of roads that provide substitute services can be measured using only data from the improved road. Not so in the absence of marginal-cost pricing; improving one road could result in net benefits and costs in road markets other than those for the improved road's services. Section 3.3 also describes both the modifications to Section 3.2's benefit-measurement theory necessary to deal with the absence of marginal-cost pricing and the ways in which real-world data can be used to quantify benefits when marginal-cost pricing is the exception rather than the rule.

3.2 Benefit/Cost Analysis in a World of Marginal-Cost Pricing

This section deals with an economy in which marginal cost prices prevail not only in such private markets as those for autos, apples, and gizmos, but also for such governmentally provided services as roads, airports, and air-traffic control. In competitive markets, marginal-cost prices come about without outside intervention. Each buyer or seller plays so small a role in each market that they all regard market prices as beyond their control.

If the prices of governmentally provided services equal their marginal costs, they do so because the responsible governmental authorities choose to set prices that way. The dominant cost of using most government-provided transport facilities is congestion. This being the case, our analysis here ignores all other costs that user impose on transport systems--road damage, in particular. With this restriction, marginal-cost road pricing would require users to pay only tolls[6] equal to the costs they impose on all other users by adding to congestion levels.

If charged, marginal-cost tolls would play the same role in financing road investments, as do the components of short-run marginal-cost prices that reward private business firms for providing the durable capital equipment they use to produce the commodities they sell. These "productivity rents" dominate the process by which competitive markets reach long-run equilibrium. If the rents a competitive firm earns on its capital equipment exceed the costs of providing that equipment, the firm and, probably, its competitors have an incentive to expand their capacity. So, too, with road authorities. If the productivity rents embodied in a road's congestion tolls exceed the costs of providing the road, expanding it would generate net benefits.

3.2.1 The Basics of Road Improvement Benefit Estimation

A demand schedule for a highway's services tabulates the number of units of the service users purchase at alternative "full prices". By "full price," we mean toll payments plus such directly incurred user costs as those of vehicle operation and the value of the time required for road use.

A variety of demand schedules can be constructed for any given road user. Which of them is relevant for an analysis depends both on the time period and on the nature of the

[6] The term "toll" as used in this paper is synonymous with the general notion of road prices, and implies no specific method of collecting revenue.

road-service product being studied. In the very short run, shippers and carriers have few degrees of freedom in responding to transportation network changes; delivery schedules and routings can be changed, but origins and destinations are fixed. In a somewhat longer run, truck-fleet characteristics can be changed while, in a still longer run, the number, sizes and locations of factories and warehouses can all be changed.

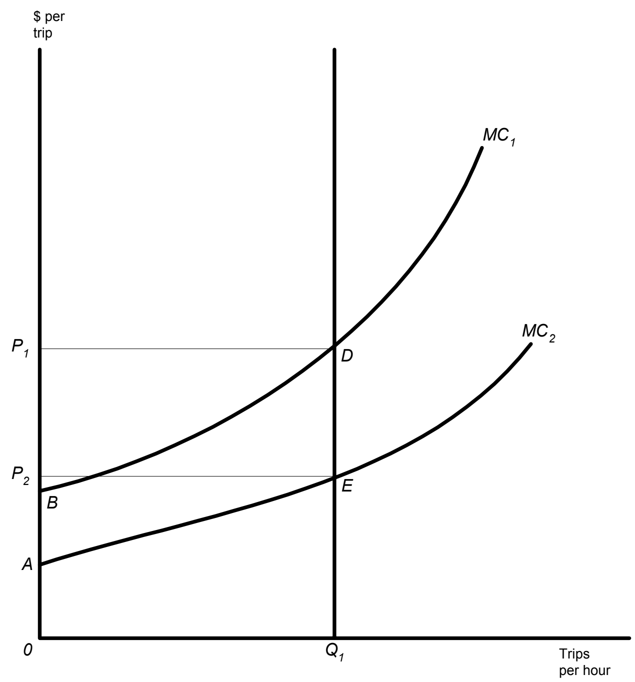

Exhibit 6: Direct very short run benefits of road improvements with marginal-cost tolls.

Suppose that an additional lane in each direction suddenly materializes on the freeway connecting Here and There. On this day, the relevant demand schedule is the vertical line in Exhibit 6. Surprised users discover that congestion has diminished sharply and that, for this reason, the full prices of trips--congestion tolls plus travel times--have fallen from OP_1 to OP_2. However, too little time has elapsed for them to adjust their travel behavior to take advantage of this change.

As news of the expressway improvement spreads, price and output levels change in a number of related markets. Most obviously, increased speeds and reduced prices on the expressway induce additional use that results in increased congestion and tolls. The increased accessibility the improvement affords may increase the values of neighboring residential, commercial, and industrial sites. The improvement's lower transportation costs apply to goods shipments as well as person trips. As a result, the delivered price of goods produced Here and sold There fall. Faster and, quite likely, more reliable travel may induce cost-saving changes in the production, distribution, and inventory practices of Here and There business firms.

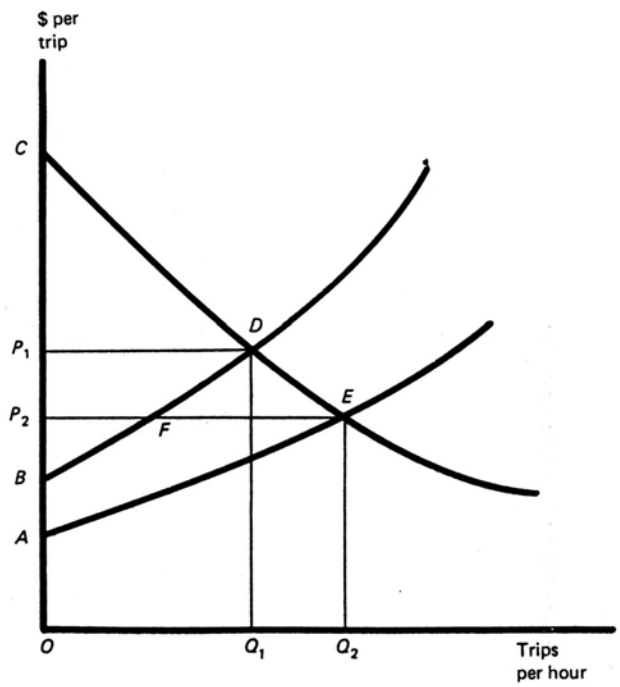

Exhibit 7: Direct intermediate run benefits of road improvements with marginal-cost tolls.

A longer-run equilibrium is pictured at Exhibit 7. On the pre-improvement expressway, OQ_1 trips took place at a price of OP_1. The net short-run benefit to users derived from these trips can be viewed as the maximum amount users would be willing to pay for them, area $OCDQ_1$, minus the tolls they pay and the values of the time and vehicle operating costs they incur in taking them, area $OBDQ_1$ yielding a net user benefit of area CDP_1. In addition, although a cost to consumers, the "quasi-rents," P_1DB, provided by toll collections are just as much social benefits of road use as are the consumers' surpluses road use generates. The rents are captured by the toll collecting agency, and hence, indirectly, by society at large. Society, in turn, can use these tolls to finance public activities for which taxes would otherwise have to be levied.

The improvement changes net short-run benefits from CDB to CEA per hour. The difference between these two, area BDEA, is the improvement's net benefit. As Exhibit 7 suggests, this net benefit does not, in general, equal its user benefits, the increase in consumers' surplus the improvement generates, area P_1DEP_2. This user benefit has only area FDE in common with the improvement's net benefit. User benefit equals net benefit only if the remainder of consumer benefit, P_1DFP_2, happens to equal the remainder of net benefit, BFEA. These two magnitudes are equal only if the Here-There road generates the same quasi-rents after the improvement as before it.

In brief, ignoring the improvement's effects on other prices in the economy, its net benefit equals its users' consumers' surplus benefit plus the change in the tolls these users pay. But is it legitimate to ignore the improvement's potential effects on other prices? We believe that it is now generally accepted that changes in land values that road improvements induce are not net benefits of improvements but, rather, that they reflect transfers to land owners of benefits initially received by users. We therefore restrict attention here to effects the Here-There improvement may have on trip costs elsewhere in the highway network and to cost-saving adjustments in production and distribution processes that transport improvements facilitate.

3.2.2 Effects of Improving One Road on Other Roads

To deal in the simplest possible way with the implications of the cost changes that improving one road can induce on other roads, suppose that two rather than one initially identical expressways, Roads 1 and 2, connect Here and There. Travel on these roads has adjusted so that, in equilibrium, each provides the same travel time and congestion tolls. Suddenly an additional lane materializes in each direction on Road 1. As news of this change in travel conditions spreads, Road 2 users shift to Road 1 until, in a new equilibrium, travel times and congestion tolls on the two roads are again equal. Exhibit 8 depicts the old and new longer-run equilibrium.

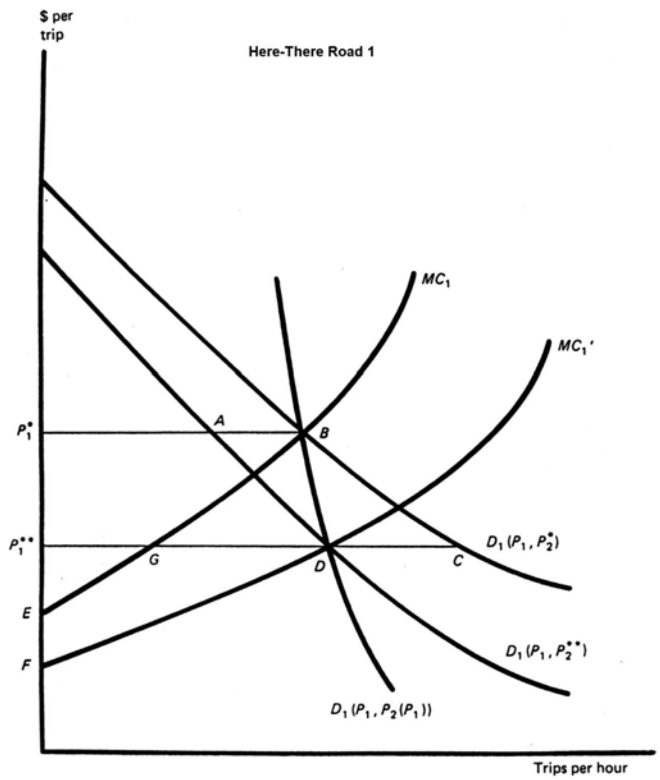

Exhibit 8: Direct and indirect effects of road improvement with marginal cost tolls.

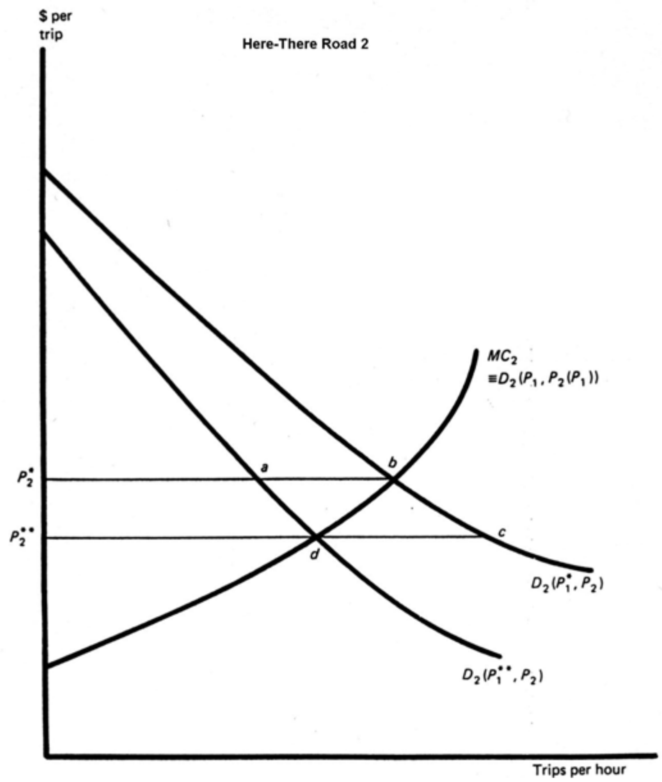

Exhibit 9: Direct and indirect effects of road improvement with marginal cost tolls.

The Here-There expressways provide substitute products. Therefore, any change that reduces the price of trips on Road 1 will divert traffic to it from Road 2. To reflect this interdependence, the demands for trips on Roads1 and 2 can respectively be written $D_1(P_1,P_2)$ and $D_2(P_1,P_2)$ where P_1 and P_2 refer respectively to the full prices of trips on Roads 1 and 2. Before the improvement, traffic on the two roads is in equilibrium at full prices of P_1^* and P_2^*. These are the prices at which "consistent" demand and marginal cost schedules simultaneously intersect on the two roads. In this context, "consistent" intersections involve D_1 (P_1^*, $P2^*$) = MC_1 = D_2 (P_1^*, $P2^{*)}$ = MC_2. As a result of the improvement in Road 1, its marginal-cost price schedule declines from MC_1 to $MC_1^{*.}$ This reduction leads both to additional trips by previous Road 1 users and to diversion of trips formerly made on Road 2. Trip diversion reduces the price of trips on Road 2 and hence leads to reverse diversion, i.e., to a shifting to Road 2 of trips formerly made on Road 1. This shifting back and forth ultimately results in a new equilibrium on the two roads at prices of P_1^{**} and P_2^{**}.

The economics literature suggests several alternative candidates as measures of consumer benefit under conditions such as those depicted in Exhibit 8. The alternative of greatest value in this discussion can be described in the following terms: visualize the price of Road 1 trips as shifting downward, not once and for all, but rather in a long series of tiny steps. Each of these price reductions determines a new, lower equilibrium price of Road 2 trips. That is, the price of Road 2 trips can be viewed as a function, P_2 (P_1), of the price of Road 1 trips. Using this function the price shifts downward, not once and for all but rather in a long series of tiny steps. Each of these price reductions determines a new, lower equilibrium price of Road 2 trips. That is, the price of Road 2 trips can be viewed as a function, P_2 (P_1), of the price of Road 1 trips. Using this function to replace P_2 in both demand schedules results in lines like BD and bd in Exhibits 8 and 9. The line bd "demand schedule," for Road 2 trips, note, is superimposed on that road's marginal cost schedule.

