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Chapter 5. Project Evaluation
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Transportation policy making frequently requires evaluating a proposed change, whether it be a physical investment or a new set of operating rules for allocating rights to an existing facility. Some, like the rail tunnel under the English channel, are one-time capital investments with enormous and complex effects on accessibility throughout a network. Others, like congestion pricing proposed for Hong Kong, may be technically reversible but require major behavioral and political groundwork.

In such cases, the optimization framework that proves useful in so much transportation analysis is often inadequate. In an optimization model, important aspects of a problem are represented as a few variables which can be chosen to maximize some objective. For example, Robert Strotz shows how highway capacity can be chosen to minimize total travel costs in the presence of traffic congestion.[1] But often the change is too sharp a break from existing practice, or the objectives too numerous, to represent the problem in a mathematical optimization framework. Perhaps a given highway improvement not only expands capacity to handle peak traffic flows but also speeds off-peak travel, reduces accidents, and imposes noise on residential neighborhoods. Perhaps the required capital expenditures occur in a complex time pattern, and the safety effects depend on future but uncertain demographic shifts. One would like a method for analyzing the merits of such a package of changes, and for comparing it to alternative packages.

Such a method is called *project evaluation*. Performed skillfully, it can identify key consequences of a proposed project and provide quantitative information about them to guide policy makers. Much of this information may be non-commensurable: i.e., the consequences may not all be measured in the same units and hence the analyst may not be able to determine the precise extent to

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[1]Robert H. Strotz, "Urban Transportation Parables," in The Public Economy of Urban Communities, ed. by Julius Margolis. Washington, D.C.: Resources for the Future (1965), 127-169.

which these effects offset each other. For example, a tax-financed improvement in airway control equipment might improve safety but magnify existing income inequalities.

The Role of Cost-benefit Analysis

One important part of the project-evaluation toolkit is *cost-benefit analysis.*[2] This set of techniques expands the analyst's ability to achieve commensurability, by quantifying as many effects as possible in terms of monetary equivalents. For example, methods are available to estimate the monetary value of travel-time savings or of newly attracted trips, and to compare costs and benefits occurring at widely different points in time. Furthermore, costs and benefits can sometimes be traced to particular income, ethnic, or occupational groups so that the effect on distribution of real incomes (i.e., on standards of living) can at least be described, if not incorporated as an additional monetary measure.

The most usual form of assessment is based on adding up all the benefits and all the costs, regardless of to whom they accrue. This has an intuitive appeal as a common-sense approach to pursuing the social good. But its simplicity is misleading, for at least two objections can be levied against it.

First, only if all the relevant effects of a project could be measured as monetary equivalents, and if decision makers were fully agreed on those measurements, could decisions on projects be reduced to a technical exercise. Many economists have tended to assume that this is the case, but others have argued persuasively that the value of cost-benefit analysis is to improve policy makers' ability to

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[2]For just a few of the extensive reviews of cost-benefit methodology, see: A,R, Prest and R. Turvey, "Cost-Benefit Analysis: A Survey," *Economic Journal*, vol. 75 (Dec. 1965), pp. 683-735; E.J. Mishan, *Welfare Economics: An Assessment* (Amsterdam: North-Holland, 1969); Anthony E. Boardman, David H. Greenberg, Aidan R. Vining, and David L. Weimer, *Cost-Benefit Analysis: Concepts and Practice* (Upper Saddle River, New Jersey: Prentice Hall, 1996); and the collected articles in Richard Layard and Stephen Glaister, eds., *Cost-Benefit Analysis* (Cambridge, UK: Cambridge University Press, 1994).

handle multidimensional problems, not to replace their subjective judgments.[3] János Kornai goes so far as to claim that it is "unnatural" to try to reduce all factors affecting a decision to a single dimension:

> A physician would never think of expressing the general state of health of a patient by one single scalar indicator. He knows that good lungs are not a substitute for bad kidneys. ... Why cannot the economist also shift ... to that way of thinking?[4]

Second, on what basis can we justify projects that create "losers" just because their aggregate benefits their costs? Only in the highly artificial "representative individual" model, where everyone is identical and is identically affected by the project, does positive aggregate net benefit imply an unambiguous improvement. Much theoretical literature has been devoted to this case, in particular to a variety of "index number" problems that arise in measuring benefits.[5] But the representative individual model is fundamentally inappropriate here. The need for cost-benefit analysis arises precisely because a real-world project creates conflicts of interest, in which people's different situations and preferences cause them to be affected differently. Otherwise all that would be needed is complete information, and the result would be a unanimous decision.

Both objections suggest that project evaluation is inherently political. Decisions about public investments are made in a political process, and the value of any particular evaluation technique, such

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[3]Christopher A. Nash, "Cost-Benefit Analysis of Transport Projects," in Alan Williams and Emilio Giardina, eds., *Efficiency in the Public Sector: The Theory and Practice of Cost-Benefit Analysis* (Aldershot, UK: Edward Elgar, 1993), pp. 83-105.

[4]János Kornai, "Appraisal of Project Appraisal," in Michael J. Boskin, ed., *Economics and Human Welfare: Essays in Honor of Tibor Scitovsky* (New York: Academic Press, 1979), p. 88.

[5]See, for example, Paul A. Samuelson, *Foundations of Economic Analysis* (Cambridge, Mass.": Harvard Univ. Press, 1947); Jerry A. Hausman, "Exact Consumer's Surplus and Deadweight Loss," *American Economic Review*, Vol. 71 (Sept. 1981), pp. 662-676; G.W. McKenzie and T.F. Pearce, "Welfare Measurement—a Synthesis," *American Economic Review*, Vol. 72 (Sept. 1982), pp. 669-682. The "index number" problem arises because the conversion factor between a travel improvement and money depends on the traveler's precise economic situation, which includes the travel conditions being changed by the project itself. Depending on how one imagines the continuous adjustment from the original state to the new one, one may assign any of several monetary measures such as *compensating variation* (amount the traveler could be paid after the change to be equally as well off as before), *equivalent variation* (amount the traveler could be paid before the change to be equally as well off as after), or change in *consumers' surplus* (the amount by which the area under a consumer's demand curve exceeds that consumer's personal payments for the commodity).

as cost-benefit analysis, depends on how it informs that process. Thus, an answer to the first objection might be that quantifying as many factors as possible disciplines debate by providing an easily understood point of comparison — for whatever "unquantifiable" factors may be brought up. Cost-benefit analysis then would not replace political decisions, but would make their implications more transparent. Similarly, a political answer to the second objection might be that cost-benefit analysis calls attention to situations where a project benefits one interest group at a high price to others.

A more formal statement of this last point is that cost-benefit analysis can identify those projects that are *potential Pareto improvements*, i.e., projects for which the winners could in principle compensate losers so as to obtain unanimous consent. This would be the result of requiring that the sum of everyone's compensating variation from a project be positive.[6] Even though it is not feasible in practice to devise such a perfect compensation mechanism, it seems plausible that consistent application of a potential Pareto criterion would make most people better off given "a rough randomness in distribution" of effects,[7] and would normally lead to "a strong probability that almost all would be better off after the lapse of a sufficient length of time."[8] The reason is that no one knows what projects will come up for evaluation in the future, or who their winners and losers will be. (At least, this applies in the absence of systematic exploitation by a politically entrenched group.) At bottom, this is a constitutional argument along the lines of Buchanan and Tullock, who argue that rational individuals would analyze a proposed decision rule "in terms of the results it will produce, not on a single issue, but on the whole set of issues extending over a period."[9] The same idea appears

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[6]Nicholas Kaldor, "Welfare Propositions of Economics and Interpersonal Comparisons of Utility," *Economic Journal*, Vol. 49 (Sept. 1939), pp. 549-552; John R. Hicks, "The Rehabilitation of Consumers' Surplus," *Review of Economic Studies*, Vol. 8 (Feb. 1941), pp. 108-116.

[7]Harold Hotelling, "The General Welfare in Relation to Problems of Taxation and of Railway and Utility Rates," *Econometrica*, Vol. 6 (July 1938), p. 259.

[8]John R. Hicks, "The Rehabilitation of Consumers' Surplus," p. 111.

