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Chapter 5. Project Evaluation
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Transportation policy making often requires evaluating a proposed discrete change, whether it be a physical investment or a new set of operating rules. Some proposals, like the rail tunnel under the English channel, are one-time capital investments with long-lasting effects. Others, like congestion pricing proposed for The Netherlands, require major behavioral and political groundwork.

The optimization framework that proves useful in so much transportation analysis is inadequate to evaluate such all-or-nothing decisions. In an optimization model, important aspects of a problem are represented by 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 this way. 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 identifies key consequences of a proposed project and provides quantitative information about them in order 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 which these effects offset each other. For example, a tax-financed improvement in airway control equipment might improve safety but magnify existing income inequalities.

Thus, project evaluation is typically embedded in a larger decision-making process. John Meyer and Mahlon Straszheim argue, in their classic work on transportation planning, that project

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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.

evaluation and pricing should be viewed as parts of a single integrated planning procedure.[2] They suggest a formal procedure which includes choosing among alternate objectives, such as maximizing profits or maximizing use of a facility. The procedure also involves identifying any constraints on optimal pricing, such as whether or not different prices can be charged to different consumers; such constraints are crucial because pricing distinctions can make a major difference in the social benefits achievable from a given facility design (see the chapter on pricing in this volume).

This chapter mainly considers one important part of the project-evaluation toolkit, called *cost-benefit analysis*.[3] I begin by offering a rationale for combining the costs and benefits accruing to various parties into a single measure. I then explain the wide applicability of "willingness to pay" as a unifying principle in measuring costs and benefits. In applying this unifying principle, I address several specific issues that often arise in transportation evaluations: issues in measuring benefits, issues related to the capital intensity and long lifetime of many transportation projects, issues in properly accounting for externalities. I also consider the effects on economic performance of raising taxes to fund projects. The concluding section returns to the place of cost-benefit analysis in overall project evaluation and decision-making.

The Role of Cost-benefit Analysis

Cost-benefit analysis achieves makes numerous and varied effects commensurate by quantifying them 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 the distribution of real incomes (i.e., on standards of living) can be described.

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2   John R. Meyer and Mahlon R. Straszheim, *Techniques of Transport Planning, Volume One: Pricing and Project Evaluation* (Washington, D.C.: Brookings Institution, 1971), ch. 14, especially pp. 232-236.

3   For just a few of the extensive reviews of cost-benefit methodology, see: A,R, Prest and R. Turvey, ₐCost-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).

The usual form of assessment is based on adding up all the costs and benefits, to whomever 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 assume these two conditions are met, but others argue persuasively that the value of cost-benefit analysis is not to replace policy makers' subjective judgments but rather to improve their understanding of the ramifications of alternative decisions.[4] 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 scaler indicator. He knows that good lungs are not a substitute for bad kidneys. ... Why cannot the economist also shift ... to that way of thinking?[5]

Second, on what basis can we justify projects that create "losers" just because their aggregate benefits exceed their costs? Only in the highly artificial "representative individual" model, where everyone is identical and all are 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.[6] 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

4   Christopher A. Nash, ACost-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.

5   János Kornai, AAppraisal 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.

6   See, for example, Paul A. Samuelson, *Foundations of Economic Analysis* (Cambridge, Mass.: Harvard University Press, 1947); Jerry A. Hausman, AExact Consumer=s Surplus and Deadweight Loss,@ *American Economic Review*, Vol. 71 (Sept. 1981), pp. 662-676; G.W. McKenzie and T.F. Pearce, AWelfare Measurement⊂a Synthesis,@ *American Economic Review*, Vol. 72 (Sept. 1982), pp. 669-682. The Aindex 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 payments for the commodity). In practice, these measures seldom differ by much, so I ignore those differences here; see Robert D. Willig, "Consumer's Surplus Without Apology," *American Economic Review*, vol. 66 (Sept. 1976), pp. 589-597.

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 to cost-benefit analysis 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 as cost-benefit analysis, depends on how it informs that process. Thus, an answer to the first objection - that not all benefits can be quantified in monetary terms - is that quantifying as many factors as possible helps to discipline 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 - that there will be losers - is that cost-benefit analysis calls attention to situations where a project benefits one interest group at a high cost to others. Both answers point to a role that recognizes the analysis as part of political decision making, but molds it to make more obvious to everyone whose interests various political decisions would favor. Far from giving free reign to politicians, then, the objective is to produce information that makes political decision-making more transparent and honest.

We can restate more formally the point about identifying decisions that benefit one interest group at a high cost to others. 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.[7] For example, an airport expansion may bring so many benefits to users that they could easily "buy off" those residents harmed by the noise, if only there were a mechanism for doing so. Noise remediation programs, such as paying for double-glazed windows, are attempts to approximate such a mechanism. In practice no such mechanism can be perfect because it is impossible to precisely measure each person's benefits and costs. Nevertheless, it can be shown that a rule requiring that the sum of everyone's net benefits from a project be positive would lead to acceptance of only those projects that are potential Pareto improvements.

Thus it seems plausible that consistent application of a cost-benefit criterion would make most people better off given "A rough randomness in distribution" of effects,[8] and would normally

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[7] This rationale is explicitly stated in the document setting out current U.S. government policy on project evaluation: 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 10.