With these two demand schedules, area $P_1^*BDP_1^{**}$ in Exhibit 8 is the improvement's benefit to Road 1 users, while $P_2^*bdP_2^{**}$ is the indirect benefit to Road 2 travelers. At the same time, however, $P_2^*bdP_2^{**}$ is also the amount by which quasi-rents (i.e., toll collections) on Road 2 decline as a result of traffic diversion to Road 1. While P_2^* bdP_2^{**} is, indeed, a benefit to these travelers, this benefit is a transfer to them of income that was formerly collected by society at large as toll revenues. This benefit is, therefore, not a net gain to society that should be added to that on Road 1.[7]

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[2]Alternative measures of consumer benefit are the areas (a) P_1*ADP_1** plus P_2*bcP_2** and (b) P_1* BCP_1^{**} and P_2*adP_2**. Alternative (a) involves determining the area under the demand schedule for Here-There trips when the price of Here-Elsewhere trips is that associated with the *improved* Here-There road plus the area under the Here-Elsewhere demand schedule when the price of Here-There trips is that associated with the *unimproved* Here-There road. Alternative (b) involves the same sort of procedure but with the positions of *improved* and *unimproved* reversed in the preceding sentence.

If the demand for trips on each road is a function only of trip prices, then each of these three measures will have the same numerical value. However, if the number of trips a representative consumer would take between Here and There depends not just on the prices of Here-There and Here-Elsewhere trips but also on

To compare the geometry of Exhibit 8 to that of Exhibit 7, the sum of areas P_1^* BD P_1^{**} and $P_2^*bdP_2^{**}$ in the more complicated situation is the equivalent of P_1DEP_2 in the simpler situation. Of the total consumer benefit, P_1DFP_2 in Exhibit 2, and P_1^* BG P_1^{**} plus P_2^* bd P_2^{**} in Exhibit 8 is the result of a transfer to road users of benefits formerly received by society at large in the form of toll revenues. The basic net short run benefit of the Exhibit 8 improvements is area EBDF, the equivalent of BDEA in Exhibit 7.

To summarize, if marginal cost tolls are charged for trips, determining the net short run benefits of improving a highway link requires only data on the use made of that link. This equals the sum of the change in consumers' surplus and toll revenues on the improved link. The benefit is true even if the improvement affects traffic conditions on other links in the system. Given marginal-cost pricing, changes in consumer benefits and toll revenues on unaltered links would exactly offset each other.

The next two sections elaborate on previous work carried out to describe the nature and extent of re-organization effects. Discussion of marginal cost pricing continues at Section 3.3.

3.2.3 "Industrial Reorganization" Benefits:[8]

The ability of a firm to exploit manufacturing scale economies can be limited by the cost of transporting its products to market. A reduction in unit transportation costs can, therefore, yield two types of benefits. First, it provides "direct" benefits by reducing the costs of distributing the outputs of existing manufacturing facilities. Second, a transport cost reduction can makes it efficient to expand the outputs and marketing areas of individual production facilities, thereby taking greater advantage of manufacturing scale

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the consumer's income, these three measure would turn out to have somewhat different values. Technically, each of these measures involves evaluation of a "line integral" along a different path. In general, the value of a line integral will be independent of the path followed only if certain "integrability conditions" are satisfied. These conditions would be satisfied if trip demands are independent of income but not otherwise.

[8] The discussion that follows is based on Mohring and Williamson [3], pp. 251-258.

economies. This use of more transportation-intensive means of production and distribution in response to reduced transportation costs generates "reorganization" benefits.

This twofold impact of transportation improvements has long been recognized. Consider, for example:

> The division of labor...must always be limited...by the extent of the market. When the market is very small, no person can have any encouragement to dedicate himself entirely to one employment.... [B]y means of water carriage a more extensive market is opened to every sort of industry than what land carriage alone can afford it... A broad-wheeled wagon, attended by two men, and drawn by eight horses, in about six weeks time carries and brings back between London and Edinburgh near four ton weight of goods. In about the same time, a ship navigated by six or eight good men, and sailing between the ports of London and Leith, frequently carries and brings back two hundred ton weight of goods....Were there no other communication between these two places, therefore but by land carriage,...they could carry on but a small part of that commerce which at present subsists between them, and consequently give but a small part of that encouragement which they at present mutually afford to each other's industry (Smith [4], pp. 17-19).

Do the analytical frameworks for dealing with transportation improvements that we have dealt with so far in this chapter take into account these "industrial reorganization" benefits of which Adam Smith wrote?[9] Or does adequately accounting for them require the development of special benefit measurement techniques? To see why the answers to these questions are respectively "yes" and "no," it is useful to consider Consolidated Gizmo of America (CGA) which monopolizes American gizmo production, a commodity it distributes over a wide geographical area. Government regulations require that whatever delivered price it sets must be charged all customers, regardless of transportation costs. At the price charged by CGA, g gizmos are demanded yearly in each square mile of its market. Total annual output is $gA = G_0$ gizmos where A is the area of CGA's entire market.

[9] The U.S. Bureau of Public Road [5], (p. 78) once answered to this question with an emphatic "Yes": "...the restructuring of households, commerce, and industry influenced by highway improvements engenders other advantages to the community-at-large over and above the savings in transportation cost."

Inputs to gizmo production are available at prices that are independent of the locations and outputs of individual gizmo factories. Gizmo manufacturing entails increasing returns--a doubling of manufacturing inputs at an individual factory would more than double outputs. The output of a given plant can be expanded, however, only by increasing the plant's market area and, hence, the average cost of transporting gizmos to final consumers. Given these assumptions, CGA would minimize total costs by determining the output per plant, say G*, which minimizes average manufacturing plus distribution costs, and then establishing G_0/G^* factories[10] distributed evenly through its market area.

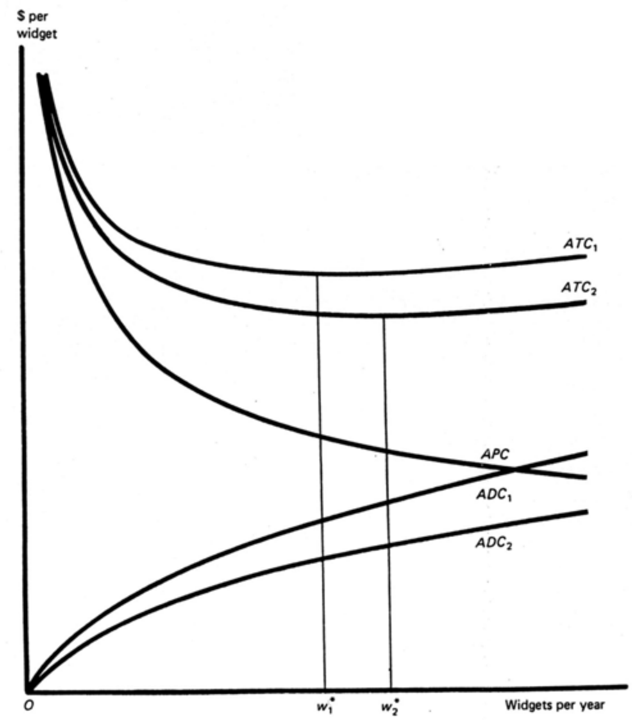

Exhibit 10: Cost characteristics of a single plant.

[10] If G_0/G^* is not an integer–it rarely will be--each plant clearly cannot be of size G^*. This problem is ignored here although the analysis could be extended to handle it.

Exhibit 10 depicts the cost characteristics of a single plant. Curves ADC_1, APC, and ATC_1 refer respectively to average distribution, average production, and average total costs before a transportation improvement is made. As the Exhibit is drawn, average total costs first decline with increases in output. In this range, the increase in unit transportation costs as output increases is more than offset by the decrease in unit manufacturing costs. Beyond output G_1^*, however, declines in unit manufacturing costs as output increases are less than sufficient to offset increases in unit transportation costs.

The size of the output level that minimizes an individual factory's sum of unit production and distribution costs depends on several factors. Of particular importance are the geographical density of demand for the product, the magnitude of scale economies, and the level of transportation costs. Actually, it is conceivable that no point such as G_1^* would exist. With substantial scale economies and small unit transportation costs, the average-total-cost curve might well decline over a range of outputs so great that a single plant would minimize CGA's total production and distribution costs for its entire marketing area. Under such circumstances, a transportation improvement would not lead CGA to increase its use of transportation services. It would only benefit from reduced costs of the transportation it already uses. Measuring this benefit is straightforward. We therefore restrict attention here to cases in which minimizing total production and distribution costs require several factories.

A reduction in unit transportation costs would immediately lower the costs of distributing gizmos from a group of factories each producing at a rate of G_1^*. In addition, it would make efficient what can be termed a more "transportation-intensive" means of producing and distributing the product. Suppose, to be specific, that a transportation network improvement reduces the average distribution and hence the average total costs of a factory to ADC_2 and ATC_2 respectively. With such a total-cost reduction, an individual plant's cost-minimizing output would increase from G_1^* to G_2^* in Exhibit 4. If the demand for gizmos is fixed, this increased optimum plant size can be realized only by eliminating some factories and, at the same time, relocating and expanding others. This being the case, depicting the aggregate benefits to CGA of a transportation improvement can best be accomplished with a second type of diagram.

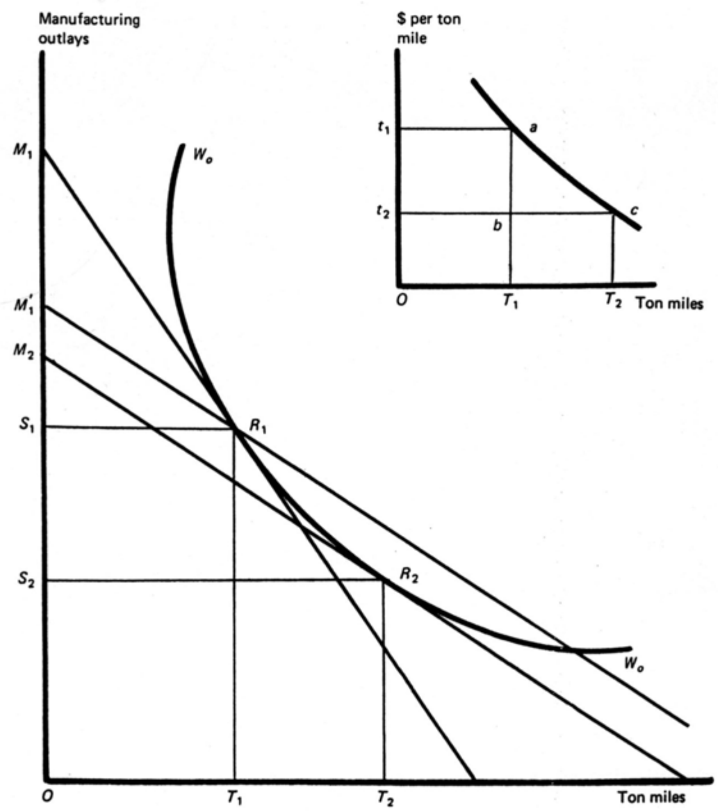

Exhibit 11: Cost minimization choice of transportation and manufacturing outlays.

Alternative manufacturing outlays for CGA's given total output are plotted vertically in Exhibit 11. Again, the level of these costs depends on the sizes of CGA's individual factories. The larger the size (and hence the smaller the number) of individual plants, the lower CGA's total manufacturing costs will be. Factory sizes can be increased, however, only by increasing their marketing areas and, hence, aggregate distribution costs. Transportation inputs measured in some homogeneous unit--e.g. ton miles, product miles, deliveries of average length--are plotted horizontally in this Exhibit.

In Exhibit 11, the line G_0G_0 is a transportation-input/manufacturing-cost "isoquant." It shows the alternative combinations of transportation inputs and outlays on manufacturing inputs that CGA would require to produce and distribute G_0 gizmos to all of firm's customers. That G_0G_0 is drawn with the curvature shown in Exhibit 11a reflects two assumptions about the production-distribution relationship implicit in Exhibit 10. First, scale economies attenuate as plant sizes increase; more exactly, successive equal increases in output produce successively smaller reductions in average production costs. Second, the units of transportation required to distribute an additional unit of output increase as output at each plant increases.

Suppose that the price (if CGA uses common or contract carriers for distribution) or the cost (if it provides its own distribution services) of transportation services is initially t_1 dollars per gizmo mile, an amount that is independent of both the length and the size of shipments. The straight line M_1R_1 (drawn with a slope of - t_1) in Exhibit 11 then represents alternative combinations of production and transportation inputs that can be bought for OM_1 dollars. Since M_1R_1 is tangent to G_0G_0 at R_1, OM_1 is the minimum cost of manufacturing and distributing G_0 gizmos. At R_1, CGA spends OS_1 and $OT_1 = S_1M_1$ respectively on manufacturing and transportation inputs.

Suppose that improvements are made to the transportation system that reduces the cost of producing ton miles from t_1 to t_2. If CGA provides its own transportation services, it will receive this benefit directly; if it relies on common or contract carriers and if the transportation industry is competitively organized, it will ultimately receive this benefit through reduced rates. In either event, since a lower outlay is required to purchase a ton mile of transportation services, new and flatter expenditure lines of the sort depicted by $M_1'R_1$ and M_2R_2 become relevant. The former expenditure line shows the benefit to CGA if it continues to produce at point R_1 in Exhibit 11. At that combination of manufacturing and transportation inputs, the transportation improvement affects CGA only by reducing the cost of OT_1 ton miles from S_1M_1 to S_1M_1'. This saving can be termed the "direct benefit": the reduced cost of pre-improvement transportation-input purchases.