[9] James M. Buchanan and Gordon Tullock, *The Calculus of Consent: Logical Foundations of Constitutional Democracy* (Ann Arbor: University of Michigan Press, 1962), p. 121. A similar view is expressed by Herman B. Leonard and Richard J. Zeckhauser, "Cost-Benefit Analysis Applied to Risks: Its Philosophy and Legitimacy," in

(continued...)

in the literature on contract and nuisance law,[10] and also in political science, where it has been shown that under certain conditions all members of a legislature will favor a constitutional rule limiting the scope of pork-barrel projects.[11]

Because cost-benefit analysis is so useful in quantifying the effects of a project and in tracing its distributional impacts, it has emerged as a primary tool for evaluating transportation projects. Applying it raises many methodological issues, some of which are especially significant for transportation. For example, transportation projects often have the purpose of saving people time or improving safety, and they often have significant environmental effects? How are these factors to be evaluated? In the rest of this chapter I select several such issues for discussion.

Willingness To Pay: The Basic Concept

The starting point for measuring costs and benefits is *willingness to pay*: the amount of money each individual would be willing to pay for the change in his or her circumstances. (If it is negative, the change is a negative benefit or, equivalently, a cost.) The idea is that if the person did pay that amount, he or she would be indifferent to the change. This powerful concept provides a consistent principle for dealing with a wide variety of measurement issues that might at first seem disjointed and intractable.

(...continued)
Douglas MacLean, ed., *Values at Risk* (Rowman & Allanheld, 1986), p. 33. See also E.J. Mishan, *Welfare Economics: An Assessment* (Amsterdam: North-Holland, 1969); James M. Buchanan, "A Contractarian Paradigm for Applying Economic Theory," *American Economic Review*, Vol. 65 (May 1975), pp. 225-230.

[10] Anthony T. Kronman, "Wealth Maximization as a Normative principle," *Journal of Legal Studies*, Vol. 9 (March 1980), pp. 227-242.

[11] Barry R. Weingast, Kenneth A. Shepsle, and Christopher Johnsen, "The Political Economy of Benefits and Costs: A Neoclassical Approach to Distributive Politics," *Journal of Political Economy*, Vol. 89 (August 1981), pp. 642-664.

The use of willingness to pay is consistent with the hypothetical compensation criterion described earlier. If the sum of everyone's willingness to pay for an entire project, including its financial elements, is positive, then it is a potential Pareto improvement.[12] Willingness to pay is grounded in an acceptance of consumer sovereignty, so does not apply to goods subject to *per se* social or moral judgment. However, it can readily be applied to cases of externalities (spillover effects) by simply including those effects in the list of things for which willingness to pay is estimated. Thus, for example, air pollution can be included in benefits and costs by measuring people's willingness to pay to avoid all its adverse effects; but if society places social value on the social interactions fostered by public transit, that will not be captured by the sum of individual willingness to pay for transit trips.

The height of the demand curve for a conventional good, such as trips from home to shopping center by bus, measures the willingness to pay for an additional unit of that good at the margin. Therefore willingness to pay for a price reduction is correctly measured by the change in an appropriate area under the demand curve: specifically the *consumers' surplus*, which is the area under the demand curve but above a horizontal line indicating the current price. This equivalence applies whether the demand curve results from continuous adjustments by each individual, or from discrete adjustments as individuals switch from one category of trip-making to another.[13]

The use of consumers' surplus can easily be extended to quality improvements. For example, suppose the demand for bus trips is a function of the "full price" of a trip, including travel time (valued at individuals' willingness to pay for travel-time savings). This demand schedule might look like that in Figure 5.1. Now suppose the waiting time for a bus is reduced, lowering the full price from C_0 to

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[12]Strictly speaking, this statement is true only if the hypothetical payment is made *after* the change, in which case the willingness to pay equals the *compensating variation* (see earlier footnote). If the payment is made *before* the change, the willingness to pay equals the *equivalent variation*. The two measures differ by an "income effect," representing the effect on consumption patterns of the change in a person's real income brought about by the adoption of a project. For most transportation projects, real income is not affected enough for this to make a noticeable difference.

[13]A formal demonstration is given by Kenneth A. Small and Harvey S. Rosen, "Applied Welfare Economics with Discrete Choice Models," *Econometrica*, Vol. 49 (Jan. 1982), pp. 105-130.

C_1. There are Q_0 existing users, each willing to pay $(C_0\text{-}C_1)$ for the improvement; their aggregate benefit is therefore measured by the rectangle $C_0 \mathrm{AF} C_1$. There are $Q_1\text{-}Q_0$ new users, some willing to pay almost the full cost reduction $(C_0\text{-}C_1)$ and others barely willing to pay anything (because even at the lower cost they are nearly indifferent between taking the bus and whatever is their next best option); therefore the aggregate benefit to new users is the triangular area ABF. The combined willingness to pay by existing and new users is therefore the trapezoidal area $C_0 \mathrm{ABC}_1$. This area is also the change in consumers' surplus, which increased from area GAC_0 to area GBC_1. This frequently misunderstood equivalence implies that it would be double-counting to add the change in consumers' surplus to the value of time savings or other improvements.[14]

If the demand curve is approximately linear between A and B, as in Figure 5.1, then area ABF is approximately triangular and thus equal to half the number of new users multiplied by the reduction in full price. This approximation, known as the "rule of one-half," greatly simplifies the estimation of benefits to new users because one need not estimate the entire demand curve, but only the number of *new* users and the cost savings to *existing* users.

One quirk in interpretation bears mention. Should the benefits to new users, area ABF, be considered travel-time savings? In many discussions they are, since they arise from the reduced travel time made possible by the project. But new users did not use the bus before the improvement, so this area does not measure the difference between the time they spent traveling before and after the change. Indeed, some new users may now spend *more* time traveling than before, for example if they switched from automobile. Nevertheless the benefits are real, representing value placed by these travelers on some characteristics of the bus mode such as convenience, low cost, or opportunity to read. If we were to try to account for actual change in travel time for new users we would also have to measure

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[14]The analysis readily extends to the case where the "full price" depends on the number of trips through economies of scale or congestion effects: see, for example, Peter Mackie, Jeremy Toner, and Denvil Coombe, "A Critical Comment on the COBACHECK Method of Estimating the Effects of Induced Traffic on the Economic Benefits of Road Schemes," *Traffic Engineering and Control*, Vol. 37 (Sept. 1996), pp. 500-502. More generally, it has been shown that under reasonable conditions, the increase in conventional consumers' surplus resulting from a quality improvement that raises the demand curve correctly measures willingness to pay for the improvement. See David Bradford and Gregory Hildebrandt, "Observable Public Good Preferences," *Journal of Public Economics*, Vol. 8 (1977), pp. 111-131.
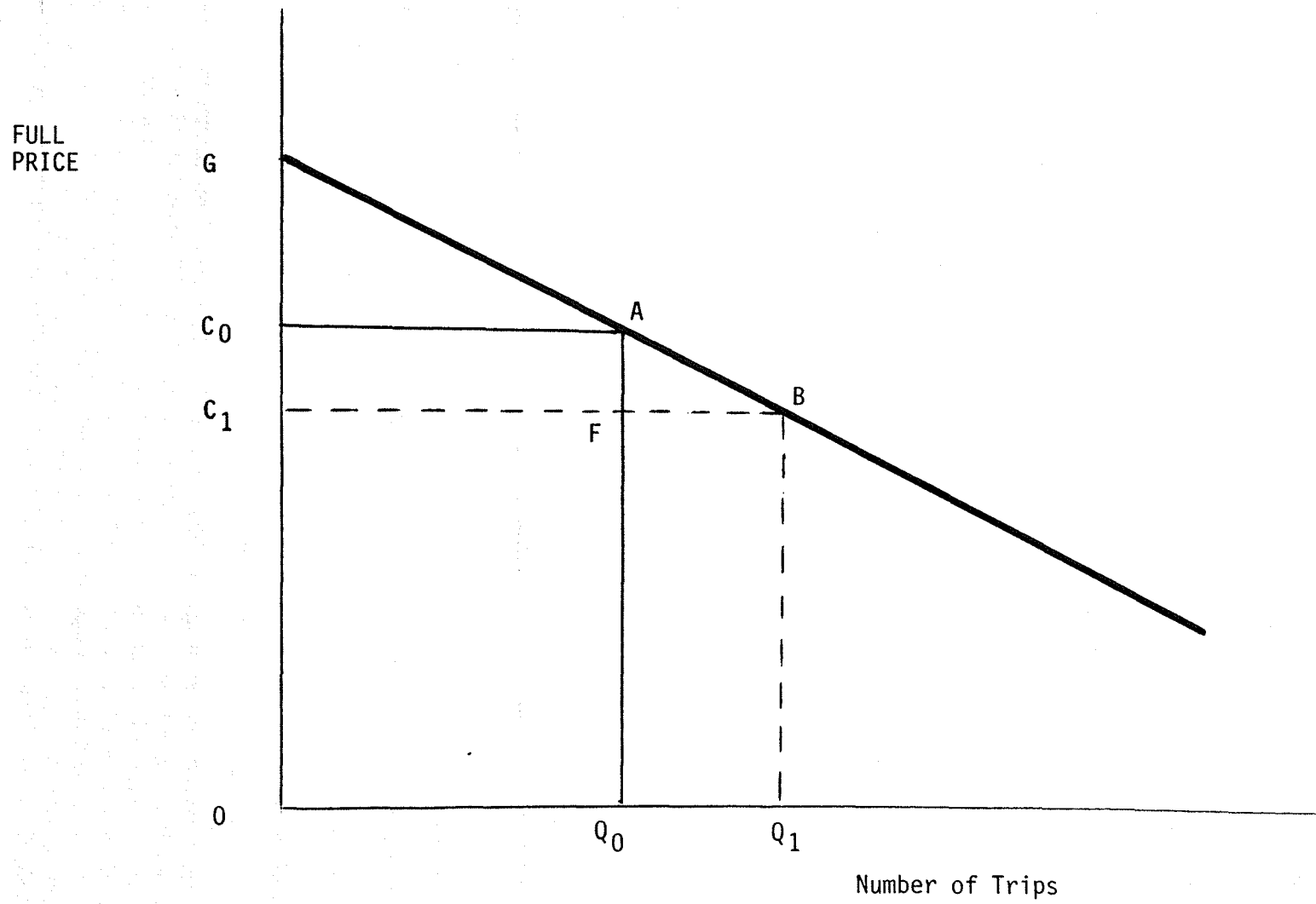
Fig. 5.1. Benefits to Existing and New Users