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

lead to "A strong probability that almost all would be better off after the lapse of a sufficient length of time."[9] The reason is that no one knows what projects will come up for evaluation in the future, or who the winners and losers from such projects 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 James Buchanan and Gordon 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."[10] The same idea appears in the literature on contract and nuisance law,[11] 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.[12]

By identifying winners and losers, it becomes possible to take them into account in future policy decisions so as to make more likely the kind of "rough randomness in distribution" just described. It is perhaps for this reason that using cost-benefit analysis to identify and measure important distributional effects is now preferred by most analysts to the explicit use of "distributional weights" on costs and benefits to specific groups that was formerly recommended by the World Bank, among others.[13]   However, there is an important caveat to estimating distributional effects: markets adjust to new situations in complex ways, causing costs and benefits to be shifted from one party to another in a manner that is often far from transparent. This is especially true of transportation projects, which interact strongly with land markets and other locationally specific activities.[14]

Ideally, in order to measure all relevant effects of a project we should use a general-equilibrium model of the entire economy. In practice, such an approach would take us beyond the bounds of what we can say with confidence about a project's effects, and would create new

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9   John R. Hicks, AThe Rehabilitation of Consumers= Surplus,@ *Review of Economic Studies*, vol. 8 (Feb. 1941), pp. 108-116; the quote is from p. 111.

10   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, ACost-Benefit Analysis Applied to Risks: Its Philosophy and Legitimacy,@ in 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, AA Contractarian Paradigm for Applying Economic Theory,@ *American Economic Review*, Vol. 65 (May 1975), pp. 225-230.

11   Anthony T. Kronman, AWealth Maximization as a Normative principle,@ *Journal of Legal Studies*, Vol. 9 (March 1980), pp. 227-242.

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

13   Glenn P. Jenkins, "Project Analysis and the World Bank," *American Economic Review, Papers and Proceedings*, Vol. 87, No. 2 (May 1997), pp. 38-42. The circular of the U.S. Office of Management and Budget, mentioned earlier, mandates that important distributional effects be analyzed and discussed (section 10).

14   J. Hayden Boyd, "Benefits and Costs of Urban Transportation: He Who Is Inelastic Receiveth and Other Parables," *Transportation Research Forum Proceedings*, Vol. 17 (1976), pp. 290-297.

debates about technical matters far removed from the project under consideration. So usually it is better to take a humbler view, measuring effects that are relatively well understood and leaving more far-reaching considerations, such as improved macroeconomic performance, to the political process.

Even so, applying cost-benefit analysis raises many methodological issues, some especially significant for transportation. For example, transportation projects often have the purpose of saving people time or improving safety. They also may have significant environmental effects. How are these factors to be evaluated? These questions are discussed in the next two sections.

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.

The concept need not be restricted to those most directly affected by a project. Expanding air traffic creates transportation services that users are willing to pay for, the direct effect; but it also creates noise that residents are willing to pay to avoid. Reduced congestion on one road changes the amount of congestion on other roads, thereby creating positive or negative willingness to pay on the part of users throughout the network. A rail station in a previously isolated community may reduce unemployment there, creating additional benefits in reduced alcoholism or crime for which people who never use the station nevertheless have a measurable willingness to pay. As we shall see, care is required to limit the analysis to effects that are realistic and causally related to the project in question.

The use of willingness to pay is what makes cost-benefit analysis 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.[15] 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 extra value on the social interactions fostered by public transit, perhaps to promote social cohesion, that value will not be captured by the sum of individual willingness to pay for transit trips. However, it would be captured if one also measured and included individual willingness to pay for the better social milieu that is posited to result from more social interaction.

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 *consumers' surplus*, which is the area under the demand curve and 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.[16] Similarly, willingness to pay by suppliers is measured by the change in *producers' surplus*, which is the area above the supply curve and below the price line.

The use of consumers' and producers' 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 C_1. There are Q_0 existing users, each willing to pay (C_0-C_1) for the improvement; their aggregate benefit is therefore measured by the rectangle C_0AFC_1. There are Q_1-Q_0 new users,[17] some willing to pay almost the full cost reduction (C_0-C_1)

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15   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).

16   A formal demonstration is given by Kenneth A. Small and Harvey S. Rosen, ₐApplied Welfare Economics with Discrete Choice Models,@ *Econometrica*, Vol. 49 (Jan. 1982), pp. 105-130. See also Thomas A. Domencich and Daniel McFadden, *Urban Travel Demand: A Behavioral Analysis*, Vol. 93 of *Contributions to Economic Analysis* (Amsterdam: North-Holland, 1975), pp. 94-99.

17   It does not matter whether these new users are making new trips or are diverted from other routes, modes, or times of day ₒ except that if they are diverted it may be necessary to account for changes in other markets to the extent they are not priced at marginal cost. An example is accounting for costs or benefits due to changes in unpriced congestion on other parts of a road network.