CGA can derive an additional benefit from the improvement. Undertaking the consolidation of production facilities implied by a move to R_2 in Exhibit 11 would entail increasing transportation purchases from OT_1 to $0T_2$ gizmo miles and increasing total outlays on transportation from S_1M_1' to S_2M_2. This increase in transportation outlays would be more than offset by the associated reduction of S_1S_2 in the cost of the manufacturing inputs required to produce and distribute G_0 gizmos. Specifically, the shift from R_1 to R_2 would result in an additional savings of $M_1'M_2$ in total costs. This latter saving is the "reorganization benefit" of the improvement: the cost reduction achievable by substituting transportation for manufacturing inputs. Exhibit 11b depicts CGA's demand schedule for transportation associated with the shift from R_1 to R_2. In this diagram, the area t_1abt_2 is the direct benefit--the reduction in the cost of OT_1 gizmo miles brought about by the reduction in their price from t_1 to t_2. This area is equal to M_1M_1' in Exhibit 11a, while area abc is equal to $M_1'M_2$, the reorganization benefit.

We should emphasize that the preceding analysis can easily be adapted to deal with a wide variety of benefit-measurement situations. With suitable re-labeling, Exhibit 10 and Exhibit 11 can be used to deal with the utility-maximizing allocation of a consumer's budget between one commodity and all others available to him, or to discuss the choices faced by a producer in selecting the cost minimizing quantities of any inputs used in its production and distribution process. Had "input T" been substituted for "gizmo miles" or "transportation services" in the above discussion, the conclusions reached would not have changed. A consumer's surplus-type measure of transportation improvement benefits would be accurate under precisely the same circumstances as would such a measure of the benefits of any other cost reduction.

3.2.4 A Sample Benefit Estimation Model

Since the reorganization benefits of transport improvements are both important and difficult to measure, estimating the relative sizes of direct and reorganization benefits could be of value even for so simple a model as the following:

1. Consolidated Gizmo's manufacturing process is homogeneous of order 1/a. That is, increasing each one of its factory's inputs by the same positive fraction, k, results in output increasing by a factor of $k^{1/a}$. If the prices of these inputs are independent of both the factory's location and the quantities in which it buys, it is possible to show that the cost of manufacturing G gizmos at a factory can be written

$M(G) = f\,G^{a}$

where the coefficient, f, is a function of input prices the form of which depends on the gizmo production function's characteristics.

2. The cost of a gizmo-mile of road services is t regardless of both length of haul and shipment size. Transportation can take place only north-south or east-west on a dense rectangular grid of roads. (This assumption greatly simplifies algebra. It allows working with a square market area for which any point on the boundary is the same distance from the factory.)

3. CGA must charge all gizmo buyers the same price regardless of how far they live from the factory that serves them. At this price, g gizmos a year are sold in each square mile of CGA's market area.

Given these assumptions, very tedious algebra[11] leads to the following conclusions: The total cost of delivering the G gizmos a factory produces is

$T(G) = (2/g)^{½}\ t\,G^{3/2}/3$

The average cost of manufacturing and delivering the output for a factory and, hence, for the firm as a whole, is

$C(G) = f\,G^{a-1} + (2G/g)^{½}\,t/2$

The factory's cost-minimizing output is

$G^* = [3(1 - a)\,f\,(2g)^{½}/t]^{b}$

where $b = 2/(3 - a)$. Substituting the expression for G* into the expressions for transportation and manufacturing costs would yield expressions for minimum total production and distribution costs. However, useful and appreciably simpler expressions can be obtained from a finding that the ratios of average total to average manufacturing costs and average distribution to average manufacturing costs can respectively be written,

[11] Described in Mohring and Williamson, [4] pp. 8-12.

$C(G^*)/[f\,(G^*)^{a-1}] = 3 - 2a$

$[T(G^*)/G^*]/[f\,G^{*\,a-1}] = 2(1 - a)$

Holding the output of all of CGA's factories fixed at gA where A is the firm's entire market area, its demand for transportation services is

$D(T\,|gA) = 2(1 - a)\,g\,A\,B^{[(3/2-a)/(1-a)]}\,(f/t)^{1/[2(1-a)]}$

Where $B = 3(1 - a)(2g)^{½}$. The total benefit of a decline in the price of a product-mile of transport from, say, t to et turns out to be

$Ben = (3 - 2a)\,g\,A\,(t/B)^{[(3/2-a)/(1-a)]}\,f^{1/[2(1-a)]}\,[1- e^{[(3/2-a)/(1-a)]}]$

Dividing D(T |gA) by Ben yields this expression:

(direct benefits)/(total benefits) = $2\,(1 - e)\,(1 - a)/[(3 - 2a)(1 - e^{[(3/2-a)/(1-a)]})]$

For a 25% reduction in the price of a product-mile of transport, Table 2 gives values of this and related expressions for alternative values of a, the scale-economies index. The results are, in a way, disappointing. Even for the smallest scale-economies index value considered, e = 0.95, reorganization benefits account for only 12% of total benefits.

Table 2: Cost Ratios and Benefits of a 25% Reduction in Transport Prices

Manufacturing Scale Economies Index Reduction in t	*Ratio of Distribution to Total Costs*	*Total Cost Reduction from 25%*	*Ratio of Direct to Total Costs*
a	*(3/2-a)/(1-a)*	$1 – 0.75^{(1-a)/(3/2-a)}$	*Ben*
0.95	*9.1%*	*2.6%*	*88.1%*
0.90	*16.7%*	*4.7%*	*89.0%*
0.85	*23.1%*	*6.4%*	*89.7%*
0.80	*28.6%*	*7.9%*	*90.5%*
0.75	*33.3%*	*9.1%*	*91.2%*
0.70	*37.5%*	*10.2%*	*91.6%*
0.65	*41.2%*	*11.2%*	*92.2%*
0.60	*44.4%*	*12.0%*	*92.6%*
0.55	*47.4%*	*12.7%*	*93.0%*
0.50	*50.0%*	*13.5%*	*93.3%*

But much more can be said. When we write about the costs people incur in traveling, we almost always include the values they attach to the time their trips require. Recently, work of Ken Small and others [8] has established that costs related to the variability of travel time are also very important. In talking of goods movement, however, we usually still write as if the dollars shippers pay carriers for moving, e.g., ton miles of gizmos cover the entire costs of shipments. Not so. Shipment time and its variability matter just as much to shippers as travel-time and its variability matter to people.

What are the time and time-variability costs of shipments? Back in the good old days of the ICC, a plywood manufacturer in Oregon could, in the late fall or winter, load a boxcar with its product and send it to Boston, say. Its right to specify the shipment's routing enabled it to maximize the number of rail yards through which it passed. When, after a month or two or three, a customer was found for the plywood, the shipper would change the destination and routing of its mobile warehouse and send it as rapidly as possible to Cleveland, say.

Now, much more normal are situations in which an increase in travel time and its variability is costly. Most obviously, money tied up in inventory isn't earning interest. The longer it takes to ship perishable goods (e.g., fresh fruit and vegetables, newspapers and magazines, high fashion clothing), the more they depreciate. It's the near elimination of travel-time variability that makes possible the "just-in-time" inventory management that has come to dominate automotive and other complex assembly processes.

The simple model that underlies Table 2 completely ignores these time-related costs of transportation. Taking them into account might well result in reorganization benefits that are an order of magnitude or more greater than those suggested by Table 2.

3.3 BCA when Marginal-Cost Pricing Is More the Exception than the Rule

In Section 3.2, we dealt with a world in which marginal-cost prices prevail not just in private markets but also for using of facilities provided by governmental agencies. In that world, we attempted to show all the benefits that an improved road provides to producers and consumers who directly or indirectly benefit from the road improvement could be measured from user demand schedules for just the improved road--if only we could measure them.

Alas, marginal-cost prices are much more the exception than the rule in the real world's economies. If marginal-cost prices are not charged for road services, determining the net benefits of a road improvement requires analysis of the use not just of the improved road itself but also of all other roads with traffic patterns that are affected by those on the improved road.

What's more, most business firms face downward-sloping demand schedules–they can raise their prices a bit without driving all of their customers away. They can lower their prices a bit without being overwhelmed by new patrons. What matters to profit-maximizing business firms in such markets is not just what newly attracted customers pay them but, rather, the additional net revenues the additional customers provide if, as is usually the case, the price reductions that attract new customers must also be provided to customers who are willing to pay higher prices. Profit maximizing firms that face downward-sloping demand schedules try to equate the marginal revenue of additional sales to the marginal cost of those sales. With downward sloping demand schedules, in equilibrium, a marginal gizmo buyer values it at more than it costs Consolidated Gizmo to produce. In turn, sellers' input demand schedules reflect the marginal revenues to which these inputs contribute, not the market values of outputs to which the inputs contribute. Input demand schedules in such markets provide downward-biased estimates of the values of the products to which they contribute. Even if we knew the demand schedules for the services of all roads affected by each road improvement, estimating accurately the benefits associated with these schedules would require us to know details of the underlying cost and demand schedules for products.

In dealing with these issues, we begin with the benefit-measurement problems associated with the absence of marginal-cost road pricing. We then move on to the theoretical problems involved in incorporating elements of monopoly into the benefit-measurement problem. We conclude by discussing how real-world data can contribute to overcoming these estimation problems.

3.3.1 Measuring Aggregate Benefits when Marginal-Cost Tolls Are Not Charged

In the United States, highway user charges normally differ--often by quite substantial amounts--from those required to equate trip prices with their associated marginal costs. As a result, the aggregate benefits derived from highway use are lower than they could be. Also, measuring benefits is considerably less difficult when marginal-cost prices prevail than when they do not. Regardless of the toll level, the benefit a highway improvement gives is the sum of the changes in consumers' surpluses and toll revenues to which it gives rise. However, while surplus and revenue benefits on other than the improved road cancel out when prices equal marginal costs this cancellation does not occur without marginal-cost prices.

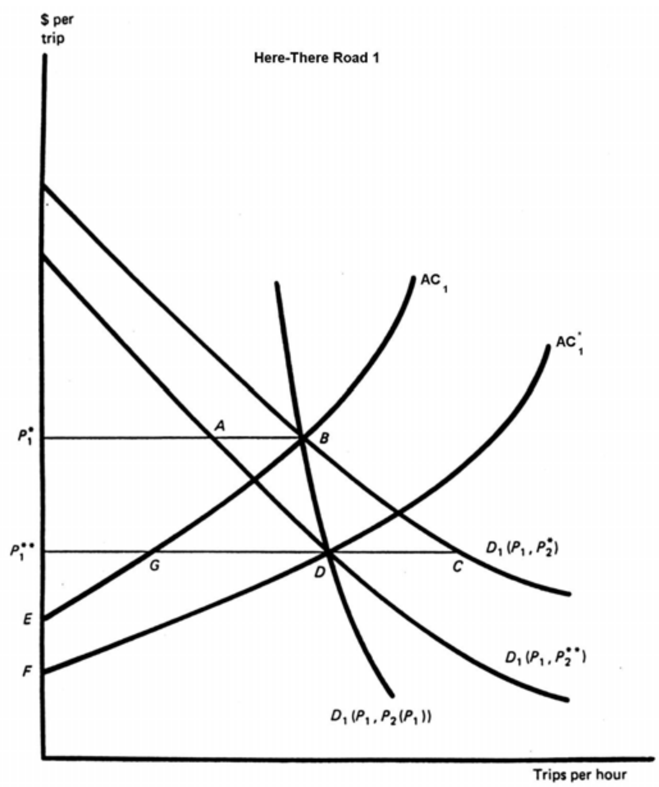

Exhibit 12: Direct and indirect effects of road improvements with zero tolls.

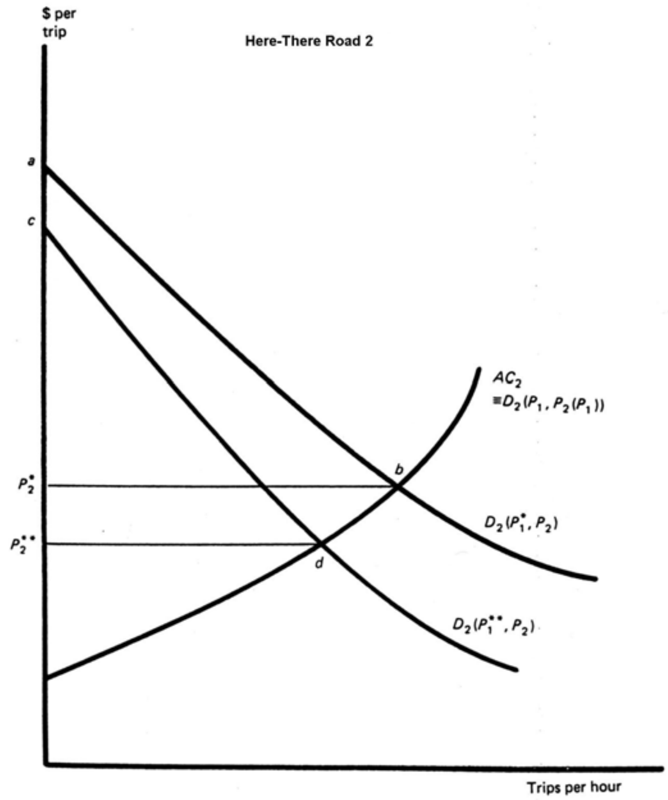

Exhibit 13: Direct and indirect effects of road improvements with zero tolls.

It is worthwhile considering two sorts of situations in which prices differ from marginal costs: first, when no tolls are levied for highway use; second while tolls are charged, they do not equate price and marginal cost. Exhibit 12 deals with the benefit implications of zero user charges. Its interpretation is quite similar to that of Exhibit 8. The basic difference between them is that the upward sloping lines in Exhibit 8 refer to the short-run marginal costs of trips while the corresponding lines in Exhibit 12 are their short-run average costs. That is, the Exhibit 8 lines include but the Exhibit 12 lines exclude the costs users of Roads 1 and 2 users impose on each other by adding to congestion levels.