each of these characteristics directly, which is virtually impossible; fortunately the indirect measure embodied in area ABF is just what we want.

Willingness to pay also deals realistically with risk, even risk of events, such as injuries or deaths, often believed not amenable to monetary evaluation.[15] Most projects affect people's health or safety in an anonymous way, as when increased air pollution causes small increases in each person's risk of getting lung cancer. Thus one does not ask Suzanne Citizen how much she would pay to avoid getting lung cancer. One instead asks (or estimates indirectly) how much she is willing to pay to avoid small measurable risks, for example by moving to a less polluted but more expensive neighborhood, by installing a smoke detector in her house, or by ordering an air bag for her new car. This kind of investigation has proven tractable, as described in a later section of this chapter.

Shadow Prices: Extensions of the Willingness to Pay concept

Willingness to pay remains an appropriate measure of benefits and costs even when markets are not free. For example, people may be willing to pay more than the quoted price for fuel that is subject to price controls, or for imports that are restricted by quotas. Considerable literature exists on how to compute willingness to pay in such situations; often, it can be done by valuing an affected resource at a *shadow price* rather than a market price, the difference being estimated from an analysis of the market imperfection.[16]

Similarly, if a resource such as labor or capital would otherwise be underused, willingness to pay may be less than the market price. Where unemployment is high, people would be willing to work for less than the going wage rate, so the social opportunity cost of labor (its shadow price) is probably

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[15]Thomas C. Schelling, "The Life You Save May Be Your Own," in Samuel B. Chase, ed., *Problems in Public Expenditure and Analysis* (Washington, D.C.: Brookings Institution, 1968), pp. 127-162; Ezra J. Mishan, "Evaluation of Life and Limb: A Theoretical Approach," *Journal of Political Economy*, Vol. 79 (July/Aug. 1971), pp. 687-705.

[16]For a rigorous and elegant general treatment of shadow prices, see Jean Dréze and Nicholas Stern, "Policy Reform, Shadow Prices, and Market Prices," *Journal of Public Economics*, Vol. 42 (June 1990), pp. 1-45. For a classic practical treatment, see I.M.D. Little, *A Critique of Welfare Economics* (Oxford: Oxford University Press, 1950).

less than wage payments. However, this argument is easily abused because what appears to be newly employed labor may actually be a shift from alternative employment. For example, macroeconomic policy aimed at preventing inflation may compensate for any improvement in a local labor market caused by a construction project.

The example of offsetting macroeconomic policies is an instance of bringing *general equilibrium* considerations to bear. Most analyses of transportation are *partial equilibrium* in the sense that they consider only a few of the many markets that are affected. But in fact, transportation is closely tied to a host of other markets through their dependence on the physical presence of people or goods. Better transportation to a particular location can dramatically increase the prices of housing, retail goods, or land at that location, and it may decrease the wages offered to workers there. These changes create benefits or costs which are measured as changes in consumers' surplus and *producers' surplus* in the associated markets, where producers' surplus is defined as the difference between the payments for a produced good or a factor of production and the area under the supply curve. If these other markets are fairly competitive, such price changes provide offsetting benefits and costs to the various parties involved: the retailer's improved revenues are its shoppers' higher costs, while the landlord's gains are the tenant's losses. For this reason, a simple partial equilibrium analysis is often sufficient for estimating total benefits and costs — but is entirely inadequate for estimating their distribution across the population. I return in a later section to the question of when adjustments in other markets engender new costs or benefits as opposed to simply transferring costs or benefits from one party to another.

Finally, willingness to pay provides a way to compare costs and benefits at different times. Numerous financial markets enable us to look at people's preferences concerning the tradeoff between current and future consumption. This tradeoff is especially important to transportation projects because so many of them require up-front capital expenditures in return for benefits extending far into the future.

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Using the willingness to pay principle, we are now in a position to deal with issues that come up frequently in transportation evaluations.

Issues in Benefit Measurement

Naturally the translation of the theoretical principles discussed above into reliable empirical measurements leaves numerous problems to be resolved. This chapter considers just a few such problems, selected for their practical importance for transportation analysis. This section treats issues in the measurement of benefits, whereas the next focuses on difficulties caused by the longevity of decisions.

Travel-Time Savings

Typically the dominant component of benefits from a transportation project consists of travel-time savings — or more broadly, benefits to existing and new users resulting from reductions in the travel time required for any particular type of trip. Air travel, surface freight shipping, and urban commuting all are examples of transportation activities in which time is thought to be an enormously important element, with costs of lost time estimated to run into many billions of dollars and competitive outcomes depending closely on the ability to shave time off certain movements.

An extensive empirical literature has established that people and firms make reasonably predictable trade-offs between travel time and other factors in making travel choices. These studies are the basis for estimates of the willingness to pay for travel-time savings, a quantity known as the "value of time." For example, in an earlier review I concluded that the value of time for the journey to work averages about 50 percent of the before-tax wage rate, with a range across different

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industrialized cities from perhaps 20 to 100 percent.[17] Values have also been established for other types of trips and for freight.[18]

Unfortunately for the analyst, there is also ample evidence that the value of time varies widely among population subgroups and probably depends critically on individual circumstances. For example, people are willing to pay more on average to avoid time walking to a bus stop, or waiting there for the bus, than for time riding on the bus. They will pay more to avoid time spent driving if it is in congested conditions. There is some evidence that people value increments of time more highly on medium-length trips than either on short trips[19] or on long trips.[20] Probably the degree of comfort plays a key role in all these examples, as exemplified by the suggestive recent finding of a quite low value of time for regular long-distance automobile commuters, who probably have adapted their cars and schedules to reduce the boredom of driving.[21] Self-selection may also play a role in this last example: those with lower values of time are more likely to drive long distances regularly.

These variations should not be surprising, as time is not fungible: time saved in one circumstance cannot automatically be used in another. Ignoring them can cause poor decisions: for

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[17]Kenneth A. Small, *Urban Transportation Economics*, vol. 51 of *Fundamentals of Pure and Applied Economics* (Chur, Switzerland: Harwood Academic Publishers, 1992), pp. 43-45.

[18]W.G. Waters II, "Values of Travel Time Savings in Road Transport Project Evaluation," in World Conference on Transport Research, *World Transport Research, Vol. 3: Transport Policy* (New York: Elsevier, 1996), pp. 213-223; David A. Hensher, "Behavioural and Resource Values of Travel Time Savings: A Bicentennial Update," *Australian Road Research*, Vol. 19 (July 1989), pp. 223-229; MVA Consultancy, Institute for Transport Studies of the University of Leeds, and Transport Studies Unit of Oxford University, *The Value of Travel Time Savings: A Report of Research Undertaken for the Department of Transport* (Newbury, England: Policy Journals, 1987); Steven Morrison and Clifford Winston, *The Economic Effects of Airline Deregulation* (Washington: Brookings Institution, 1986); Clifford Winston, "A Disaggregate Model of the Demand for Intercity Freight Transportation," *Econometrica*, Vol. 49 (July 1981), pp. 981-1006.