Full
Price   G

C_0

C_1

A

B
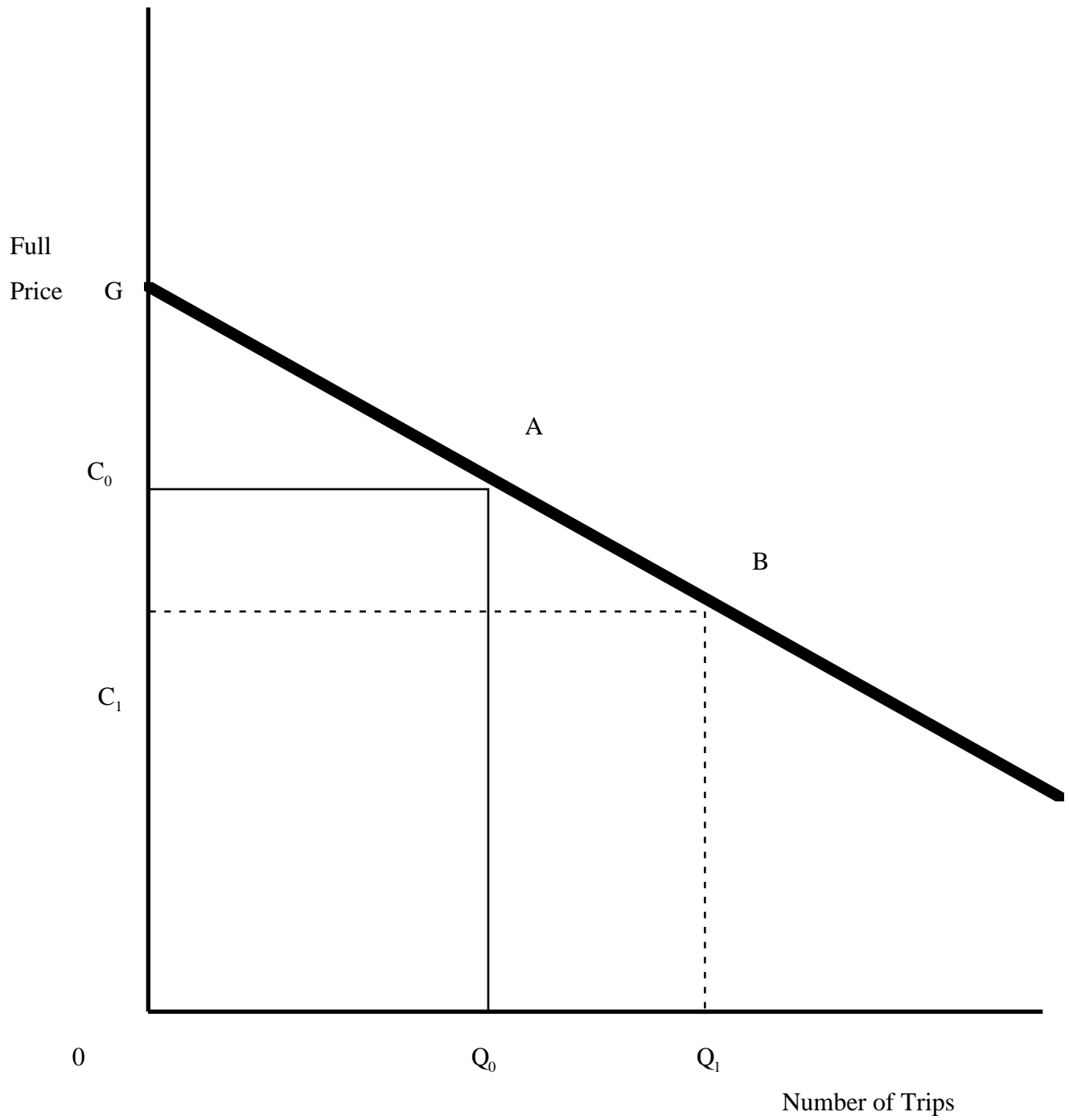
0   Q_0 Q_1

Number of Trips

Fig 5.1 Benefits to Existing and New Users

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); adding all of them together, 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_0ABC_1. This area is also the change in consumers' surplus, which increased from area GAC_0 to area GBC_1. (Hence it would be double-counting to add the change in consumers' surplus to the value of time savings or other improvements.)[18]

If the demand curve is approximately linear between A and B, as in Figure 5.1, then area ABF is approximately 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 part of the 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 while traveling. If we were to try to account for actual changes in travel time for new users, we would also have to measure and value each of these characteristics directly, which is virtually impossible; fortunately the indirect measure embodied in area ABF is just what we want.

What if the model used to measure the demand curve in Figure 5.1 implies values of time that differ from those mandated by a government agency for use in cost-benefit analysis? For example, Transport Canada assigns to all adult non-business travel a uniform value of time equal to 50

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18   The analysis readily extends to the case where the ₐfull price₉ depends on the number of trips through economies of scale or congestion effects: see, for example, Peter Mackie, Jeremy Toner, and Denvil Coombe, ₐA Critical Comment on the COBACHECK Method of Estimating the Effects of Induced Traffic on the Economic Benefits of Road Schemes,₉ *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, ₐObservable Public Good Preferences,₉ *Journal of Public Economics*, Vol. 8 (1977), pp. 111-131.

percent of the national average wage rate;[19] but the demand model used to analyze a particular Canadian project might imply some other value of time. It is relatively easy to "correct" the rectangle C_0AFC_1 by decomposing (C_0-C_1) into its money component and its time component; but there is no obvious "correction" to the triangle ABF because line AB is inconsistent with the official value of time. Often the triangle is much smaller than the rectangle so it does not matter much. Where it does matter, one solution is to re-estimate the underlying demand model while forcing the coefficients to bear a relationship to each other consistent with the official value of time.[20] The resulting demand model may not fit the data as well, but in a crude way it takes into account additional information embodied in the earlier choice of the official value of time.

Willingness to pay also deals realistically with risk, even risk of events, such as injuries or deaths, often believed not amenable to monetary evaluation.[21] 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 and others are willing to pay to avoid small measurable risks, for example by moving to less polluted but more expensive neighborhoods, by installing smoke detectors, or by ordering air bags for their cars. This kind of investigation has proven tractable, as described in a later section of this chapter.

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. Similarly, if a resource such as labor or capital would otherwise be underused, willingness to pay may be less than the market price. 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.[22] A warning is in order, however, when considering underemployed labor: it is important to recognize that macroeconomic policies may offset any job-creating or job-destroying effects of the project being

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19   Transport Canada, *Guide to Benefit-Cost Analysis in Transport Canada* (Ottawa: Transport Canada, Sept. 1994), p. 47.

20   An example of fitting a demand model to imply a specified value of time is provide by Kenneth A. Small, "Bus Priority and Congestion Pricing," in Theodore E. Keeler, ed., *Research in Transportation Economics, Volume 1* (Greenwich, Connecticut: JAI Press, 1983), pp. 27-74; in particular Models C and D described on pp. 43-46.

21   Thomas C. Schelling, ₐThe 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, ₐEvaluation of Life and Limb: A Theoretical Approach,@ *Journal of Political Economy*, Vol. 79 (July/Aug. 1971), pp. 687-705.