In the absence of tolls, consumers and carriers incur only travel-time and vehicle-operating costs. The equilibrium travel rate on each road is, therefore, that which the "last" traveler values at its direct costs. Before the improvement, these equilibrium occur at points B and b respectively on Roads 1 and 2. Net consumer benefits on the two roads are therefore areas ABP_1* and abP_2*. If user charges are not imposed, these consumer benefits are all society gains from using the roads.

Through a process identical to that discussed in describing Exhibit 8, improving Road 1 would lead to new equilibrium travel rates at points D and d respectively on Roads 1 and 2. As with Exhibit 8, a variety of consumer benefit measures with approximately equal values could be described for the shift from B and b to D and d. As before, the measure of greatest interest is the sum of P_1*BDP_1** on Road 1 and P_2*bdP_2** on Road 2. As with Exhibit 8, constructing this benefit measure requires viewing the price of Road 2 trips as a function, $P_2(P_1)$, of the price of Road 1 trips. The resulting demand schedule for Road 1 trips is $D_1[P_1,P_2(P_1)]$, while that for Road 2 trips is superimposed on the average cost schedule for these trips. Unlike the situation with Exhibit 8, however, the benefit to Road 2 road users is a net benefit. Since no tolls are collected, there is no transfer to users of income formerly received by society at large.

To summarize, if trips are not tolled, determining the net short-run benefits of improving one link on a highway system requires information on the effects of that improvement on the use of all other links in the network. Specifically, the benefit equals the sum over all affected links of the changes in consumers' surplus benefits–some of which may be negative–that the improvement induces.

In the United States, the basic "toll" for highway use is that implicit in federal and state gasoline taxes and other excises that are related to the rates at which vehicles are operated. For the use of expressways, these taxes work out to roughly 1 cent per private passenger vehicle mile, regardless of traffic conditions. If the occupants of the average private passenger vehicle value their time at $1.55 an hour, 1 cent per mile is approximately the cost any given expressway trip imposes on other expressway travelers only when the volume-capacity ratio on the expressway is about 50 percent. For a volume-capacity ratio of 90 percent, an expressway toll on the order of 3.7 cents per vehicle mile would be required to equate the price of a trip with its marginal cost, while for a 10 percent volume-capacity ratio, a toll of about 0.1 cents would be appropriate.

The corresponding optimum tolls for travel on city streets are 0.4, 2.9, and 11.7 cents for respective volume-capacity ratios of 0.1, 0.5, and 0.9[12].

To repeat, regardless of the toll levels set, an improvement's net benefit equals the sum of the changes in consumers' surplus and toll-revenue benefits to which it gives rise. Measuring net benefits when price and marginal cost are unequal would simply require adding up these changes for all affected highway links with, of course, a heavy computational burden. This computational burden can be reduced somewhat and additional insights into the economic processes involved can be obtained by employing "dead-weight loss" geometry.

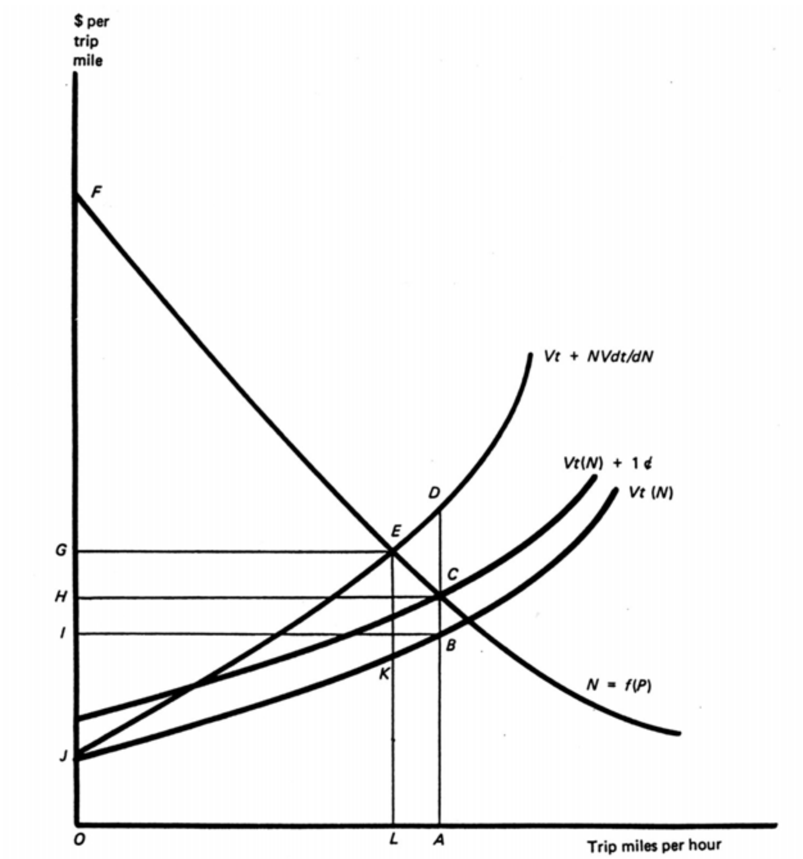

Exhibit 14: Direct benefits of road use with inefficient tolls

[12] Illustrative Exhibits are shown. In practice, the latest numbers should be used.

Exhibit 14 describes a single one-mile highway when the marginal-cost toll exceeds that actually charged. With a marginal-cost toll of KE per trip mile, OL trips per hour would be taken. Total hourly benefits of FEJ would result. Of this total, traveler benefits would equal FEG while highway tolls or rents would equal GEJ. However, if a toll of only BC = 1 cent per vehicle mile is charged, OA trips per hour would be taken, this being the travel rate at which the price charged for trips equals the number demanded at that price. With this travel rate, total hourly benefits equal the area FCBI--a traveler benefit of FCH plus tolls of HCBI.

Consumer benefits with the 1-cent toll are GECH greater than those associated with a marginal-cost price. However, these additional consumer benefits are more than offset by the associated reduction in highway rents. Specifically, in going from a marginal-cost toll to a 1-cent toll, the decrease from GEJ to HCBI in rents collected exceeds the increase, GECH, in consumer benefits by an amount equal to area EDC. Put differently, with a 1-cent toll, total short run benefits generated by the highway equal area FEJ minus area EDC.

Area EDC itself can be interpreted as the total short-run costs (area LEDA) of increasing trip consumption from OL to OA minus the total value (area LECA) consumers attach to these addition LA trips. Areas such as EDC are often referred to as "dead-weight losses"--i.e., amounts by which the maximum benefits that could be derived by society from some economic activity are reduced through inefficient pricing.

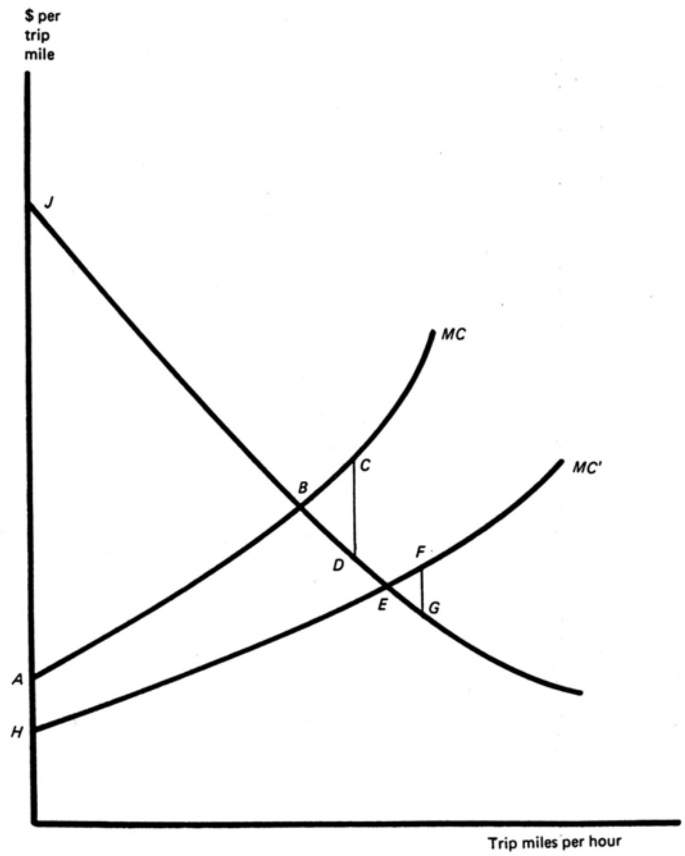

Exhibit 15: Change in dead-weight loss with road improvement.

Suppose that an improvement is made to a highway that is initially priced in the inefficient fashion described in Exhibit 14. As a result, the situation depicted in Exhibit 15 comes about. Even with the improved highway, a 1-cent per mile toll is less than that required to equate demand and marginal-cost schedules. A dead-weight loss is therefore still involved in the highway's pricing. However, the size of the loss has diminished from BDC (equals EDC in Exhibit 3-2 to EFG. The incremental net benefit of the improvement can therefore be viewed as ABEH (the equivalent of, e.g., BDEA in Exhibit 6Exhibit 6) plus the difference between BCD and EFD.

To generalize, a given improvement to a highway will lead to a somewhat greater net benefit if its services are initially underpriced than if a marginal-cost price is charged for them. By the same token, however, a given improvement will lead to a smaller net benefit if a highway's services are initially overpriced rather than priced at marginal-cost.

That is, if price initially exceeds marginal-cost, an improvement will almost invariably serve to increase the gap between price and marginal cost and thereby the deadweight loss.

At least on urban highways, the user charge implicit in gasoline and related excises seems typically to fall considerably short of the appropriate marginal-cost toll during peak travel periods and to be somewhat greater than marginal cost during other times of day. This being the case, the changes in deadweight losses associated with urban highway improvements tend to offset each other. An improvement can generally be expected to decrease deadweight losses during peak travel hours but to increase them during off-peak hours.

3.3.2 Taking Monopoly Elements into Account in Measuring Aggregate Benefits

The nature of the problem here can be suggested with the aid of a simple diagram, Exhibit 12. Suppose, initially, that the gizmo industry is competitively organized. Each of its members incurs manufacturing and transport costs of OA and AC, respectively, per gizmo. The industry demand schedule intersects its supply/unit-cost schedule at H for a weekly output of OY. At this output rate, gizmo buyers receive a weekly consumers' surplus benefit of LHC while gizmo manufacturers just break even.

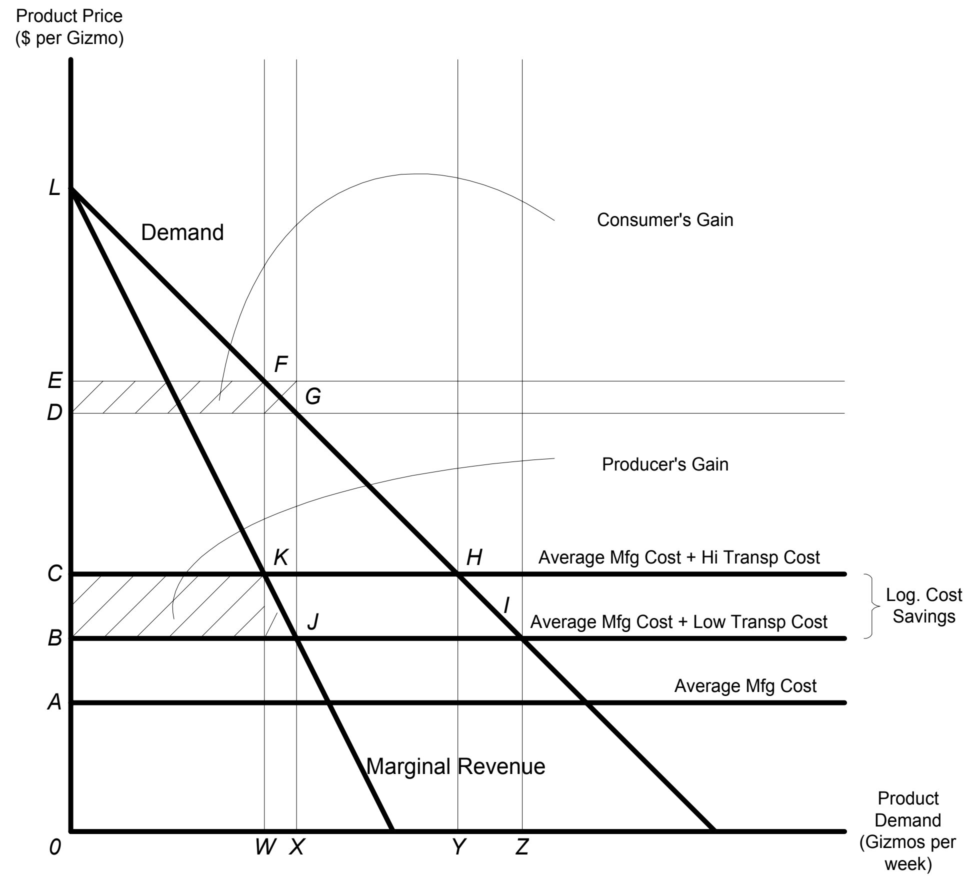

Exhibit 16: Monopoly and benefit allocation.

Suppose, now, that transportation improvements cut gizmo unit transportation costs in half, from AC to AB. After a period of adjustment, industry output expands from OY to OZ per week and the gizmo price falls to OB. The benefit of the improvements to gizmo buyers is area CHIB, the area under the industry's transport demand schedule between prices of OC and OB. As in the previous equilibrium, gizmo consumers reap all benefits from the improvement; after the market fully adjusts to changes in its cost structure, gizmo producers again just break even.

Now suppose that, before the transportation improvement is made, a plutocrat forms Consolidated Gizmo of America to buy out all gizmo producers in the United States. Ignoring the possibility that gizmo price increases would induce new entry to the industry, in the interests of maximizing profits, CGA would reduce its capacity from OY to OW per week, the level at which its marginal-revenue and unit-cost schedules intersect. Its profit-maximizing price is OE. Its customers receive a consumers' surplus benefit of LEF while CGA's profits are twice that, LCK = EFKC.