[19]Moshe Ben-Akiva and Steven R. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand* (Cambridge, Mass.: MIT Press, 1985), pp. 174-177. This result is for work trips and may indicate that people appreciate some transition time between home and work.

[20]MVA Consultancy et al., *The Value of Travel Time Savings*, p.150.

[21]John Calfee and Clifford Winston, "The Value of Automobile Travel time: Implications for Congestion Policy," working paper, Brookings Institution (October 1996).

example, some evaluations of rapid rail systems have failed to account for the reluctance of people to make extra transfers or to walk extra distances to transit stops relative to a bus system.

However, there is sometimes a tendency among analysts to overstate the specificity of the situation facing a person. For example, even though many people face fixed work hours in the short run, they may have a choice among jobs with different work hours and therefore may in the long run be able to use travel-time savings to work longer hours. More generally, the constant turnover in jobs, residential locations, family status, habits, and other circumstances affecting trips guarantees that a particular travel-time saving — such as thirty seconds due to a new traffic signal installed on a particular day — will soon be incorporated into the routine of life and will not pose an indivisibility problem for people. For this reason, there is no merit in claims that small time savings lack value because people can't do anything productive in short time segments.[22]

Predicting the travel-time savings from many projects is complicated by offsetting behavioral shifts as a result of changes in congestion when it is unpriced. Suppose a particular measure relieves congestion. After it is adopted, the system will tend to re-equilibrate as people previously deterred by congestion, constituting what is known as *latent demand* for the facility, take advantage of the improved conditions. In extreme cases, latent demand may constitute such a large reservoir that congestion reverts to its former level, giving the false appearance that the project has no benefits.[23] More commonly, latent demand undoes some but not all of the expected congestion relief.

These behavioral shifts, if not fully accounted for, create two offsetting sources of error in estimating benefits from such a project. On the one hand, the amount of travel-time savings to

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[22]An example of this fallacy is the strong dependence of value of time on "amount of time saved" in the summary recommendations of the influential manual published by American Association of State Highway and Transportation Officials (AASHTO), *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements* (Washington, D.C.: AASHTO, 1977). As William Waters has pointed out, such dependence would make project evaluation inconsistent because the evaluation of a project would depend critically on whether it was considered as a single project or as the cumulation of many small projects: W.G. Waters II, *The Value of Time Savings for the Economic Evaluation of Highway Investments in British Columbia* (Vancouver: Centre for Transportation Studies, University of British columbia, March 1992).

[23]Examples are given by Arthur C. Pigou, *The Economics of Welfare* (London: Macmillan, 1920), p. 194; and Anthony Downs, "The Law of Peak-Hour Expressway Congestion," *Traffic Quarterly*, Vol. 16 (1962), pp. 393-409.

existing users (area C_0AFC_1 in Figure 5.1) will be overestimated because the reduction in full price, (C_0-C_1), will be overstated. On the other hand, the benefits to new users (area ABF) will be underestimated or perhaps ignored entirely. Two examples illustrate the problem.

In the first example, the source of latent demand is people previously traveling at other times of day. This can be examined using a bottleneck model pioneered by William Vickrey.[24] Commuters face a unit cost β for each minute early they arrive at their destination, and a unit cost γ for each minute they are late; these costs are known as "schedule delay costs." The equilibrium time pattern of trips involves maximum congestion at the times that people most desire to travel, with less congestion at other times, thereby serving as an inducement for some people to suffer the schedule delay costs. Now suppose the analyst thinks incorrectly that the observed trip pattern will not change in response to an expansion in capacity. It turns out that this analyst will overestimate the marginal benefits of expansion if the harmonic mean of β and γ is less than the value of travel time.[25] The reason is that the low cost of schedule delay results in a lot of time-of-day shifting, undermining the hoped-for reduction in congestion. In the opposite case, where schedule-delay costs are high so time-of-day shifts are small, the forecast of congestion reduction is pretty accurate but the analyst neglects savings in schedule-delay costs, so the benefits of capacity expansion are underestimated.

The second example is land-use distortions. In a typical model of urban residential location, failure to price highway congestion causes the city to be inefficiently decentralized. Expansion of highway capacity tends to exacerbate this effect, as induced residential relocations create longer trips and hence new traffic, whose marginal cost exceeds private cost, at each location. If this new traffic

[24]William S. Vickrey, "Congestion Theory and Transport Investment," *American Economic Review, Papers and Proceedings,* Vol. 59 (May 1969), pp. 251-260; Richard Arnott, André de Palma, and Robin Lindsey, "Economics of a Bottleneck," *Journal of Urban Economics,* Vol. 27 (Jan. 1990), pp. 111-130.

[25]Kenneth A. Small, *Urban Transportation Economics,* p. 137. The harmonic mean of β and γ is defined as $[\frac{1}{2}(\beta^{-1}+\gamma^{-1})]^{-1}$.

is not accounted for in the predictions underlying the cost-benefit analysis, the benefits of the highway expansion will be overestimated.[26]

Accidental Injuries and Deaths

Safety is perhaps second only to travel time in public perceptions of important issues in modern transportation systems. Airline crashes or train derailments make national headlines, while local car wrecks are a routine of the evening news. A great deal of effort and expense has been poured into largely successful efforts to reduce safety hazards in transportation. How can we evaluate the claims that such efforts make upon public resources? And how can we evaluate the safety effects of inter-modal substitutions, such as from rail to trucking in freight shipment, that may occur due to other policies?

I have indicated earlier how changes in the risk of injuries, fatal or otherwise, can be evaluated based on the willingness-to-pay principle. Empirically, the most reliable method to value risk of death appears to be to compare wages for jobs that are similar in all respects except occupational risk. Reviews of the numerous studies of this type suggest that on average, people in high-income nations in the mid 1990s are willing to pay something like US$5 for each reduction of one in a million in the risk of death.[27] Looking at a million such people, their aggregate willingness to pay for such a change is $5 million and it saves one expected life. This result is summarized in the convenient but easily misunderstood statement that the *value of life* is $5 million. Valuations may deviate from this for specific types of situations; for example, evidence suggests that people are more reluctant to undertake

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[26]Richard J. Arnott, "Unpriced Transport Congestion," *Journal of Economic Theory*, Vol. 21 (1979), pp. 294-316.

[27]V. Kip Viscusi, "The Value of Risks to Life and Health," *Journal of Economic Literature*, Vol. 31 (Dec. 1993) pp. 1875-1911; Shulamit Kahn, "Economic Estimates of the Value of Life," *IEEE Technology and Society Magazine*, Vol. 5, (June 1986), pp. 24-31; Kenneth A. Small and José A. Gómez-Ibáñez, "Urban Transportation," draft manuscript for: Paul Cheshire and Edwin S. Mills, eds., *Handbook of Regional and Urban Economics, volume 3: Applied Urban Economics* (Amsterdam: North-Holland, forthcoming). A reasonable range for this figure is $1.5 to $9 at 1989 dollars: see Kenneth A. Small, *Urban Transportation Economics*, pp. 79-80.

risks over which they have no control, so the value of life for train accidents may be higher than that for car accidents.

The figure of $5 million is far higher than the average person's personal wealth or the discounted sum of future earnings. But this poses no contradiction: no one is paying to avoid a sure death, just to lower the probabilities slightly. Using future earnings to value risk of death is an older but now discredited technique.

Risks of serious injuries or illnesses can be evaluated through similar means. A recent study suggests that the willingness to pay to reduce the risk of a typical serious (but non-fatal) traffic injury is about ten percent of the willingness to pay to reduce the risk of a traffic fatality.[28] Because non-fatal injuries are much more numerous than fatal ones, this adds significantly to estimates of the total costs of accidents. Plausible estimates of these costs are quite high — comparable, for example, to total travel-time costs in the case of a typical urban commuting trip by automobile.[29]

A number of conceptual issues complicate the empirical estimation of such benefits. One is whether an individual's willingness to pay to avoid injury or death should be supplemented by further benefits to relatives, insurance companies, or governments. All have an emotional or financial interest in the injured person's well being; the question is whether the estimated willingness to pay already takes this into account. Assuming we have used labor-market studies to measure willingness to pay, we need to know whether the individual's tradeoff between wages and safety fully accounts for willingness to pay by all parties.