22   For a rigorous and elegant general treatment of shadow prices, see Jean Dréze and Nicholas Stern, ₐPolicy 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).

evaluated because those policies are aimed at other goals such as price stability, foreign exchange rates, or trade balances.

As already noted, 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. If these associated markets are 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 ("External Costs, External Benefits, and Transfers") 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. This is discussed later in the subsection entitled "Discounting the Future."

Issues in Benefit Measurement

Using the willingness to pay principle, we are now in a position to deal with issues that come up frequently in transportation evaluations. I begin in this section with three important categories of benefits: travel-time savings, safety improvements, and environmental improvements. This listing is roughly in order of their quantitative importance as components of measurable benefits from transportation projects.

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 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. Time savings may occur from a number of sources: a new service such as high-speed rail, a new route such as a highway through previously undeveloped land, congestion relief from expanding capacity, an operational improvement such as from improved rail switching facilities, or an upgraded line-haul facility to permit higher speeds.

An extensive empirical literature, based on demand models like those discussed in Chapter 1 of this volume, 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 estimating the willingness to pay for travel-time savings, a quantity known as the "value of time." For example, one review 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 industrialized cities from perhaps 20 to 100 percent.[23] Values have also been established for other types of trips and for freight.[24]

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

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

[24] W.G. Waters II, ₐValues 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, ₐBehavioural 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, ₐA Disaggregate Model of the Demand for Intercity Freight Transportation,@ *Econometrica*, Vol. 49 (July 1981), pp. 981-1006.

time more highly on medium-length trips than on short or long trips.[25] 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.[26] 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 such variations can result in poor decisions. For example, some evaluations of rapid rail systems have failed to account fully for the reluctance of people to make extra transfers or to walk longer distances to transit stops.

However, some analysts overstate the specificity of the situation facing a person.   For example, although 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.[27]   Rather, observed variations in the marginal valuation of different lengths of time savings are probably due to the variation in value of time with individual trip length or with total amount of time spent traveling.

Predicting the travel-time savings from many projects is complicated by offsetting behavioral shifts as a result of changes in unpriced congestion. Suppose a particular measure relieves congestion. After it is adopted, the system will tend to re-equilibrate as people previously deterred

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25   On medium versus short trips, see Moshe Ben-Akiva and Steven R. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand* (Cambridge, Mass.: MIT Press, 1985), pp. 174-177; their result is for work trips and may indicate that people appreciate some transition time between home and work. On medium versus long trips, see MVA Consultancy et al., *The Value of Travel Time Savings*, p.150.

26   John Calfee and Clifford Winston, ₐThe Value of Automobile Travel time: Implications for Congestion Policy,@ *Journal of Public Economics* (forthcoming).

27   An example of this fallacy is the strong dependence of value of time on ₐamount 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).

by congestion, constituting what is known as the 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.[28] 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 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 if those new users are not anticipated. 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.[29] Commuters face a cost   for each minute early they arrive at their destination, and a cost   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 incorrectly thinks 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   and   is less than the value of travel time.[30] 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 by encouraging residential relocations which in

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

29   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.

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

turn create longer trips and hence new traffic. For this reason, congestion will not be reduced by as much as would otherwise be predicted. Again, there are offsetting benefits to the people who now can exercise their preferences for larger lots in outlying residential areas. However, in this case it has been shown that at least for fixed workplace locations, the net effect of ignoring the land-use changes is to overestimate benefits of capacity expansion.[31]

One important source of latent demand for a given route is traffic diverted from other routes. This can often be analyzed by a network model. If congestion is prevalent, it is important to accurately measure how congestion levels change throughout the network and to take into account the resulting costs and benefits.

Accidental Injuries and Deaths

Safety ranks high in public perceptions of transportation problems. Airline crashes or train derailments make national headlines, while local car wrecks are a routine of the evening news. Much effort and expense has been poured into largely successful efforts to reduce safety hazards in transportation. Some of this effort is market-driven, while some is government-mandated. How can we evaluate the case for public-policy intervention on behalf of safety? 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 that changes in the risk of injuries, fatal or otherwise, can be evaluated based on the willingness-to-pay principle. We all make decisions every day that implicitly place values on additional risks incurred; by making such valuations explicit, we can make public decisions more consistent with private ones. Empirically, the most reliable method to value risk of death appears to be comparisons of 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 early 1990s were willing to pay US$3 to $7 for each reduction of one in a million in the risk of death.[32] Taking the midrange value of $5 and looking at a million

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31   Richard J. Arnott, ₐUnpriced Transport Congestion,@ *Journal of Economic Theory*, Vol. 21 (1979), pp. 294-316. Empirical estimates suggest that the urban interstate highway system was overbuilt as a result of this effect: see William C. Wheaton, "Price-Induced Distortions in Urban Highway Investment," *Bell Journal of Economics*, Vol. 9 (Autumn 1978), pp. 622-632.

32   V. Kip Viscusi, "The Value of Risks to Life and Health," *Journal of Economic Literature*, Vol. 31 (Dec. 1993) pp. 1912-1946, especially p. 1930; Shulamit Kahn, "Economic Estimates of the Value of Life," *IEEE Technology and Society Magazine*, Vol. 5, (June 1986), pp. 24-31.

such people, their aggregate willingness to pay for a risk reduction of that amount is then $5 million, and one life is expected to be saved. This result is summarized in the convenient but easily misunderstood statement that the *value of life* is $5 million.