After the major transport improvement cuts CGA's unit transport costs from AC to AB, its new profit-maximizing output and profit rates are respectively OX and LBJ, an amount that is CKJB greater than its previous profit rate. This is the amount that its transportation demand schedule shows CGA to receive from the improvement. In addition to CGA's gain, however, its customers benefit by EFGD each week. This benefit is not part of CGA's profit increase; true net benefits of the improvement are, therefore, 1.5 times those that would be inferred from CGA's transport demand schedule.

The fraction of the total benefits of a transport improvement that elements of monopoly can hide depends on specifics of the cost and demand schedules that monopolists face. We restrict attention here to markets that are characterized by "Constant elasticities of demand" and to costs that are proportional to sales. The elasticity of demand for a commodity is the percentage change in the quantity sold divided by the percentage change in its price that brought the sales change about. A general expression for a constant-elasticity-of-demand schedule is $Q = a / P^b$ where Q is the quantity that would be sold at a price of P and where a and b are constants. It can be shown that b is the elasticity of demand.

It is possible to show[13] that, given a constant demand elasticity, if P is the current price of gizmos, reducing the price by just enough to sell one more of them would generate (1 - 1/b)P in additional revenues. Note that, if b is less than one, (1 - 1/b) is negative; an additional sale would reduce total revenue. A gizmo monopolist would not willingly set its price at a level for which b is less than one.

[13] If $Q = a / P^b$, P = (a/Q)1/b. Total revenue, PQ, is R = a1/b Q(1-1/b). Marginal revenue, therefore, is dR/dQ = (1 - 1/b)(a/Q)1/b = (1 - 1/b)P.

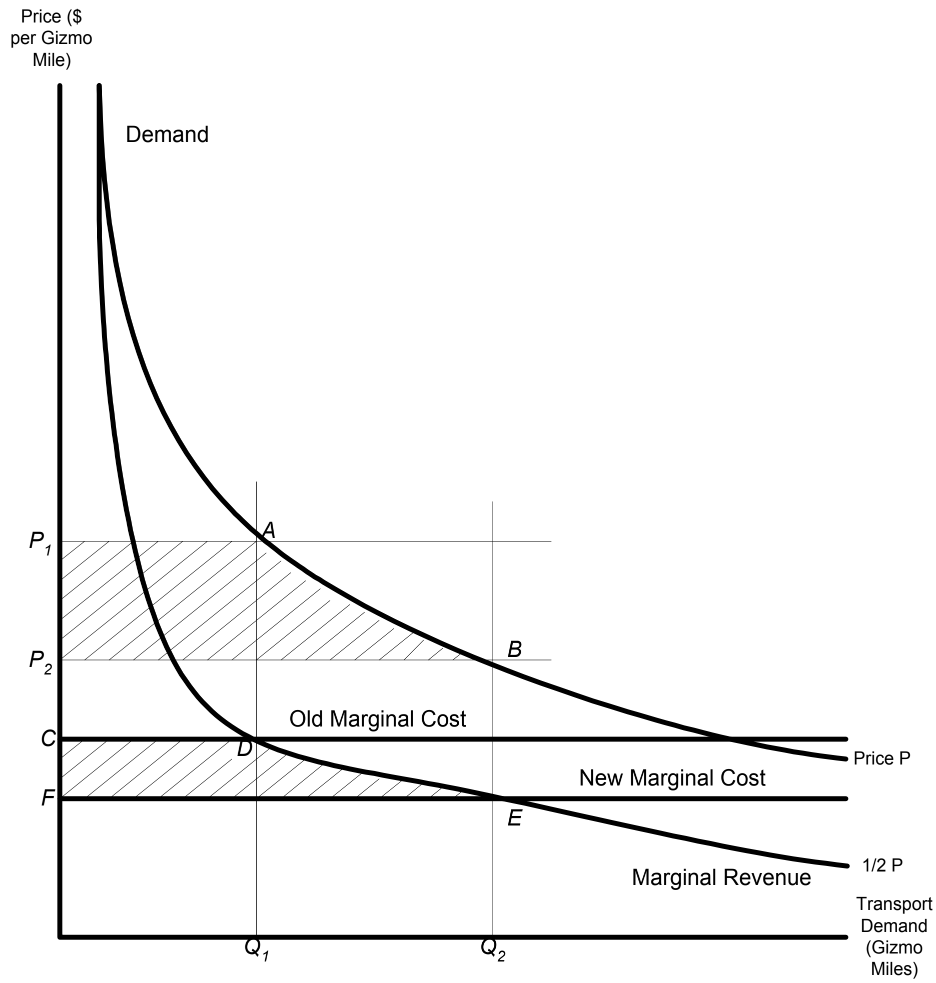

Exhibit 17: Monopoly benefit under-estimation.

Exhibit 17 shows the relationship between price and marginal revenue for a specific instance where the constant elasticity of demand, b, is 2. For this case, marginal revenue at any given price is half that price. Suppose that the marginal cost of producing and delivering a gizmo is OC, along the line labeled "Marginal Cost Old." Marginal revenue equals marginal cost at an output of Q_1. Suppose that a reduction in transportation costs– or any other cost, for that matter–reduces production plus distribution costs to "Marginal Cost New." Marginal revenue now equals marginal cost at an output of OQ_2.

Again, in this example, marginal revenue equals the market price divided by two; $OC = P_1/2$ and and $OF = P_2/2$. Hence, $OC - OF = (P_1 - P_2)/2$; the transportation improvement results in a price reduction equal to twice that of its reduction in marginal cost. In Exhibit 3-5, CDEF is CGA's benefit from the transport improvement. It is CDEF that we would compute if we observed CGA's transport demand schedule. With a demand elasticity of 2, consumers receive twice the producer's benefit from this cost reduction; the producer's benefit is only a third of the total benefit.

Table 3: Consumer Benefit v. Monopoly Benefit with Constant Elasticity Demand Schedules

Elasticity	*Marginal Revenue/Price*	*Consumer/Producer Benefit*
1.5	*0.33*	*3.00*
2.0	*0.50*	*2.00*
2.5	*0.60*	*1.67*
3.0	*0.67*	*1.50*
3.5	*0.71*	*1.40*
4.0	*0.75*	*1.33*
4.5	*0.78*	*1.29*
5.0	*0.80*	*1.33*

For alternative demand elasticities, Table 3 lists the ratio of marginal revenue to price and the ratio of the consumer benefits to the monopolist's benefit. Clearly, the excess of the consumer benefit to that of the monopolist diminishes with increases in the demand elasticity, but the producer benefit is less than the consumer benefit for less than infinite elasticities.

3.4 Review of NCHRP 342

To date, the most complete theoretical and mathematical treatment of benefits estimation is in the supplement to NCHRP 342 [3], and particularly in Appendix D. Much of this material is highly technical and not easily accessible to a reader without a strong knowledge of micro-economic theory and a good grasp of mathematics.

3.4.1 Approach and Assumptions

Appendix D to NCHRP Report 342 developed a method to calculate the increase in consumer surplus resulting from a road network improvement. It assumed that road network improvements impact private sector productivity. Transport intensive firms were expected to alter their logistics to take advantage of road network improvements.

The basis for the approach was the assumption that a network improvement results in a shift in the demand curve for transportation. The conventional approach to measuring benefits of infrastructure investment is to estimate the direct cost savings to current users, and add an additional allowance for the benefits of increased infrastructure use caused by the lowered costs. Before the road improvement, current use is VM_0 and the cost of operations to users is an average C_0. Demand for road use is a function of the cost of road use, expressed in \$ per vehicle mile. This corresponds to a generalized cost since it includes time, fuel, wear, etc., as well as delays due to congestion. The lower the cost of using the road network, the more it will be used.

After road network improvement reducing congestion, saving time, fuel, and depreciation, the reduced cost per vehicle mile is estimated at C_1. Because of the lower cost of using the road, use expands to VM_1. For simplicity, the model assumed a linear demand curve, and used the elasticity of demand as its primary input. With P as transport cost C, Q as transport demand VM, and N as the price elasticity of demand, it is possible to write:

$$\begin{aligned} P &= a + bQ \\ &= (P_0 - P_0/N) + (P_0/NQ_0) \cdot Q \end{aligned} \tag{1}$$

The higher demand curve D' represents the shift in demand due to logistics re-organization. The combined lower operating costs per vehicle mile and the logistics savings results in volume of use VM_2. The benefits are given by the increase in surplus, areas (a+b+c). Under this model, area c is the impact of logistics changes, and would have been missed by previous practice.

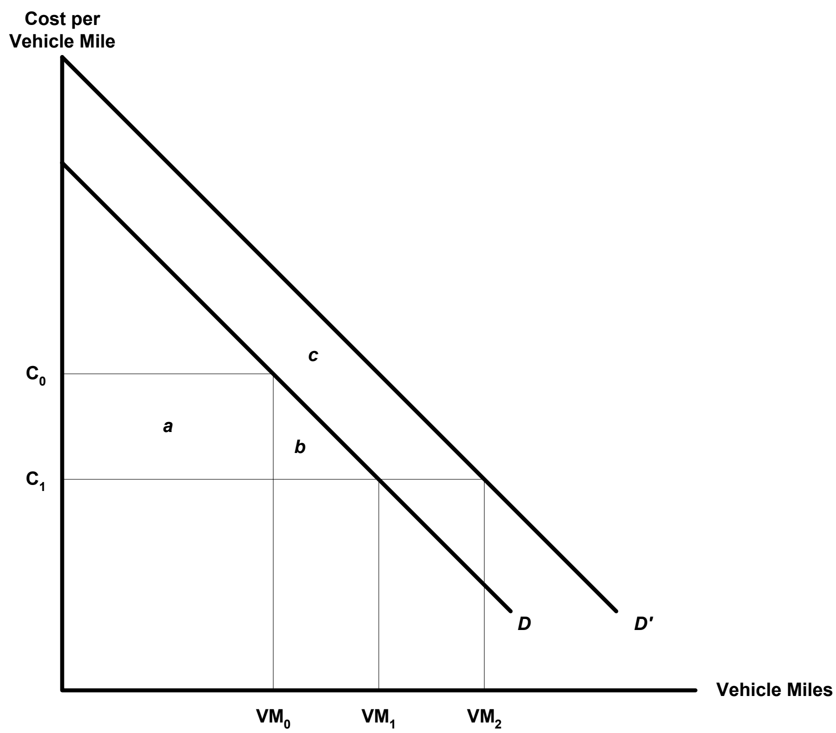

Exhibit 18: Productivity gains due to road improvements.

After re-organization, the new demand curve (shifted), was estimated as:

$$C = a' - b'VM \tag{2}$$

where a and b are changed to reflect operating costs and demand for transport:

$$\begin{aligned} a' &= \left(C_0 + \left(C_0/N\right)\right)/\left(1 + DVM\right) \\ b' &= \left(C_0/N\,VM_0\right)/\left(1 + DVM\right)^2 \end{aligned} \tag{3}$$

The term DVM was defined as the percent change in road use required by road using firms to provide their clients with the same level of service as before the infrastructure investment. It will be shown later that network improvements result in a progressive extension or tilt of the demand curve vice a shift.

In NCHRP 342, it was also assumed that there were no economies of scale for shippers. That is the per-unit cost of transport did not vary with volume of traffic (transport service used). This was seen as a conservative estimate since cost will tend to fall when serving greater volumes within a given delivery area. This again must be estimated at the level of the firm. The report stated it was possible to improve the algorithm but did not propose a procedure.

While reviewing Report 342, a problem was identified with the definition and derivation of DC, as the proportional change in operating costs per vehicle mile of use at current volumes or level of service. The problem, stemming from non-additive proportional changes, has been resolved and can be found at Appendix 2. The new expression states that the proportionate change in average cost per vehicle mile is a combination of proportionate savings in transportation and a scaled change in other costs. With this correction, the expression for DC can then be carried forward in the determination of consumer surplus.

3.4.2 Benefits Derivation

The end result of NCHRP 342 was the determination of gains in consumer surplus (areas a+b+c). For the case of a linear demand curve, this was derived as:

$$\mathrm{BEN}_{\mathrm{Net}} = \mathrm{SPLUS}_1 - \mathrm{SPLUS}_0 \qquad (4)$$

where the surplus before highway improvements is:

$$\mathrm{SPLUS}_0 = [C_0 + (\frac{C_0}{N})] \times VM_0 - 0.5 \times [C_0 / (N \times VM_0)] VM_0{}^2 - C_0 \times VM_0 \qquad (5)$$

and the after investment surplus is:

$$\text{SPLUS}_1 = [C_0 + (\frac{C_0}{N})] \times \frac{VM_1}{(1+DVM)} - 0.5[C_0 /(N \times VM_0) \times (1+DVM)^2]VM_1^{\ 2} \\ -C_0 \times (1-DC) \times VM_1 \tag{6}$$

The net benefits from an increase in consumer surplus is therefore a function of:

C_0 = Initial cost of transport

N = elasticity of demand

VM = vehicle miles used

DVM = proportional change in vehicle miles

DC = proportional change in logistics costs

An alternate derivation was also provided based on the observation that the new cost of transporting S units can be expressed as:

$$CS_1 = C_0 \times (1-DC) \times (1+DVM) \tag{7}$$

which says the new cost is proportional to the increase in transportation use as well as the decrease in cost. Assuming suitable estimates can be obtained for all these quantities, it is a simple matter to calculate benefits.

3.4.3 Conclusion

The above derivation suffers from a number of shortfalls. The level of output of the firm remains fixed, an assumption that we wish to relax in a revised framework. A linear demand curve was also assumed, but for small changes in logistics costs, this may be a reasonable approximation. The theoretical framework should hold for any demand curve. Furthermore, it was also assumed that absolute logistics cost savings were known. Some form of aggregation through the estimation of elasticities is required – this was addressed in the follow-on work documented in NCHRP 2-17(4).

The above derivation establishes benefits measurement through a relationship between transportation cost and transportation service (VM), while quantity shipped remained fixed. In fact quantity shipped would be expected to increase thereby improving firm productivity and so a simpler more direct and transparent method to measure benefits is needed.