First, consider family members or other loved ones. If emotional bonds are mutual, my willingness to pay for safety already accounts for my family's concern for me. Furthermore, if it is my welfare as opposed to theirs that is my family's concern, then their altruism extends to both sides of the tradeoff I am making — safety against other consumption — so does not necessarily affect the

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[28]Michael W. Jones-Lee, Graham Loomes, and P.R. Philips, "Valuing the Prevention of Non-Fatal Road Injuries: Contingent Valuation *vs.* Standard Gambles," *Oxford Economic Papers*, Vol. 47 (1995), pp. 676-695.

[29]Kenneth A. Small, *Urban Transportation Economics*, pp. 75-85.

marginal rate of tradeoff of one for the other.[30] So there is not much case for adding benefits accruing to family and friends.

Next, consider the effects of life, health, or disability insurance. If the differential job risks faced by an individual are reflected in differential insurance rates, then part of the observed wage premium for safety is compensating him or her for the insurance company's extra costs; in that case no additional amount need be added to the measured willingness to pay. If no such differential insurance rates exist, perhaps due to an inability of the insurance companies to monitor these risk differentials, then the costs paid by insurance should be added to the willingness-to-pay measure.

Finally, consider government-borne costs of medical treatment or of living expenses. It seems unlikely that the individual would demand a wage premium to cover such costs, so they need to be added explicitly.

Just as programs designed to relieve congestion release latent demand for the congested facility, programs designed to improve safety may result in offsetting behavior that reduces safety. This is because the safety improvement reduces the marginal risk of related behavior such as driving fast. Air bags, anti-lock brakes, and straightened roads are therefore likely to result in partially offsetting changes such as driving faster, talking on mobile telephones, or failing to fasten safety belts.[31] These behavioral adjustments not only offset part of the direct safety impacts, but may even cause a safety program to backfire by raising the danger to third parties such as bicyclists and pedestrians.

Such behavioral changes may or may not be considered when the effects of a project are predicted. If they are, then this offsetting behavior may provide some additional benefits that should

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[30]Theodore C. Bergstrom, "When Is a Man's Life Worth More than His Human Capital?", in Michael W. Jones-Lee, ed., *The Value of Life and Safety* (Amsterdam: North-Holland, 1982), pp. 3-26.

[31] See Sam Peltzman, "The Effects of Automobile Safety Regulation, *Journal of Political Economy*, vol. 83 (August 1975), pp. 677-725. Most but not all empirical studies find that these offsetting behavioral changes occur but only partially offset the original safety improvement: see Robert S. Chirinko and Edward P. Harper, Jr., "Buckle Up or Slow Down? New Estimates of Offsetting Behavior and Their Implications for Automobile Safety Regulation," *Journal of Policy Analysis and Management*, Vol. 12 (1993), pp. 270-296; Steven Peterson, George Hoffer, and Edward Millner, "Are Drivers of Air-Bag-Equipped Cars More Aggressive? A Test of the Offsetting Behavior Hypothesis," *Journal of Law and Economics*, Vol. 38 (October 1995), pp. 251-264.

in principle be valued and added to the evaluation — for example, the enjoyment of high-speed telephone conversations or the value of time saved by not putting on seat belts (which Peltzman estimated to be substantial over the life of a car). If the offsetting behavioral changes are not forecast, then we have the odd situation in which the predictions of safety effects are faulty, yet the estimated benefits may be fairly accurate. The reason is that the benefits from reduced injuries are overstated, but those from the offsetting behavioral changes are ignored. In theory, these would be fully offsetting if the behavioral changes were small, involved no externalities, and were deemed socially valid goals for the individual.[32] In practice some behavioral changes, such as more aggressive driving, are likely to be viewed by most people as inappropriate for inclusion as benefits; so on balance the social benefits of safety improvements are probably somewhat overstated if offsetting behavior is ignored.

As with value of time, the value of reducing accident risk seems to vary with circumstance, as suggested by the earlier observation that people prefer risks they think they can control. However, it is important to distinguish true preferences from misperceptions. If people appear to place an unusually high or low value on a particular risk because they are misinformed about it, there is a case for overriding those apparent preferences by using more accurate information available to the decision maker. It may sometimes be more feasible to promote cost-effectiveness in investments to save lives by using technical information at the project evaluation stage than by launching public education campaigns concerning the actual risks.

Clearly, measuring the benefits of safety improvements is filled with difficult conceptual and practical issues. But the methodology is sufficiently advanced to warrant incorporating them into a project evaluation. The implied research agenda is to push forward with the resolution of the remaining measurement issues.

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[32]This statement is based on a version of the envelope theorem, which implies that if a person is optimizing both before and after a change in an external parameter, the first-order behavioral readjustments cause no additional changes to utility.

It is now well recognized that transportation activities have substantial environmental effects. These are frequently debated as part of a proposed policy, whether it be building a new airport or raising the gasoline tax. Furthermore, some policies proposed explicitly on environmental grounds, such as the development of electric vehicles, are extremely expensive. How can we evaluate the merits of the claims that such policies make on public resources?

In principle, environmental effects can be evaluated using the principles already outlined. However, they raise issues that are considerably more difficult even than safety. Not only must we deal with health effects and offsetting behavior, but in addition environmental effects are more varied, more diffusely distributed, and perhaps more prone to raising moral issues. Space precludes resolving these difficulties here, and I limit the discussion to the question: Is it worth quantifying environmental benefits and costs in monetary terms as part of project evaluation?

The primary argument for doing so is that it enables bringing environmental and other benefits (and costs) into a single comprehensive framework. If the quantitative estimates are credible, a unified framework should promote better decisions by forcing decision makers to realistically trade off environmental considerations against others. Thus for example, several estimates of the air pollution costs of motor vehicles imply that they are significant when compared to the costs of potential emission-control options, but rather small in relationship to the implied value that people place on trip-making by motor vehicles.[33] If these results hold up, they suggest both a direction and a limitation on policy toward air pollution: namely, that further emissions control policies are probably warranted, but that air pollution alone cannot justify sweeping measures to reduce motor vehicle traffic.

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[33]Kenneth A. Small and Camilla Kazimi, "On the Costs of Air Pollution from Motor Vehicles," *Journal of Transport Economics and Policy*, Vol. 29 (Jan. 1995), pp. 7-32; Donald R. McCubbin and Mark A. Delucchi, *The Social Cost of the Health Effects of Motor-Vehicle Air Pollution*, Report #11 in the Series: *The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data*. Report UCD-ITS-RR-96-3 (11) (Davis: Institute of Transportation Studies, University of California, August 1996). Other reports in the UC Davis series consider the costs of crop damage and loss of visibility, which appear to be much smaller than the costs of health damage.

The primary argument against quantifying environmental effects in monetary terms is that doing so adds considerable uncertainty to the resulting evaluation. Quantification can lend an unwarranted aura of precision, misleading decision makers into thinking they have taken environmental effects fully into account. For example, the above mentioned research on air pollution is mainly on conventional pollutants accumulating in the lower atmosphere. Extending the estimates to destruction of the stratospheric ozone layer or to global warming from greenhouse gases is highly speculative; they occur over very long time scales, the scientific modeling process is uncertain, and there is unknown potential for technological change that might ameliorate them. Simply adding such estimates to others might erode confidence in the entire cost-benefit analysis.

My own view is that the methodology of evaluating lower-atmosphere air pollution is sufficiently advanced to justify incorporating such estimates, but that the resulting numbers should be kept separate. Users of the analysis can then easily see what influence they have on the results and apply their own degree of uncertainty to them. The same is probably true of noise.[34] For other environmental effects such as global warming, wildlife disruption, loss of biodiversity, and damage from urban water runoff, the effects are too uncertain to warrant adding them to other benefits. Quantification in monetary terms is still useful for thinking about their importance; but the decision maker should not be encouraged to act as though there is a credible set of numbers in which all environmental effects are fully taken into account.

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[34]Mark A. Delucchi and Shi-Ling Hsu, *The External Damage Cost of Direct Noise from Motor Vehicles*, Report #14 in the Series: *The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data.* Report UCD-ITS-RR-96-3 (14) (Davis: Institute of Transportation Studies, University of California, Dec. 1996).

Issues Due to Longevity of Decisions

Transportation investments are notable for their length of life. Land clearance, rail trackage, port facilities, and tunnels are all examples involving heavy capital expenses that cannot be recovered later in light of new information. Therefore, it becomes crucial to develop a clear understanding of the limits of forecasting and of the means for evaluating the tradeoffs between present costs and future benefits.