Valuations of risk of death may deviate from this amount for specific types of situations; for example, evidence suggests that people are more reluctant to undertake risks over which they have no control, so the value of life for train accidents may be higher than that for car accidents. Willingness to pay for risk reduction appears to be approximately proportional to income. There is an open question of whether it also depends on age or life expectancy.[33]

Many governmental agencies use a "value of life" that is considerably below the range suggested by the labor-market studies: for example, Transport Canada uses 1.5 million 1991 Canadian dollars, or about US$1.3 million.[34] Nevertheless, the figure of $5 million, or even $1.3 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; rather, people are paying to lower the probabilities slightly. Using discounted future earnings to value risk of death is an older technique that is now discredited because it does not apply the willingness-to-pay principle, and because it attempts to value the full transition between life and death rather than the small changes in risk that people actually face as a result of public policies.

Risks of serious injuries or illnesses can be evaluated in a similar way. 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.[35] Because non-fatal injuries are much more numerous than fatal ones, this adds significantly to estimates of the total costs of accidents, which are quite high - comparable, for example, to total travel-time costs in the case of a typical urban commuting trip by automobile.[36]

Several additional conceptual issues complicate the empirical estimation of safety 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

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[33]   Viscusi, "The Value of Risks to Life and Health," p. 1930 and pp. 1920-1925.

[34]   Transport Canada, *Guide to Benefit-Cost Analysis in Transport Canada*, p. 43, converted to US$ using the 1991 exchange rate of US$1=CA$1.146.

[35]   Michael W. Jones-Lee, Graham Loomes, and P.R. Philips, ₐValuing the Prevention of Non-Fatal Road Injuries: Contingent Valuation *vs.* Standard Gambles,@ *Oxford Economic Papers*, Vol. 47 (1995), pp. 676-695. See also Viscusi, "The Value of Risks to Life and Health," p. 1933.

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

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 and fully recognized, 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 marginal rate of tradeoff of one for the other.[37] So there is not much case for adding benefits accruing to family and friends.

Next, consider the effects of life, health, and 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 implicitly pays 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 is unlikely that an individual would demand a wage premium to cover such costs, so they need to be added explicitly.

Another conceptual issue is related to the prediction, rather than the valuation, of the reduction in injuries or deaths. 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.[38] These behavioral adjustments not only offset part of

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37   Theodore C. Bergstrom, ΑWhen 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.

38   See Sam Peltzman, ΑThe Effects of Automobile Safety Regulation,@ *Journal of Political Economy*, vol. 83 (August 1975), pp. 677-725. Most 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., ΑBuckle 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, ΑAre 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.

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 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.[39]

If the offsetting behavioral changes are not included in the forecast of a project's effects, then we have an odd situation: the predictions of safety effects are wrong, yet the estimated benefits may be fairly accurate. The reason is that the benefits from reduced injuries are overstated, because some of those reductions will not actually occur due to offsetting behavior; but the benefits from that offsetting behavior are ignored. For example, suppose an analysis of disk-lock brakes ignores the fact that people with disk-lock brakes are more willing to drive when it is raining. Then not as many lives will be saved as thought, but people are receiving value from going on rainy days to events they would otherwise miss. In theory, these two errors in forecasting benefits fully offset each other provided the behavioral changes are small, involve no externalities, and are deemed socially valid goals for the individual.[40] 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. We may be happy about the people with disk-lock brakes who can get to church on rainy days, but not about those who use their newfound confidence to terrorize slower drivers.

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. This is a legitimate basis for differentiating values of different kinds of risks. 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

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[39]   For a more thorough analysis of the time putting on seat belts and how it affects cost-benefit analysis, see Fred Mannering and Clifford Winston, "U.S. Automobile Market Demand," in Clifford Winston and Associates, *Blind Intersection?: Policy and the Automobile Industry* (Washington, D.C.: Brookings Institution, 1987), ch. 3.

[40]   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.

those apparent preferences by using more accurate information available to the decision maker.[41] It is sometimes more feasible to promote cost-effectiveness in safety investments by using technical information at the project-evaluation stage than by launching public education campaigns concerning the actual risks.

Environmental Improvements

It is now well recognized that transportation activities often damage the environment. These effects are frequently debated as part of a proposed policy, whether it be building a new airport or raising the gasoline tax. Furthermore, some very expensive policies are proposed explicitly on environmental grounds: for example electric cars and certain rail transit systems. How can we evaluate such policies? How do we know how much environmental protection is enough?

In principle, environmental effects can be evaluated using the principles already outlined. People are willing to pay for a better environment. However, accounting for these effects raises measurement issues that are more difficult even than those related to 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 can bring 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. 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 relation to the implied value that people place on trip-making by motor vehicles.[42] If these results hold up to further refinement, they suggest both a

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41   For a discussion of whether people misperceive the probabilities associated with various risks, see John Calfee and Clifford Winston, "The Consumer Welfare Effects of Liability for Pain and Suffering: An Exploratory Analysis," *Brookings Papers on Economic Activity (Microeconomics)*, (1993), pp. 133-96. A related issue is whether such misperceptions bias the empirical estimates of "value of life"; one reason for preferring labor-market studies for such estimates, as described earlier, is that people are likely to be well informed about the nature of their jobs.

42   Kenneth A. Small and Camilla Kazimi, ₐOn 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*

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.

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 and completeness. 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 because those impacts occur over very long time scales, the scientific modeling process is uncertain, and there is unknown potential for technological change that might ameliorate adverse effects. Simply adding such estimates to others might erode confidence in the entire cost-benefit analysis.

In some cases, the uncertainty in benefits can be reduced by accepting as binding a political decision to hold harmful effects at specified levels, as for example by ratifying a greenhouse-gas treaty. Then the benefit of reducing one source can be measured as the marginal control cost at another source. However, such political decisions may in fact be revised over time.

My own view is that in the case of "ordinary" (lower-atmosphere) air pollution, the methodology is sufficiently advanced to justify incorporating monetary estimates of its effects into cost-benefit analysis. The same is probably true of noise.[43] (Results should, of course, be shown disaggregated whenever possible to facilitate sensitivity analysis.) 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, although quantification is still useful for purposes of prioritizing further research.