3.5 Review of NCHRP 2-17(4)

3.5.1 Approach and Assumptions

The methodology in 2-17(4) focused on trade-offs between freight transport and other logistics inputs. Again, constant output of the firm is assumed. Logistics cost savings may allow firms to reduce their price, thereby increasing product demand, sales and transportation used. These relationships are illustrated in the influence diagram at Exhibit 22. The effect of additional demand will be covered in section 4.1.

The shipment is considered the basic unit of transportation provided. It is assumed that there are M types of transportation services available to the firm. The relevant characteristics of a shipment $S_i = S(L_i, W_i, M_i, V_i, T_i, \sigma_{T_i})$ are:

L_i = origin-destination pair (transportation link)
W_i = shipment weight
M_i = transport mode
V_i = Value-added services
T_i = expected travel time
σ_{T_i} = variance of travel time

The relationship between logistics inputs and level of service needed to support the production and distribution function of the firm are described by the production function:

$$Y = f(S_i, I_j, B_k, IT_l) \tag{8}$$

where Y is the output of the firm (final sales), S_i are the shipments, I_j are the inventory stocks, B_k are the warehouse spaces, and IT_l is an information input related to order processing[14]. As a result of infrastructure investment, characteristics of shipments may

[14] This last term acknowledges the importance of IT in production but did not appear in NCHRP 2-17(4).

change and the firm will seek to minimize its total costs subject to maintaining or improving production.

3.5.2 Benefits Derivation

The measurement of benefits was achieved through a derivation of the total willingness to pay (WTP), in dollars. This WTP is based on aggregate logistics cost savings for like firms and industries.

WTP has been expressed as:

$$\mathrm{WTP} = \mathrm{TS} \times \alpha_{Log} \times F(\mathrm{T}, \eta_{\mathrm{T}}, \sigma_T, \eta_{\sigma_T}) \qquad (9)$$

where,

TS = Total sales ($)
α_{Log} = logistics cost as percent of total sales (%)
T = average travel time (hours)
σ_T = variance of travel time (hours**2)
η_T = elasticity of logistics cost with respect to travel time
η_{σ_T} = elasticity of logistics cost with respect to travel time variance.

The specific form of the dimensionless function F depends on the nature of joint effects of travel time and variability on logistics costs. In the case where savings due to travel time and variability are assumed additive, the expression was written as follows:

$$\mathrm{WTP} = \mathrm{TS} \times \alpha_{Log} \times \left(\eta_{\mathrm{T}} \frac{\Delta \mathrm{T}}{\mathrm{T}} + \eta_{\sigma} \frac{\Delta\sigma}{\sigma}\right) \qquad (10)$$

An alternate derivation of WTP was proposed for the case where a complementary relationship exists between travel time and reliability. Since it was not used, we do not discuss it further here. The above derivation for WTP was used to calculate changes in the firm's logistics costs via sampled elasticities. This function could be generalized to also include other effects of highway improvements such as heavier loads, larger capacity trucks, and changes in hours of service.

Sampled Elasticities

It is not practical to attempt to quantify each firms "absolute" logistics cost savings. What is possible, rather, is to qualify the nature and extent of logistics re-organization for a statistical sample of firms and to infer elasticities as a measure of their response to infrastructure improvements. The error in the slope of the curve (elasticity) can be estimated and controlled based on the variability of the sample. A cost-effective solution can then be found for the estimation process itself.

There is a requirement for systematic and transparent interviews of firms' logistics planners to obtain information on the impact of transportation cost reductions. The points at which re-organization occurs and its extent is also required as part of the sample. As is demonstrated at Exhibit 19, re-organization creates a jump gain in proportional logistics cost savings at specific levels of time savings. There could be several steps at which savings occur - one for inventory policy changes[15], a second for warehouse consolidation as part of logistics system changes.

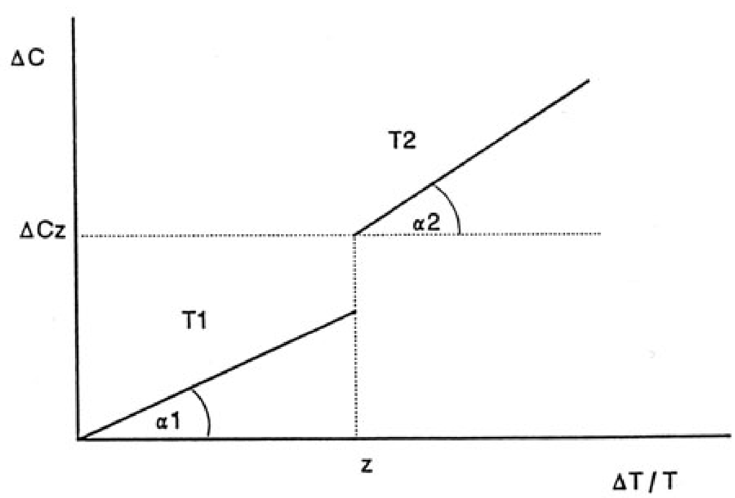

Exhibit 19: Cost Savings by firm for relative changes in travel time.

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[15] Inventory could also be reduced continuously as transportation services improve.

The aggregate savings can be computed for the sample of firms, as shown at Exhibit 20. The aggregate cost savings function was shown to be $\sum \Delta C_i \left(\Delta T / T \right) / \sum C_i$.

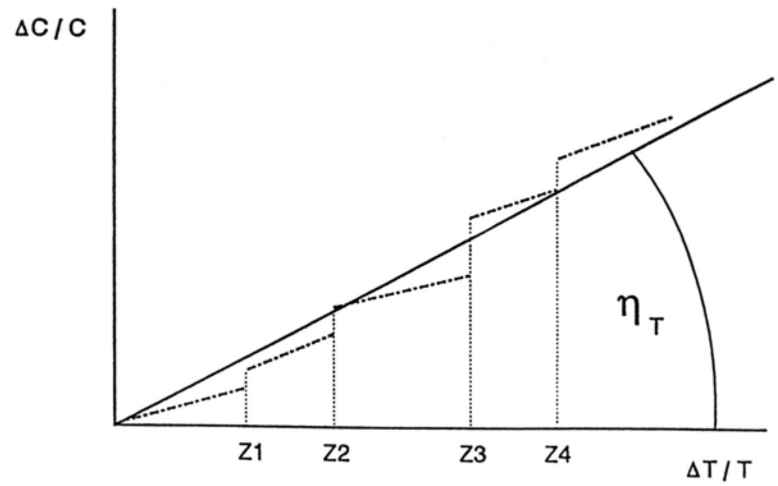

Exhibit 20: Aggregate industry relative cost savings and estimation of elasticity.

Given total sales, logistics costs as a proportion of total sales, elasticity of logistics costs with respect to travel time and travel time variability, the willingness to pay, WTP, can be computed by commodity across various industries.

3.5.3 Productivity Gains

Although the BCA framework will capture productivity effects, we expand on the description provided in NCHRP 2-17(4) to relate productivity gains to logistics cost savings.

Once firms identify ways to reduce costs and restructure their logistics as a result of better highways, they will combine inputs in a different way to produce the same level (or more) of output. Restructuring can be seen as a more efficient employment of resources. In this case, it is possible to quantify changes in firms' productivity.

Productivity is the ratio of outputs to inputs. This can be written

$$\text{Productivity} = \frac{Output}{Input} \tag{11}$$

A change in productivity may occur as a result of logistics restructuring. This change is given by:

$$\begin{aligned} \Delta P &= \frac{O}{I_2} - \frac{O}{I_1} = O\left(\frac{I_1 - I_2}{I_1 I_2}\right) \\ &\approx O\left(\frac{\Delta C_{Log}}{I_1 I_2}\right) = P_1\left(\frac{\Delta C_{Log}}{I_2}\right) \end{aligned} \tag{12}$$

Productivity gains can then be expressed in terms of previous productivity and relative logistics savings with respect to the new input level. For the case of changing output, productivity gains $\Delta P'$ can be written as:

$$\begin{aligned} \Delta P' &= \frac{O_2}{I_2} - \frac{O_1}{I_1} \\ &= \left(\frac{O_2 I_1 - O_1 I_2}{I_1 I_2}\right) \end{aligned} \tag{13}$$

Productivity gains can be realized as a result of improved transportation infrastructure. Benefits from these gains will be captured as part of net benefits in the BCA framework to be developed later in the report. Even if productivity gains are a useful indicator of the value of infrastructure investment, they are not an addition to what is reported in net benefits in the proposed approach.

3.6 Critique of Developments to Date

The scope and general approach of previous HLB studies can be seen from the revised influence diagram at Exhibit 22 below. The focus and scope of each study is highlighted with an area covering the primary variables and their relationships in deriving total benefits. NCHRP 342 considered logistics cost savings, and the shift in demand for transport, while NCHRP 2-17(4) considered net logistics cost savings as a function of travel time and travel time variability changes.

With this work, we are attempting to build on previous studies while letting the firm's output vary. In measuring infrastructure improvement benefits, improved firm productivity will be an important effect to capture. Industrial re-organization can lead to reduced logistics costs that can be passed on to consumers thereby increasing product demand.

In the first instance, NCHRP 342 assumed a shifting demand curve for transportation services. This implies that if, for whatever reason, the price increases back to its old level, demand would be higher than originally. One could imagine such a case but only in the very short run. In the long run, the process should be reversible.

What is more plausible is an outward sloping demand curve given the opportunity for firms to re-organize their logistics over time. Exhibit 21 indicates the demand D for transportation given no re-organization effect. With re-organization, the demand for transportation, noted D`, may increase at any given price level. "By how much" is an essential question which will help solve the overall benefits assessment problem. In the Exhibit below, area a represents the immediate direct benefit to a firm. It is the cost savings based on current road use, while area b is the medium run net value of the increase in road use (possibly due to changes in inventory). Area c represents the benefit from a longer run response to logistics re-organization such as for warehouse consolidation or other long-term changes.

The second major study, NCHRP 2-17(4) addressed net benefits as a willingness to pay for overall logistics cost savings. With this approach, it is difficult to address possible increases in product demand and the effects of marginal cost pricing. A more conventional approach based on consumers surplus is seen as better suited. As we shall see in the proposed framework, however, elements of 2-17(4) will be retained in the determination of firms' responses to infrastructure investments and elasticity estimation.

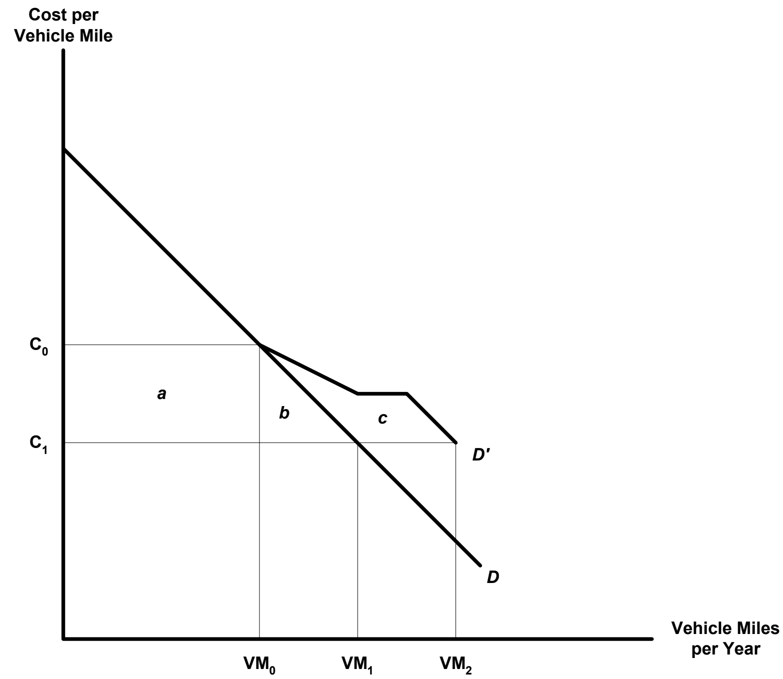

Exhibit 21: Demand curve as affected by logistics re-organization.

3.7 Conclusion

The overall framework described in the next section shall be based on a variant of the shifting demand curve method from NCHRP 342 for the change in consumer surplus, as well as elements of NCHRP 2-17(4) for elasticity estimation. This is to be enhanced with strategies to allow for changes in output of final products, absence of marginal cost pricing, and presence of possible monopolies.