Projections of Capital Costs and Travel Demand

Obviously, sound evaluation of a project depends on accurately predicting its effects. The stakes are especially high for the durable investments typical of transportation projects. Mistakes can result in disruptive bankruptcies or in burdensome taxpayer obligations for future bond payments on unproductive investments. For many transportation projects, the most important factors are the up-front capital expenditures, the future operating costs, and the future demand for travel on the facility. All are estimated from projections, some over many years.

The record for such projections is not very encouraging. Don Pickrell demonstrates that in the project evaluations used at the decision point for ten rail transit systems recently built in the United States, capital cost was underestimated in all but one case, operating cost was underestimated in all but two, and ridership was overestimated in every case. The errors were very large: in the median case, capital and operating costs were underestimated by one-third and ridership was overestimated by a factor of three. As a result of these errors, average cost per rail passenger turned out to exceed the forecast in every case by at least 188 percent, and in three cases by more than 700 percent![35] Even for toll highways, where the use of private bond financing exerts more discipline on the initial

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[35]Don H. Pickrell, *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs* (Cambridge, Mass.: Transportation Systems Center, U.S. Department of Transportation, October 1989), Table S-1.

projections, ten of fourteen projects recently examined experienced toll revenues in their first four years well below projections.[36] The same bias was found for seven large Danish bridge and tunnel projects, somewhat more so for rail than for road projects.[37] Given that capital projects are heavily promoted by interested parties, it is difficult to avoid the conclusion that these errors are partly strategic.[38]

A comparison of three cost-benefit studies of a new toll road near Vancouver, British Columbia, illustrates how dependent results can be on travel forecasts.[39] The road opened in phases between May 1986 and October 1990, and the three studies were conducted in mid 1986, late 1987, and early 1993. From the latest study it appears that the first two drastically underestimated both actual construction costs and actual traffic. Perhaps it is because these were academic studies, and so presumably without strategic bias, that the errors were offsetting. Still, their sheer magnitude is humbling.

A reasonable conclusion is that the real value of forecasting and analyzing the future is to learn about the factors affecting success rather than to definitively predict success. To paraphrase Kenneth Boulding, predictions are useful so long as we do not believe them. At a minimum, it is important to carry out sensitivity analysis using alternate values of crucial parameters. More generally, it is reasonable to place the burden of proof on the proponents of a costly project to show that a favorable evaluation is robust to reasonable variations in crucial forecasts.

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[36]Robert H. Muller, "Examining Toll Road Feasibility Studies," *Public Works Financing* (June 1996), pp. 16-20.

[37]Mette K. Skamris and Bent Flyvbjerg, "Accuracy of Traffic Forecasts and Cost Estimates on Large Transportation Projects," *Transportation Research Record*, No. 1518 (1996), pp. 65-69.

[38]For a well documented example, see John F. Kain, "Deception in Dallas: Strategic Misrepresentation in Rail Transit Promotion and Evaluation," *Journal of the American Planning Association*, Vol. 56 (Spring 1990), pp. 184-196.

[39]Anthony Boardman, Wendy L. Mallery, and Aidan vining, "Learning from *Ex Ante/Ex Post* Cost-Benefit Comparisons: The Coquihalla Highway Example," *Socio-Economic Planning Sciences*, Vol. 28 (June 1994), pp. 69-84.

The principle of willingness to pay tells us that costs and benefits occurring in the future are valued less than those occurring today. This may be regarded as due to people's impatience or due to the productive possibilities for investing their money. In either case, the traditional way of accounting for the difference is to multiply later-year quantities by a *discount factor* equal to $(1+r)^{-1}$, where r is a *discount rate* closely related to the interest rate on financial assets. Presuming the costs and benefits occurring in later years are measured in real (i.e. inflation-adjusted) money units, then the discount rate should also be real, meaning it is approximately the nominal rate less the rate of inflation.[40]

Many transportation projects require large initial investments and create benefits extending far into the future. The evaluation of these projects turns out to be critically dependent on the discount rate used. If a single market interest rate prevailed throughout the economy, the choice would be simple. In reality, numerous departures from perfectly competitive markets result in wedges between the interest rates faced by various economic actors. Among the most important wedges are those resulting from corporate and personal income taxes and from the incompleteness of capital markets, the latter arising in turn from the inability of lenders to perfectly monitor and enforce repayment agreements.

A simplified picture suffices to lay out the main issues. Consumers can shift consumption from one time period to another by increasing or decreasing their holdings of a risk-free government bond with real after-tax interest rate i, often taken to be 4 percent. (This value is somewhat higher than the typical after-tax rate on government bonds, in part to account for the fact that many consumers are net debtors rather than lenders in financial markets.) So i could be taken as the *marginal rate of time preference*, indicating consumers' willingness to pay to accelerate consumption benefits from later

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[40]More precisely if n is a nominal discount rate (such as the market interest rate on government bonds) and π is the expected rate of inflation, the corresponding real discount rate r is defined by the equation $(1+r)(1+\pi) = 1+n$. If π is small, this yields the approximation $1+r \approx (1+n)(1-\pi) \approx 1+n-\pi$, or $r \approx n-\pi$.

to earlier years. Investment, on the other hand, is undertaken by private firms and earns the real net social return r. A recent estimate gives the value of r for 1989 to be 9.6 percent.[41]

One approach is simply to take a weighted average of these two rates, i and r, the weights reflecting the proportions of the project's financial flows which are believed to be drawn from consumption and investment, respectively. This is a reasonably simple and plausible procedure, but it is somewhat arbitrary because the flows determining the weights should themselves be discounted, creating a problem of simultaneity in the definition of the resulting average. A theoretically more rigorous approach, which essentially solves that simultaneity problem, is to convert each expenditure or benefit to an equivalent flow of consumption by taking account of any investment consequences it has. These consumption flows are then all discounted at the marginal rate of time preference, i.

This latter approach amounts to multiplying each investment expenditure by a *shadow price of capital*, which measures capital's contributions to future consumption.[42] The logic is like that of other shadow prices. For example, if labor is diverted from private employment, its social opportunity cost includes any payroll taxes that would have been paid by that private employer. Similarly if capital is diverted from private investment, its social opportunity cost includes the income or other taxes it would have generated. William Vickrey makes this point specifically for urban land taken for road improvements, which if left in private hands would generate revenues from corporate and private

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[41]This is based on estimating $r=w-\delta$, where w is the pretax real gross rate of return on investment and δ is the rate of depreciation on physical assets. For w, we start with the average return on Aaa corporate bonds of 9.26 percent; adjust upward by a factor $(1-0.38)^{-1}$ to get pre-tax returns (assuming an average marginal corporate tax rate, federal plus state, of 38 percent), to get a pre-tax nominal return of $n=14.9$ percent; then adjust downward for inflation of $\pi=4.8$ percent per year according to the formula $(1+r)(1+\pi)=1+n$, presented in an earlier footnote. This calculation is in Boardman et al, *Cost-Benefit Analysis*, p. 172, whose analysis I follow in much of this section.

[42]This approach was pioneered by David F. Bradford, "Constraints on Government Investment Opportunities and the Choice of Discount Rate," *American Economic Review*, Vol. 65 (Dec. 1975), pp. 887-899, and refined by Robert Mendelsohn, "The Choice of the Discount Rate for Public Projects," *American Economic Review*, Vol. 71 (March 1981), pp. 239-241. For a good review, see Robert C. Lind, "The Shadow Price of Capital: Implications for the Opportunity Cost of Public Programs, the Burden of the Debt, and Tax Reform," in Walter P. Heller, Ross M. Starr, and David A. Starrett, eds., *Social Choice and Public Decision Making: Essays in Honor of Kenneth J. Arrow, Volume I* (Cambridge, UK: Cambridge University Press, 1986), pp. 189-212.

income taxes, property taxes, and perhaps sales taxes;[43] but the point applies to all capital. What makes it more complicated than labor is that the taxes are paid in a stream over many years rather than at the time of the initial investment. The calculation of this shadow price is presented in the Appendix; plausible parameters for 1989 yield a value of 1.5, with a range from about 1.2 to 2.0.