Issues Due to Longevity of Decisions

Transportation investments are notable for their length of life. Frequently, large up-front capital requirements will yield benefits, as well as incur maintenance costs, many years into the

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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.

43   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).

future. For example, the "Big Dig" in Boston, involving a complex of highway connections around and across Boston Harbor, is estimated to cost $12 billion. 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 tradeoffs between present costs and future benefits.

In this section I consider three issues raised by having to weigh the future against the present. First is forecasting capital cost and usage. Second is the choice of an interest rate. Third is the question of whether unborn generations of people are properly accounted for by conventional discounting procedures when decisions have very long lifetimes.

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 projection.

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.[44] 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!

Even for toll highways, where the use of private bond financing exerts more discipline on the initial projections, ten of fourteen projects recently examined experienced toll revenues well below

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44   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.[45] The same bias was found for seven large Danish bridge and tunnel projects, the bias being somewhat greater for rail than for road projects.[46] Given that capital projects are heavily promoted by interested parties, it is difficult to avoid the conclusion that these errors are strategic.[47] In most cases, taxpayers will be left footing the bill for cost over-runs, for revenue shortfalls, or simply for the carrying costs for capital expenditures that turned out to have few benefits.

A comparison of three cost-benefit studies of a new toll road near Vancouver, British Columbia, illustrates how dependent the results can be on travel forecasts.[48] The road, known as the Coquihalla Highway, connects the Vancouver region with popular resort areas to the northeast. It 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 because these were academic studies, and so presumably without strategic bias, these two errors had offsetting rather than compensating influences on the cost-benefit analysis; still, their sheer magnitudes are 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.

Discounting the Future

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, equivalently, as due to the productive possibilities for investing their money. In either view, the

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45   Robert H. Muller, ₐExamining Toll Road Feasibility Studies,₎ *Public Works Financing* (June 1996), pp. 16-20.

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

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

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

traditional way of accounting for the difference is to divide t-year-later quantities by $(1+r)t$, where r is a *discount rate* closely related to the interest rate on financial assets.[49] 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.[50]

As already noted, 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 stable 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. Suppose consumers can shift consumption from one time period to another by increasing or reducing their holdings of a risk-free government bond with real after-tax interest rate r_c, 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.) Then they would adjust their planned consumption paths until their marginal rate of time preference in consumption, defined as consumers' willingness to pay to accelerate consumption benefits from later to earlier years, is equal to r_c. Investment, on the other hand, is undertaken by private firms and earns a real net social rate of return (also called the value of marginal product of capital), which we may call r_i. A recent estimate gives the value of r_i for 1989 to be 9.6 percent.[51]

One approach to choosing the discount rate r for cost-benefit analysis is simply to take a weighted average of these two rates, r_c and r_i. The weights would reflect the proportions of the project's financial flows which are believed to be drawn from consumption and investment,

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49   The quantity $(1+r)-1$ is sometimes called the *present value discount factor*, but terminology is not uniform.

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

51   This is based on the average nominal after-tax rate of return on Aaa corporate bonds of 9.26 percent. Adjusting upward by a factor $(1-0.38)-1$ (assuming an average marginal corporate tax rate, federal plus state, of 38 percent), gives a pre-tax nominal return of n=14.9 percent; we then adjust downward for inflation of _=4.8 percent per year according to the formula $(1+r_i)(1+\_)=1+n$, presented in an earlier footnote. This calculation is in Boardman et al, *Cost-Benefit Analysis*, p. 172.

respectively. If these proportions are about equal, for example, then using the above values for r_c and r_i yields an interest rate of 6.8 percent.

The weighted average interest rate is a reasonably simple and plausible procedure, but it is somewhat arbitrary because the flows determining the weights should themselves be discounted. A theoretically more rigorous approach, discussed in the Appendix, overcomes this problem by converting each expenditure or benefit to an equivalent flow of consumption, taking account of any investment consequences it has. The equivalent consumption flows are then discounted at the marginal rate of time preference, r_c. This approach is known as the shadow price of capital because to every capital expenditure, it applies a multiplier indicating how much consumption must be given up because of that expenditure. A reasonable value for this multiplier is 1.5, based on U.S. conditions in 1989.

If an economy is open to foreign capital, internal conditions are less important because capital for transportation projects is likely to be drawn, directly or indirectly, from foreign sources. In the case of a small country with a very open economy, the opportunity cost of capital is close to the market interest rate on international loans, and this rate can be used for most discounting purposes.

Market interest rates also incorporate various degrees of risk. Loans to firms or nations with doubtful repayment prospects command a higher rate than other loans. However, it can be argued that it is better to consider the risk of the project explicitly through some form of sensitivity analysis, as described in the concluding section of this chapter, rather than to try to account for risk through adjustments to the interest rate. This is especially true when the risks for various projects under consideration are not highly correlated and are shared across the society at large.

The methods discussed here require considerable judgment on the part of the analyst. In practice, there are reasons to constrain the exercise of such judgment, for example to foster uniformity. As a result, government manuals often specify the real discount rate r to be used, unless there is a demonstrable reason that it should be different for the project in question. In the United States, that 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.[52] For Australian road projects it is also specified to be 7 percent, while Transport Canada mandates 10 percent.[53] In all these cases, sensitivity analysis is recommended to show how much the results are affected by assuming

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

[53]   Austroads, *Benefit Cost Analysis Manual* (Sidney: Austroads, 1996), p. 10. Transport Canada, *Guide to Benefit-Cost Analysis in Transport Canada*, p. 66.

different interest rates. Note that the U.S. and Australian mandated interest rates are virtually identical to the figure derived earlier using the weighted-average method.