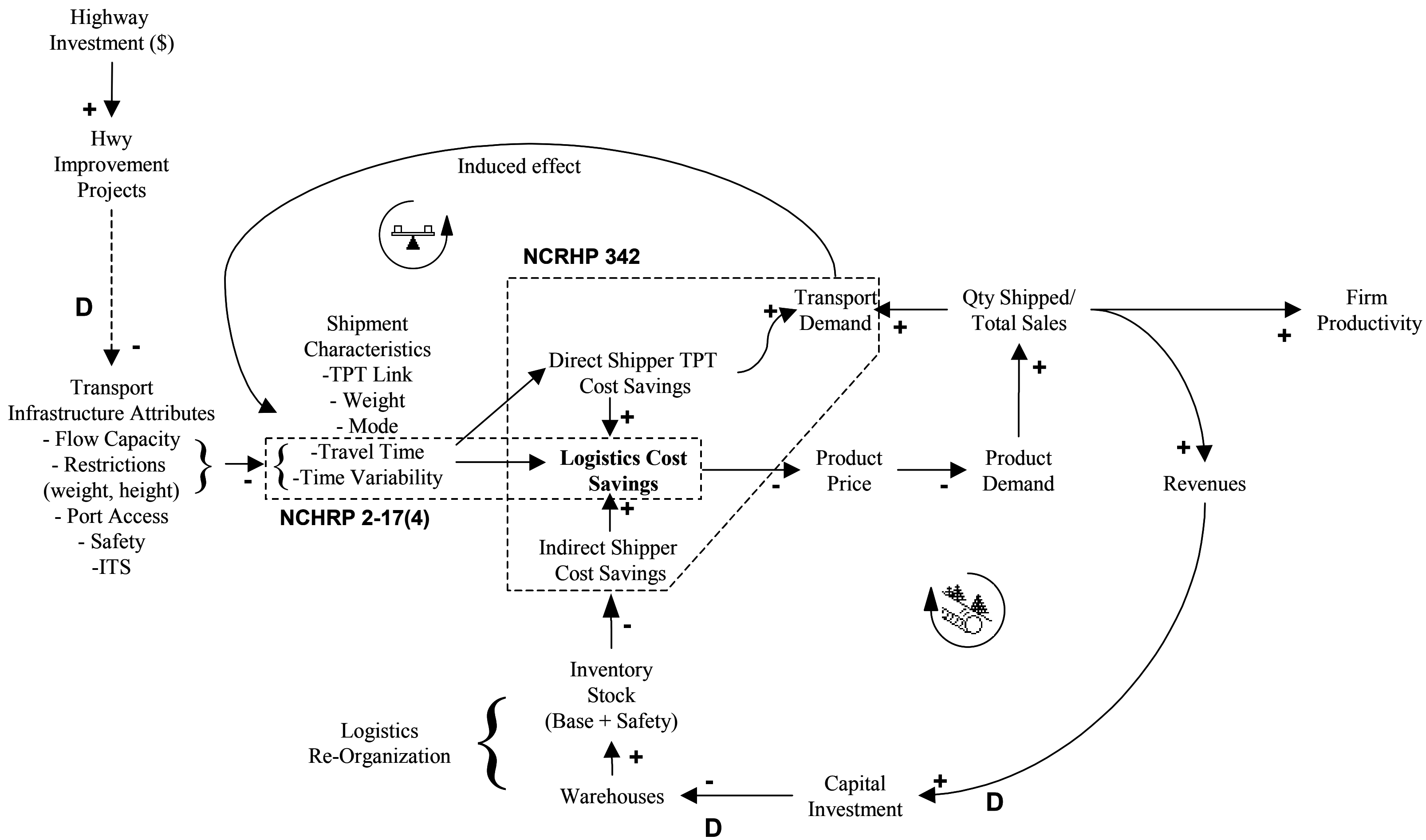

Exhibit 22: Freight economics influence diagram and previous studies

4. PROPOSED FRAMEWORK

Based on the previous discussion, this section addresses the general micro-economic framework in both geometric as well as mathematical terms. The framework is general in the sense that it captures benefits of any highway improvement[16]. The introduction of ITS, for instance, to manage congestion would translate into reduced travel times and enhancing reliability. Benefits of any initiative affecting overall logistics costs - such as vehicle operating limits - could be considered. An explanation of key parameters within the framework will be given so as to build a practical cost-benefit model.

4.1 Approach

Recall that in NCHRP 2-17(4) [2], a method was developed to estimate the elasticity of logistics cost with respect to travel time savings, call it η_T^C. This quantity was derived from a sample of firms' response (cost savings) to travel time improvements. A similar approach can be used to determine a firm's elasticity of demand for transportation as a result of travel time savings and changes in logistics, call this elasticity η_T^{VM}. This last quantity encapsulates the firm's response to highway improvements in terms of new transportation demand as a result of possible substitutions. The quantity is shown graphically below over a sample of several firms. The points at which re-organization occurs, W_i, may be specific to individual firms. The trend will allow the inference of effects (slope of the curve) over a range of firms.

[16] Both infrastructure and info-structure changes.

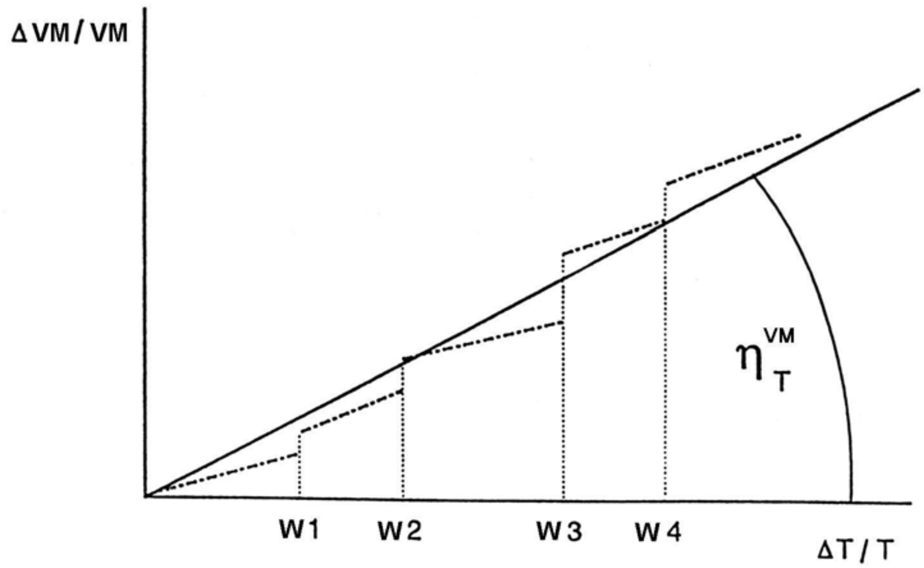

Exhibit 23: Aggregate relative change in transportation demand
with respect to relative travel time savings.

According to 3.6, to calculate benefits of road improvements, the elasticity of transportation demand with respect to transportation cost η_C^{VM} is required. A simple relationship can be established between these two elements. We can write η_C^{VM} as:

$$\eta_C^{VM} = \frac{\Delta VM / VM}{\Delta C / C}$$

$$= \frac{\dfrac{\Delta VM / VM}{\Delta T / T}}{\dfrac{\Delta C / C}{\Delta T / T}} \qquad (14)$$

$$= \frac{\eta_T^{VM}}{\eta_T^{C}}.$$

This last expression is the ratio of the elasticity of transport demand with respect to travel time η_T^{VM}, and the elasticity of transportation cost with respect to travel time η_T^C. Both of these might be estimated using a suitable sampling methodology within various industries.

Central to the framework, increases in transport demand are needed as a result of infrastructure improvements. It is acknowledged that the elasticity of vehicle miles may be difficult to obtain. Options may include simulation, or a generalized demand function.

There is one modification that must be brought to the approach. While the units for C were previously logistics costs, the new units will be logistics cost per unit of transportation (vehicle-mile, product-mile, ton-mile etc). This change of scale will allow the integration of the demand curve into net benefits. Estimation of transportation user costs should not present a problem. For instance, assuming for the sake of argument that wages accounted for 30% of transport operating [9], a 20% decrease in travel time could result in a 6% decrease of direct transportation cost per vehicle mile. In reality, other substitutions could also take place.

This approach has the added advantage that the demand for transportation services can be aggregated across markets or commodities thereby facilitating benefits estimation for highway network improvements. Aggregation using a product demand curve may be difficult due to the varying nature of products. We now turn to the problem of changes in product demand.

The fundamental determination of the demand curve for transportation services involves two quantities, price and vehicle miles used or traveled. The change in each of these components was derived as a function of some third dimension - travel time and/or travel time variability. This third dimension is in turn a function of highway investment. Once time savings are known or estimated, logistics cost savings estimation can be carried out at the level of the firm to include logistics re-organization effects. Each firm is different, but with a representative sample the general response trend can be quantified over specific industries. Note that the third dimension could also include changes in vehicle capacity or service hours thereby increasing freight throughput. Whatever effect is considered, it is the net change in generalized logistics cost per vehicle mile that must be estimated.

Changes in Output/Product Demand

The demand for freight services is derived from the demand for final products carried. Because freight transport is closely related to land use patterns, it is also important to consider at the same time influences affecting industrial location and distribution. Transport demand could thus increase due to two effects – both of which have been mapped at Exhibit 22. First, logistics re-organization may result in substitution of additional transport for inventory and holding locations. Second, savings from lower transportation and overall logistics costs may be passed on to consumers resulting in an increase of consumer product demand. This increase in demand is embodied in increases in transportation services required. Both these components must be part of the effective demand upon which net benefits are derived.

4.2 Competitive Market

The benefits of infrastructure investment can be derived from the change in consumer surplus for transportation demand. In general form, it is possible to write:

$$\begin{aligned} Ben_{Net} &= \Delta CS \\ &= CS_1 - CS_0 \\ &= \left(\int_0^{q_1} p(q)dq - p_1 q_1 \right) - \left(\int_0^{q_0} p(q)dq - p_0 q_0 \right) \\ &= \int_{q_0}^{q_1} p(q)dq - p_1 \Delta q \ + q_0 \Delta p \end{aligned} \tag{15}$$

In our case, price $p(q) = C(VM)$ the cost of transport per vehicle mile at a level of demand $q = VM$. This general expression encapsulates the net benefit of the infrastructure improvement in the absence of marginal cost pricing.

One approach to evaluating the integral above would be to assume constant elasticity of demand near the present demand level. A general expression for a constant-elasticity-of-demand schedule is Q = a /P [b] where Q is the quantity that would be sold at a price of P and where a and b are constants. It is a simple matter to evaluate the integral.

$$\begin{aligned} Ben_{Net} &= \Delta CS \\ &= \left(\frac{a}{q_0 q_1}\right)^{1/b} \left(\frac{2(b-1)q_0^{(1+1/b)} + q_1 q_0^{1/b} - (2b-1)q_1^{1/b} q_0}{(b-1)}\right) \end{aligned} \qquad (16)$$

The next section shows the derivation for a linear case as was done in NCHRP 342.

4.2.1 Special Case - Linear Demand Curve

If q_1 is much larger than q_0 and/or the demand curve is highly concave, then the shape of the demand curve may have an effect on benefits estimation. If $q_0 \cong q_1$ and the demand curve $p(q)$ is well behaved, then a linear approximation may be adequate.

For the simple case of a linear demand curve, $C = a - bVM$. For this case, it is possible to show that:

$$Ben_{Net} = a(VM_2 - VM_0) - \frac{b}{2}(VM_2^2 - VM_0^2) - C_1 \Delta VM + VM_0 \Delta C \qquad (17)$$

where $a = (C_0 + C_0 / \eta_C^{VM})$ and $b = (C_0 / \eta_C^{VM} \cdot VM_0)$.

The change in transportation cost can be estimated as:

$$\begin{aligned} \Delta p &= \Delta C \\ &= C_0 \cdot \eta_T^C \frac{\Delta T}{T} \end{aligned} \qquad (18)$$

We can therefore derive the new price p_1 as:

$$p_1 = p_0 - \Delta C \cdot \varepsilon \qquad (19)$$

where ε is the fraction of the per mile cost savings transferred to customers.

The change in demand can be estimated as:

$$
\begin{aligned}
\Delta q &= \Delta VM \\
&= VM_0 \cdot \eta_T^{VM} \frac{\Delta T}{T}
\end{aligned}
\tag{20}
$$

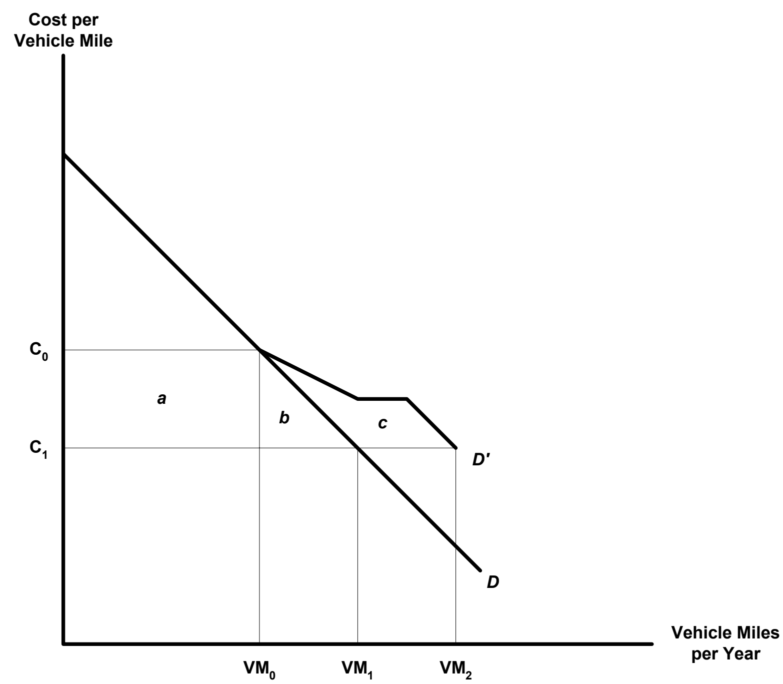

Exhibit 24: Demand curve for transportation.

Net benefits are represented by areas a, b, and c, the direct benefit, the medium and long run demand changes respectively. Instead of a uniform shift in the demand curve, there is an extension of demand made possible by re-organization, product price reductions, and increased product demand. With this approach, it is possible to estimate total benefits with and without re-organization as was done in NCHRP 2-17(4). The great advantage of using a simple demand curve is that it includes all benefits.