While the shadow price of capital is theoretically appealing, there are practical reasons for government agencies to constrain the agencies doing cost-benefit analyses in their exercise of judgment. As a result, government manuals often specify a particular discount rate to be used unless there is a demonstrable reason that it should be different for the project in question. In the United States, the rate is specified by the Office of Management and Budget (OMB); it was 10 percent for many years, but was changed to 7 percent in 1992.[44] For Australian road projects it is also specified to be 7 percent.[45]

The Far Distant Future

The use of discounting has important and controversial implications for evaluating policies affecting distant generations. Examples include nuclear waste disposal, global warming, species preservation, and soil conservation, all issues that can arise in evaluating transportation projects. Adverse future consequences of actions taken today, even dire consequences, have very small weight in a cost-benefit comparison if they occur in the distant future. For example, a climate disaster occurring in 150 years that causes damage of $10 trillion (more than today's U.S. annual gross domestic product) has a discounted cost today of only $391 million using OMB's discount rate of 7

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[43]William S. Vickrey, "General and Specific Financing of Urban Services," in Howard G. Schaller, ed., *Public Expenditure Decisions in the Urban Community*, (Washington, D.C.: Resources for the Future, 1962), pp. 62-90.

[44]U.S. Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, Circular No. A-94, Revised* (October 29, 1992), Section 8.

[45]Austroads, *Benefit Cost Analysis Manual* (Sidney: Austroads, 1996), p. 10.

percent.[46] Many analysts have questioned whether the marginal rate of time preference applying to private individuals can be extrapolated to distant unborn generations, and have advocated imposing explicit social preferences for maintaining future viability of human life with living standards deemed acceptable. Others, noting that living standards have increased steadily over much of the world's history, suggest that future generations will be richer than we are and do not need our altruistic concern.

There is nothing wrong with adjusting private rates of time preference to account for social objectives about the future. However, the connection with the opportunity cost of capital is not so easily dismissed. Consider, for example, whether we should restrict consumption of fossil fuels in order to prevent global warming, whose worst effects would be manifested in the twenty-second century. The conventional analysis assumes that the considerable expense this would entail will to some extent reduce capital investment, which would have yielded net returns forever at rate r, compounded perennially. If that is true, then arguably we can confer on the world a greatly expanded capital stock by not taking action now. Future generations can use that capital stock either to prevent undesirable climate changes or to adjust to them. If these assumptions are not true, then it is inappropriate to apply the same interest rate to far-distance benefits as we do to those in the nearer time horizon.

The question, then, is really one of forecasting the distant future rather than one of moral imperatives. This adds yet another difficult forecasting task to the already strained ability to predict future climate change and its effects: we must also predict whether future economic and political conditions warrant the assumption that capital invested today will have the long-term beneficial effects implied by use of compound interest formulae. This kind of decision is ultimately political; the analyst can inform decision makers by showing the consequences of alternative assumptions about future productivity of capital and future savings out of the returns on capital.

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[46]Calculated from $\$10 \times 10^{12} \times (1.07)^{-150}$.

Externalities, "External Benefits," and Transfers

Recently the role of "external effects" has come to be recognized as crucial to transportation policy. Individual travelers or firms making transportation decisions cause significant effects on others, from congestion to noise to better business opportunities. How should these be treated in project evaluation?

If every market affected by a transportation project could be accurately modeled, all costs and benefits would be accounted for by measuring the changes in the associated consumers' and producers' surpluses. In practice, it is more common to measure the primary effects in the transportation market itself, and to consider ancillary changes separately. We may divide these ancillary changes into two categories.

First, there are direct effects on other parties that are outside the market system. Such effects are called *technological externalities*. The formal definition is that activities of one party appear as arguments in the utility or production function of another. Most instances of technological externalities are negative, for example air pollution (affecting people's utility) or airport runway congestion (affecting airlines' production functions). Others are positive, such as the deterrent effect of passing traffic on street crime.

Second, there are effects on other parties due to changes in the prices at which they can engage in transactions. Such effects are known as *pecuniary externalities*; some examples were mentioned earlier when illustrating general-equilibrium effects. In competitive markets, pecuniary externalities are transfers of benefits from one party to another. If a new subway improves accessibility to a particular street corner, stores located there may raise their prices, while office activities located there may be able to attract workers at lower wages. Landowners, in turn, raise rents, and if the land is sold it will be at a higher price. Thus the original benefit, measured as reduced travel cost (including value of time), does not stay with the shoppers or workers who travel to that location but rather is transferred to landowners. If markets are fully competitive and none of these activities create technological

externalities, the "lucky" shoppers and workers whose travel costs were reduced in the first instance will, in the end, find themselves exactly as well off as before; the retail store and the office firm will still just be able to make a competitive return after paying higher lease rents; and the existing landowner will end up with a transferred benefit exactly equal to the originally measured travel benefit. That is, the transfer is complete and no new benefits or costs are created.

If markets are not competitive, or if there are sources of technological externalities in the associated markets, then additional benefits or costs are created in these ancillary markets. This is an example of the more general proposition that pecuniary externalities have real effects where there is imperfect competition.[47]

Considerable interest has centered on alleged positive effects in ancillary markets, usually called "external benefits." It is well known that transportation improvements spur local business and thereby boost incomes. However, most of these benefits turn out on close examination to be just transfers, either transfers of travel benefits from travelers to other businesses or transfers of activity from one location to another. New jobs and increased property values in the vicinity of locations made more accessible are to a large extent displaced from other locations; but even aside from that they mostly represent the transfer of benefits of lower transportation costs to other actors in the economy rather than new benefits. Thus including them as additional benefits is double-counting.

A more interesting example is benefits of "industrial reorganization." Often a transportation improvement makes possible a reorganization of production to take advantage of the increased ease of shipping intermediate goods. Plants or warehouses may be consolidated, inventories may be reduced, divisions of an enterprise may become more specialized — in each case because additional transportation can now be profitably substituted for other inputs to the production process. These look like important benefits, and they are: Herbert Mohring and Harold Williamson show that in plausible examples for the U.S. they can easily exceed ten percent of the total benefits of a transportation

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[47]See, for example, Paul Krugman, *Geography and Trade* (Leuven, Belgium, and Cambridge, Massachusetts: Leuven University Press and MIT Press, 1991).

improvement.[48] However, Mohring and Williamson also show that these benefits are fully captured in the demand curve for transportation, and hence are transfers rather than new benefits. The reasoning is identical to our earlier discussion of benefits to new and existing users, illustrated in Figure 5.1. The benefits of industrial reorganization are simply benefits attributable to new uses of the transportation system, made newly profitable by the improvement. Thus if quantity Q in the figure is interpreted as use of a transportation system by a firm, these new uses are represented by the quantity of trips Q_1-Q_0 and the benefits of industrial reorganization are precisely equal to area ABF.[49]

Mohring and Williamson's demonstration assumes that the cost savings from transportation are internalized within a monopoly firm. If they are not, some of the "industrial reorganization" benefits leak out to the firm's customers. However, Sergio Jara-Díaz shows that for a competitive industry, the benefits are still captured by the demand curve for transportation.[50]

So when do pecuniary externalities create genuinely new external benefits? One example is when there are technological externalities among firms that are strengthened by improved transportation. Probably the most important example is external economies of agglomeration, which are advantages that firms confer on each other through proximity. Examples include information sharing, ability of suppliers to take advantage of scale economies, access to venture capital, access to local public goods, and access to a common pool of specialized labor to help buffer unexpected expansion or contraction. Such advantages have been extensively analyzed as part of our understanding of the sources of urban agglomeration.[51] If a transportation improvement facilitates the

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[48]Herbert Mohring and Harold F. Williamson, Jr., "Scale and 'Industrial Reorganisation' Economies of Transport Improvements," *Journal of Transport Economics and Policy*, Vol. 13 (Sept. 1969), pp. 251-271.

[49]Mohring and Williamson, "Scale and 'Industrial Reorganization' Benefits," Figure 2b and p. 256.

[50]Sergio R. Jara-Díaz, "On the Relation Between Users' Benefits and the Economic Effects of Transportation Activities," *Journal of Regional Science*, Vol. 26 (May 1986), pp. 379-391.

[51]See, for example, Edgar M. Hoover, *The Location of Economic Activity* (New York: McGraw-Hill, 1948); Raymond Vernon, *Metropolis 1985*, (Cambridge, Massachusetts: Harvard University Press, 1960); Benjamin Chinitz,. "Contrasts in Agglomeration: New York and Pittsburgh," American Economic Review, Papers & Proceedings, May 1961, 51(2), pp. 279-89; Randall W. Eberts and Daniel P. McMillen, "Agglomeration Economies and Urban Public (continued...)