The Far Distant Future

The use of discounting has important and controversial implications for evaluating policies affecting distant generations. Examples of such policies include those related to nuclear waste disposal, global warming, species preservation, and soil conservation. Increasingly, transportation activities are being linked to such long-lived effects - electricity use in some nations will increase the use of nuclear power stations, new rural or suburban roads destroy wildlife habitat, extensive paving increases water runoff resulting in damage to adjacent soils and watersheds. Of particular concern today is that burning fossil fuels contributes to a long-term accumulation of carbon dioxide in the atmosphere, which probably will have a global warming effect, causing changes in weather patterns and possibly in sea levels.[54] Because motor vehicle transportation consumes such large amounts of fossil fuel, whose combustion produces carbon dioxide, the manner in which such future costs are accounted for has major implications for transportation policy decisions.

Using conventional discounting, adverse future consequences have very small weight in a cost-benefit comparison if they occur in the distant future. For example, imagine a climate disaster occurring in 150 years that causes damage of $10 trillion in constant 1998 dollars (more than today's U.S. annual gross domestic product). It has a discounted cost today of only $391 million using OMB's discount rate of 7 percent.[55] Many analysts question whether the marginal rate of time preference applying to private individuals can be extrapolated to distant unborn generations, and advocate 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 so do not need our altruistic concern.

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[54] See Richard Schmalensee, "Symposium on Global Climate Change," *Journal of Economic Perspectives*, vol. 7 (Fall 1993), pp. 3-10, and the accompanying symposium articles. See also William R. Cline, *The Economics of Global Warming* (Washington, D.C.: Institute for International Economics, 1992); Intergovernmental Panel on Climate Change (IPCC), *Second Assessment Report* (Cambridge, UK: Cambridge University Press, 1996).

[55] Calculated from $10x1012/(1.07)150.

A more rigorous theoretical approach suggests that both arguments are partly right. The applicable principle comes from the theory of long-run growth with finite resources.[56] Suppose the welfare of future generations is given equal weight to that of today's consumers in an intertemporal social welfare function. The consumption path that maximizes social welfare then has the property that consumption is forever increasing, but at a growth rate that gradually approaches zero. Consumption at any time t is valued less than consumption at an earlier time, by a factor derived from a discount rate equal to the marginal productivity of capital. (In the version sketched here, this preference for earlier consumption results from people setting their marginal rate of time preference, r_c, exactly equal to the marginal rate of return on investment, r_i, thus ignoring the tax wedges discussed in the previous subsection.)

So far this looks like the case for conventional discounting. But not quite. In this scenario, the marginal productivity of invested capital r_i is not constant, but rather it declines gradually to zero as the capital stock continues to expand indefinitely. So costs saved today can be invested in capital which in turn accumulates, but it accumulates at a gradually diminishing rate. Discounting future benefits or costs therefore still applies, but it must account for this saturation effect.

Suppose, for example, that when our $10 trillion disaster occurs 150 years hence, capital's annual rate of return will have decreased from its value of 7 percent today to 3.5 percent, due to the increased capital intensity of the economy. Suppose also that the two rates r_c and r_i are equal at every point in time (as they are in the theory just described) due to market adjustments. Then the disaster has a discounted cost of about $4.75 billion[57] - twelve times as large as that computed at a constant interest rate at seven percent. This is still a very heavy discount, and it can be argued that it should be heavier still because new technologies seem to enhance the productivity of new capital and thereby prevent the posited decline in capital's rate of return.

Whatever the discount rates used, the discounting approach assumes - in the climate example - that if we undertake the considerable expense of restricting greenhouse gas emissions today we will to some extent reduce capital investment, which would have yielded net returns accumulating far into the future. Hence by not taking action now, we can confer on future generations a much larger capital stock, which they can use to prevent or cope with climate changes. Is such an

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[56]   Partha Dasgupta, "Exhaustible Resources: Resource Depletion, Research and Development and the Social Rate of Discount," in Richard Layard and Stephen Glaister, eds., *Cost-Benefit Analysis* (Cambridge, UK: Cambridge University Press, 1994), pp. 349-372; see especially pp. 363-369.

[57]   Calculated as $10x1012/[(1.07-_)(1.07-2_)(1.07-3_)$$$(1.07-150_)]$, where $\_=(.070-.035)/150$ is the amount the discount rate is assumed to decline each year over the 150-year period.

assumption realistic? Can we legitimately model the distant future as an extension of today's world of economic interrelationships? Again, it is the political system that will decide how these questions should be answered for purposes of guiding social decisions. What the technical analysis described here accomplishes is to demonstrate the consequences of alternative assumptions about future productivity of capital, and to show that ultimately the question of discounting is not one of moral imperative but of predicting the future.

External Costs, 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. Many 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.[58] If a new subway improves

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58   The extent of such transfers depends on the relative elasticities of supply and demand in these ancillary markets, as nicely explained by Boyd, "Benefits and Costs of Urban Transportation." For further discussion, see John R. Meyer and Mahlon R. Straszheim, *Techniques of Transport Planning, Volume One: Pricing and Project Evaluation*, pp. 199-202.

accessibility to a particular street corner, stores located there may raise their prices, while occupants of office buildings 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 creates technological externalities, and if the project is too small to alter aggregate market supplies, then 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, while the existing landowner will end up with a transferred benefit exactly equal to the originally measured travel benefit. That is, landowners' increased rent is a measure of the subway's benefits, not an added benefit.

If markets are not competitive, however, or if there are technological externalities in the ancillary markets, then additional benefits or costs are created. This is an example of the more general proposition that pecuniary externalities have real effects where there is imperfect competition.[59] Let us examine this possibility more closely.