4.3 Monopoly

For the case of monopoly, it was shown that net benefits involve both a consumer's gain as well as a producer's gain. This is true not just for transportation, but also for other markets.

$$Ben_{Net} = \Delta CS + \Delta CS' \tag{21}$$

The consumers gain ΔCS is as above. The producer's gain $\Delta CS'$ has the exact same form except that the price is replaced by marginal revenue $\frac{\partial R}{\partial q}$. The new price that maximizes the monopolist's profit can be approximated as $B = A - \Delta C_{Log}$. These two areas are illustrated graphically below. In the case of monopoly, two areas must be considered, but the overall procedure for each is the same. The expression is:

$$\begin{aligned} Ben_{Net} &= \Delta CS + \Delta CS' \\ &= \left(\frac{2b-1}{b}\right)\left(\frac{a}{q_0 q_1}\right)^{1/b}\left(\frac{2(b-1)q_0^{(1+1/b)} + q_1 q_0^{1/b} - (2b-1)q_1^{1/b} q_0}{(b-1)}\right) \end{aligned} \tag{22}$$

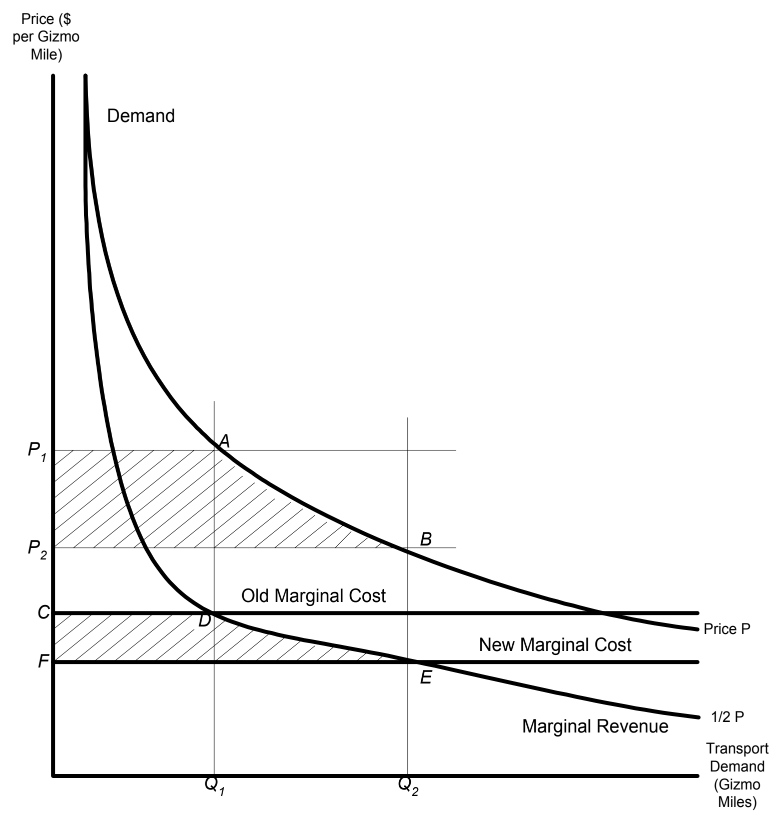

Exhibit 25: Benefits in the presence of Monopoly

4.4 Accounting for Non-Marginal Cost Pricing

A simple adaptation of the cost-benefit methodology can be used to correct for non-marginal cost pricing. If TC is the total cost of providing a road with N trips made along it per unit time, then this total cost can be defined as:

$$TC = N \cdot C(N, K) + f(K) \tag{23}$$

where C is the cost of one trip to a vehicle and $f(K)$ is the cost per time period of providing K units of road capacity. The short-term marginal cost becomes:

$$\frac{\partial TC}{\partial N} = C(N, K) + \frac{N \cdot \partial C}{\partial N} \tag{24}$$

The N^{th} vehicle then incurs a cost itself and imposes a cost on other users. This is demonstrated graphically at Exhibit 26 below.

The cost-benefit analysis could be revised with estimated marginal social cost prices for the use of transport services - at a given level of use. These estimated price adjustments could have a wide margin of uncertainty. However, if a highway improvement option remains justified and highly ranked compared to other competing alternatives in the presence of approximate marginal cost pricing, then there is good confidence that the option valuations are robust to underlying assumptions. The actual estimation of marginal cost prices is work to be carried out as part of a follow-on task.

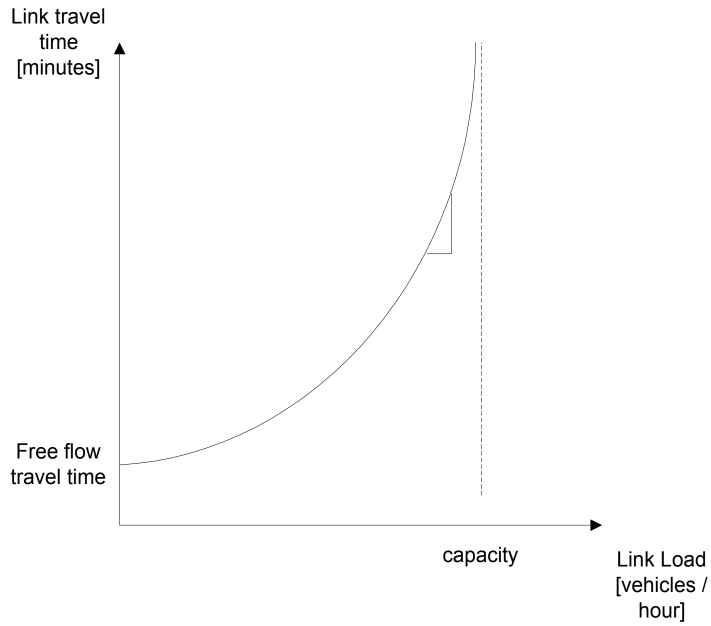

Exhibit 26: Typical user link travel time graph and marginal cost.

4.5 Approach Summary

In summary, our method rests on estimating the change in consumer surplus reflected in the 'shift' in the demand curve for freight transport that follows the improvement. This was the general idea presented in Appendix D of 342, but significant changes are made (aside from resolving the mathematical problems we found): the 'shift' in the demand curve now reflects increasing output as well as trade-offs between transportation spending and total logistics costs. We have thus moved away from the "simplified approach" presented at the end of Appendix D.

From a theoretical standpoint, we could stop here but we now turn to implementation. One possibility for empirical estimation of the demand curve is to use elasticity estimates of the type developed in 2-17(4). These elasticities embody increases in output as well as substitution of transportation for inventory-holding points. Corrections have been proposed for monopoly and marginal-cost pricing.

5. IMPLEMENTATION ISSUES

The methodology described will allow the quantification of the effects of transportation system improvements in relation to freight transportation. First order benefits include immediate cost reduction to carriers and shippers. Second order effects include the impact of improved logistics while keeping output fixed. Finally, third order effects consider additional gains from re-organization such as increased demand, new or improved products, and so on.

Section 3.2's message was that, in a world where marginal-cost prices prevail in all markets including those for transportation facilities, only information on the use made of improved transport facilities is necessary to measure completely the benefits it yields to its users and provider. Section 3.3's first message was that the absence of marginal-cost pricing on roads and other governmentally provided facilities makes benefit measurement much more difficult; determining the full benefit of an improvement requires analyzing not just its use but also the use of other facilities that the improvement affects. Section 3.3's second message was that, if elements of monopoly exist in the markets in which road users participate, sellers' transportation demand schedules understate total benefits. In the simple model used to illustrate the phenomenon, monopoly hides a third of the benefits.

5.1 Information Requirements

Benefits measurement can be achieved equivalently through the transport demand schedule or the product demand schedule. In this paper, we chose to work with changes in transportation demand. It was argued that a different procedure must be used for monopoly as compared to a competitive market. In this case, benefits accrue to consumers through a consumer's gain from lower prices as well as producers gains through increased profits at their new profit maximization production levels.

In order to quantify overall economic benefits of infrastructure improvements on freight transportation, it will be necessary to quantify the following basic entities:

- Direct logistics cost savings, from travel time savings and reduced variability, due to highway improvements, AND indirect savings from logistics re-organisation (including the threshold at which re-organisation would occur) for a sample of firms;
- The elasticity η_T^C of transportation costs with respect to travel time savings (derived from the above);
- Current transportation demand VM_0 & elasticity of transportation demand with respect to travel time η_T^{VM};
- Current product demand (q) & elasticity of product demand with respect to price, for changes in firms' output (η),
- For the case of monopolies – marginal revenue and elasticities of marginal revenue with respect to logistics cost savings;
- Volume of freight traffic and product movement across transportation links by commodity and market,
- Average travel time and variability following highway improvements for various transportation network links and nodes. These values may also be a function of other parameters such as relaxed weight or height restrictions, port clearance characteristics, etc.

The first point demonstrates recognition of the need for a total integrated logistics system (ILS) cost view of a firm's operations as opposed to an isolated transportation cost component. From this information, the elasticity of logistics cost savings with respect to travel time and/or variability reductions can be estimated. A statistically valid sample of firms' responses by industry and by transportation link will provide a robust estimate of these elasticities aggregated at the system level. The survey will have to be carefully designed to capture re-organization effects. Additional work remains for developing strategies to obtain robust estimates of all parameters described above.

One final point can be made regarding the last point in our list. The most significant attributes of shipments after highway improvement are average travel time and travel time variability. Although these can be treated separately, an alternative approach could be to combine them with a percentile value expressed as the mean travel time plus a fixed number of standard deviations. This way, the two measures merge into one. The meaning of this new measure is that x percent of all trips can be achieved within the new time metric.

5.2 Reliance on Stated/Revealed Preferences

A previous NCHRP study [8] quantified the value of travel time savings and reliability based on a survey using a stated preference methodology. The results of this study should be considered as indicative only since the sample was restricted to 20 carriers, the characteristics of which were not controllable.

Using the stated preference approach, it was found that carriers on average value freight travel time savings at $144-$192 per hour (depending on model specification) and savings in schedule delay late at $371 per hour depending on model specification. These results confirm the importance of transit time and freight costs in shipping decisions.

Several recommendations were made to improve future valuation studies and their findings. These included:

- Increased sample size,
- Increased comprehension of stated preference experiments,
- Adjusting variable values with simulations, and
- Developing a theoretical model of carrier behaviour.

The study also recommended applying a mark-up factor of 2.5 to the value of time when the time savings are under highly congested conditions. The use of stated preference surveys may assist in the estimation of the elasticity of transportation costs with respect to travel time savings.

5.3 Way Ahead

The foregoing discussion does not completely address the following:

- Mode choice switching in response to logistics cost changes from road transport improvements[17]. It is possible that, for instance, some rail shipments would be moved by road due to lower freight rates, and that air shipments would also be moved by road due to shorter and more reliable delivery times. Cross elasticities would need to be estimated.
- Delays and hurdle rates for re-organisation of firm logistics systems. Firms have much invested in present infrastructure and may be reluctant to make immediate changes. What is the Net Present Value (NPV) of the future benefits when re-organisation occurs.
- The effects of e-business growth on transport demand (parcel transport vice TL or LTL)

If the methodology is endorsed, additional work remains for developing strategies to obtain robust estimates of basic parameters described in Section 5.1. Accounting for marginal cost pricing has also been described conceptually. Empirical estimation is the subject of a later research paper.

[17] Note that this issue is not relevant in the presence of marginal cost pricing.

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APPENDIX 1: LOGISTICS COST EXPRESSION

It is possible to express logistics cost trade-offs as a function of primary cost components [7]. The relevant expression is:

Cost = direct shipping cost + in-transit inventory cost
+ ordering cost + receiver's inventory carying cost
+ Backorder cost

The cost expression can be expressed directly for each component. Based on [7], it is possible to show that:

$$C = (c_{hr} \cdot D + \mu D)t + aD/Q + wQ/2 + wk(Q + tD + k'\sigma D)^{1/2} + BackorderCost(t,\sigma) \tag{25}$$

where,

C = total annual cost ($)

D = total annual demand (units)

c_{hr} = shipping cost ($/day)

t = average delivery time (days)

μ = carrying cost of in-transit inventory ($/unit/day)

w = carrying cost of receiver's inventory ($/unit/day)

a = replenishment order processing cost ($/order)

Q = receiver's base stock (units)

BackorderCosts = $f(\sigma, t)$ (a direct function of travel time and variability)

The before last term at equation 23 is related to the average inventory required at a specific level of service. Total logistics cost has thus been expressed as an explicit function of delivery time and delivery time variability.

APPENDIX 2: NEW DERIVATION OF DC FOR NCHRP342

While reviewing Report 342, a problem was identified with the definition and derivation of DC, as the proportional change in operating costs per vehicle mile of use at current volumes or level of service. The problem, stemming from non-additive proportional changes, has now been resolved and can be found below.

At Appendix D, DC was defined as the proportional change in total operating costs to the firm per physical unit given current transport volume or level of service. A problem was determined with the derivation of DC when substituted into subsequent expressions. The cause of these difficulties was identified as taking a sum of proportional changes. A revised derivation is developed here.

By definition, it is possible to write DC as $DC = \left(C_0 - C_1\right)/C_0$, where C_0 is the current average user cost per physical unit, and C_1 is the user cost per physical unit after highway improvements. The problem arises when DC is expressed in terms of direct and indirect savings. In general, proportionate changes are not additive. A revised expression is developed below based on first principles.

Let $C_0^{\,T}$ be the total annual logistics cost to the firm. This cost is decomposed as:

$$C_0^{\,T} = C_0^{\,TPT} + C_0^{\,INV} + C_0^{\,PROC} \tag{26}$$

where total cost $C_0^{\,T}$ is the sum of transportation costs, inventory costs (incl. warehousing and holding), and procurement costs. In-transit inventory carrying costs are assumed to be captured by overall procurement costs. For simplicity, the later two costs in (1.1) will be denoted as $C_0^{\,OTHER}$.

The average cost per vehicle mile is then:

$$
\begin{aligned}
C_0 &= \frac{C_0^{\ T}}{VM_0} \\
&= \frac{C_0^{\ TPT}}{VM_0} + \frac{C_0^{\ OTHER}}{VM_0}
\end{aligned} \tag{27}
$$

This expression, and that for C_1 can be substituted into DC. We obtain:

$$
\begin{aligned}
DC &= \frac{C_0 - C_1}{C_0} \\
&= \frac{C_0^{\ TPT} - C_1^{\ TPT}}{C_0} + \frac{\dfrac{C_0^{\ OTHER}}{V_0} - \dfrac{C_1^{\ OTHER}}{V_1}}{C_0} \\
&= \frac{C_0^{\ TPT} - C_1^{\ TPT}}{C_0} + \frac{C_0^{\ OTHER}\left(\dfrac{V_1}{V_0}\right) - C_1^{\ OTHER}}{C_0 V_1}
\end{aligned} \tag{28}
$$

The new expression states that the proportionate change in average cost per vehicle mile is a combination of proportionate savings in transportation and a scaled change in other costs. With this correction, the expression for DC can then be carried forward in the determination of consumer surplus.