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development of an urban agglomeration that depends on such economies, it may confer benefits beyond those measured by private demand curves for transportation — provided the agglomeration is really new, and not just relocated from elsewhere.

Another situation where external benefits are genuine is when the transportation improvement reduces monopoly power. This case, which illustrates the more general advantage of opening trade between regions, is carefully examined by Sergio Jara-Díaz.[52] He considers two regions, each with a monopoly supplier of some commonly consumed good. If transportation cost is lowered between the regions, it becomes possible for either firm to attract some customers from the other by lowering its price. The resulting increased competition reduces prices throughout, and thereby reduces the deadweight losses associated with monopoly pricing. As an example, if the demand curve in each region is linear and the firms are identical with constant marginal cost, the total benefit from the transportation improvement is half again as large as the change in consumers' surplus as measured by the market demand curves. Thus, it is at least theoretically possible for external benefits to be considerable.

Both sources of external benefits are likely to be largest when a transportation improvement opens up a new area for development, thereby tapping new sources of agglomeration economies and bringing previously isolated regional economies into a wider and more competitive economic system. By contrast, external benefits are probably small in large urban agglomerations in which competition is already strong and agglomeration economies are already being realized.

Finally, what about the much-noted effects of public infrastructure, including transportation, on productivity?[53] The same principles apply. It is no news that a transportation improvement results in

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Infrastructure," in Paul Cheshire and Edwin S. Mills, eds., *Handbook of Applied Urban Economics* (Amsterdam: North-Holland, forthcoming).

[52]Sergio R. Jara-Díaz, "On the Relation Between Users' Benefits ..."

[53]Excellent reviews include Clifford Winston and Barry Bosworth, "Public Infrastructure," in Henry J. Aaron and
(continued...)

higher productivity — that is one of the main effects of the transportation-cost savings that are made possible by the improvement. Thus higher productivity could be solely a reflection of direct travel benefits or a transfer of such benefits. If the higher productivity is also part of a process of taking advantage of agglomeration economies, or if it results in increased competition among formerly monopolistic suppliers, then some portion of it may represent external benefits that should be added to conventional benefit measures. More definitive statements will be possible only when the microeconomic underpinnings of productivity improvements are better understood.

Conclusion: Project Evaluation as a Public Choice Process

This chapter covers many of the technical issues needed to provide sound evaluations of transportation projects. However, project evaluation is, in the end, for decision makers rather than technicians. As noted in the introduction, the need for formal tools such as cost-benefit analysis arises because proposed projects create conflicting interests. How can these tools be designed to promote good decisions in such situations?

A pessimistic view would be that project evaluation is inevitably corrupted by the interests of those who sponsor it or carry it out. Certainly there is ample evidence to support such a view. I noted earlier the systematic forecasting errors that seem to favor transit and highway projects being promoted by interested parties, whether private or public. Another example is the use for many years of unrealistically low discount rates for evaluating inland waterway and irrigation projects in the United States.

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Charles L. Schultze, eds., *Setting Domestic Priorities: What Can government Do?* (Brookings Institution, 1992), pp. 267-293; and Edward M. Gramlich, "Infrastructure Investment: A Review Essay," *Journal of Economic Literature*, Vol. 32 (Sept. 1994), pp. 1176-1196.

But just as accounting rules curtail the tendency of corporations to manipulate financial statistics in their favor, professional standards for project evaluation limit the extent of deception that can pass for objective analysis. Furthermore, formal project evaluation promotes understanding of the multiple effects of a project:

> [C]ost-benefit analysis ... has accustomed preparers of decisions ... to examine each project within comprehensive social interrelationships ... [and] to examine thoroughly the whole series of expectable direct and indirect effects. ... [It] develops in those who practice it 'conditioned reflexes' to such complexity of analysis.[54]

One justification of the recent interest in legislation requiring cost-benefit analysis of major regulatory actions is to create some new "conditioned reflexes" to consider the complex direct and indirect effects of a regulation, as well as to shift to regulators the burden of proof that the benefits are significant enough to justify the costs.

Another benefit of formal project evaluation is that it can be used to force explicit consideration of alternatives, including lower-cost variants of the primary proposal and alternative policies to make best use of existing capital facilities. For example, proposed rail rapid transit systems have been required to be compared to alternative bus systems. A more dramatic example, not implemented, would be to require highway improvements to be weighed against pricing alternatives.

Don Pickrell suggests a number of ways to narrow the range of discretion for manipulating the results of project evaluations. Possibilities include requiring peer review of evaluations, limiting the time horizon that can be considered, requiring more detailed engineering support of cost estimates, and requiring specified types of sensitivity analysis.[55]

David Lewis suggests going a step further and embedding the entire evaluation process in a public decision-making format that includes interactive sensitivity analysis and open discussion of the merits of assumptions used. Called "risk analysis process," this proposal is in the spirit of more open

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[54]János Kornai, "Appraisal of Project Appraisal," p. 95.

[55]Don H. Pickrell, "A Desire Named Streetcar: Fantasy and Fact in Rail Transit Planning," *Journal of the American Planning Association*, Vol. 58 (Spring 1992), pp. 158-176.

public involvement in decision making. It combines the technical steps of cost-benefit analysis with educational and consensus-building tools. Lewis' version emphasizes the graphical presentation of probability distributions for results under alternative assumptions about the uncertainty in model inputs. At a minimum it is hoped that this procedure will reduce the scope for technical argument among the various stakeholders in a decision. Lewis reports that in favorable circumstances it leads to a surprising degree of consensus.[56]

Project evaluation exists within a political context, whether we like it or not. Conceptual difficulties are inevitable; the important thing is to make them transparent rather than hide them. Far from making the analysis the sole province of experts, these difficulties are the grist for political debate. The job of experts is to accurately describe the effects of particular assumptions, and to develop frameworks for presenting data that clarify relationships.

Appendix: Calculation of the Shadow Price of Capital

Each dollar of investment displaced by the proposed project is assumed to provide an infinite stream of net gross returns, as a fraction of the investment, at annual rate w. In each year some portion of the return is consumed; the rest is reinvested, creating a similar set of future effects. One possible assumption is that a fraction s of the gross return is being reinvested, where s is the average savings rate in the economy. If all rates of return are constant in time and annual depreciation is a constant fraction δ of the capital stock, then these assumption imply that each dollar of investment in year zero has value V calculated from the following effects that it produces in year one:

- Original capital depreciates to a fraction $1-\delta$ of its value;
- Gross return results in new investment equal to sw;

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[56]David Lewis, presentation at Transportation Research Board annual meeting, Washington, D.C., Jan. 1997; U.S. Federal Highway Administration, *Exploring the Application of Benefit/Cost Methodologies to Transportation Infrastructure Decision Making, Searching for Solutions: A Policy Discussion Series*, No. 16 (July 1996), pp. 36-40.

- Gross return results in consumption equal to $(1-s)w$.

The first two items are new capital, so have value V per dollar as measured from year one; the third item is consumption, valued in year one at one dollar per dollar. Hence the year-one value of the effects of the original dollar of investment are $(1-\delta+sw)V + (1-s)w$. Discounting these by $(1+i)^{-1}$ gives the original shadow price V. Thus V is the solution to the equation:

$$(1+i)V = (1-\delta+sw)V + (1-s)w,$$

which gives the following formula for the shadow price of capital:[57]

$$V = (w-sw)/(i+\delta-sw).$$

This value is usually but not necessarily greater than one. Using a rough estimate of 10 percent for the depreciation rate δ, 15 percent for the savings rate s, and the earlier estimates of $i=0.04$ and $w-\delta=0.096$, the formula above gives 1.51 for the shadow price of capital. In other words, each item in the calculation that reduces or adds to capital investment is multiplied by 1.51, then all future costs and benefits are discounted at 4 percent. For i between 2 and 6 percent and $w-\delta$ between 8.6 and 10.6 percent, V takes values ranging from 1.20 to 1.97.

Different formulae result from alternative assumptions about savings behavior. For example, if it is assumed that a fixed fraction s_r is saved from the *net* return $r=w-\delta$, a similar argument gives for the shadow price of capital:

$$V = (r-s_r r)/(i-s_r r).$$

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[57] This equation is given by Randolph M. Lyon, "Federal Discount Policy, the Shadow Price of Capital, and Challenges for Reforms," *Journal of Environmental Economics and Management*, Vol. 18, no. 2, part 2 (March 1990), pp. S29-S50, Appendix I. I have simplified the derivation by using the recursion approach which attributes value V to investment in year one. Lyon also gives the subsequent alternative formula involving s_r.