Considerable interest has centered on alleged positive effects 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 benefits from travelers to other businesses or transfers of activity from one location to another. 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 improvement. However, Mohring and Williamson also show that these benefits are

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

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 ways of using 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 Q1-Q0 and the benefits of industrial reorganization are equal to area ABF.[60]

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.[61]

So when do pecuniary externalities create genuinely new external benefits? One case is when technological externalities among firms 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. Such advantages include information sharing, ability of suppliers to reap 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.[62] If a transportation improvement facilitates the 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 in which external benefits are genuine is when the transportation improvement reduces monopoly power. This case, which illustrates the more general advantage of

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60   Herbert Mohring and Harold F. Williamson, Jr., ₐScale and >Industrial Reorganisation₌ Economies of Transport Improvements,@ *Journal of Transport Economics and Policy*, Vol. 13 (Sept. 1969), pp. 251-271; especially Figure 2b and p. 256.

61   Sergio R. Jara-Díaz, ₐOn the Relation Between Users₌ Benefits and the Economic Effects of Transportation Activities,@ *Journal of Regional Science*, Vol. 26 (May 1986), pp. 379-391.

62   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, ₐAgglomeration Economies and Urban Public Infrastructure,@ in Paul Cheshire and Edwin S. Mills, eds., *Handbook of Applied Urban Economics* (Amsterdam: North-Holland, forthcoming); Alex Anas, Richard Arnott, and Kenneth A. Small, "Urban Spatial Structure," *Journal of Economic Literature*, forthcoming Sept. 1998.

opening trade between regions, is carefully examined by Sergio Jara-Díaz.[63] He considers two regions, each initially with a monopoly firm supplying the same good. If transportation cost is lowered between the regions, it becomes possible for the firm in one region to attract customers from the other by lowering its price.   The resulting increased competition reduces prices throughout, and thereby reduces the deadweight loss associated with monopoly pricing. As an example, suppose the demand curve in each region is linear and the firms are identical with constant marginal cost; Jara-Díaz show that the total benefit from the transportation improvement is then half again as large as would be measured in the usual way. 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.[64] Thus they are likely to be important for less developed nations. By contrast, external benefits are probably small in large urban agglomerations in which competition is already strong and agglomeration economies are already fully realized.

Finally, what about the much-noted effects of public infrastructure on productivity?[65] The same principles apply.   It is no news that a transportation improvement results in 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.

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63   Sergio R. Jara-Díaz, AOn the Relation Between Users= Benefits ...@

64   For an early exposition of this view, see Julius Margolis, "Secondary Benefits, External Economies, and the Justification of Public Investment," *Review of Economics and Statistics*, vol. 39 (1957), pp. 284-291.

65   Excellent reviews include Clifford Winston and Barry Bosworth, APublic Infrastructure,@ in Henry J. Aaron and Charles L. Schultze, eds., *Setting Domestic Priorities: What Can government Do?* (Brookings Institution, 1992), pp. 267-293; and Edward M. Gramlich, AInfrastructure Investment: A Review Essay,@ *Journal of Economic Literature*, Vol. 32 (Sept. 1994), pp. 1176-1196.

Tax Distortions and the Marginal Cost of Public Funds

Most cost-benefit analyses proceed as though raising revenue to fund the project under consideration were just a matter of instructing citizens to turn it over, with no other effects on the economy. This would be true of the "lump-sum" taxation of traditional welfare economics. Real taxes, however, are based on citizens' economic decisions and therefore have the potential to alter those decisions. What effect does this potential for distortion have on project evaluation?

A convenient metric for the distortionary effect is the "marginal cost of public funds" (MCF): the total reduction in utility, expressed in dollars, required to raise $1 of revenue for public use (not counting the benefits from spending that money). In comparing costs and benefits of a project, any costs funded by raising taxes should then be multiplied by the MCF that is appropriate for that tax source.

The trouble is, the MCF varies widely according to the way tax revenues are raised, and it is also quite sensitive to assumptions about economic behavior. One study from the 1980s found that the MCF of the raising all U.S. income tax rates proportionally was between 1.21 and 1.74 - that is, it costs consumers between $1.21 and $1.74 to raise $1.00 of new revenue in this way.[66] The range represents alternate assumptions about the elasticity of labor supply and the extent to which project benefits substitute for private consumption.[67] A less progressive tax increase, representing increases in sales, excise, or Social Security payroll taxes, is estimated to have an MCF of only 1.12 to 1.32; whereas a highly progressive increase, obtained by increasing marginal tax rates while holding inframarginal rates constant, costs $1.44 to as high as $2.60 for every dollar of revenue raised.[68]

Clearly, these alternate assumptions about the MCF can make a great deal of difference to the viability of any project financed by public funds. However, it can be argued that progressive

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[66] Edgar K. Browning, "On the Marginal Welfare Cost of Taxation," *American Economic Review*, vol. 77 (March 1987), pp. 11-23. The figures quoted are for two rows in Table 2 labelled *dm/dt*=1.39, which is Browning's estimated ratio between the marginal and average tax rates (p. 19); and for the column labelled *m*=0.43, indicating a 43 percent marginal tax rate, Browning's preferred estimate (p. 21).

[67] The compensated labor supply elasticity was assumed alternately to be 0.2, 0.3, or 0.4. Project benefits were assumed alternately to have no effect on labor supply or to have the same effect as would a cash transfer. The former case would apply if the project benefits are in the form of a public good that is mathematically separable from private goods in consumers' utility functions, whereas the latter case would apply if the project benefits are a perfect substitute for private goods. For clarification of this distinction, see Charles L. Ballard and Don Fullerton, "Distortionary Taxes and the Provision of Public Goods," *Journal of Economic Perspectives*, vol. 6 (Summer 1992), pp. 117-131; and Shaghil Ahmed and Dean Croushore, "The Marginal Cost of Funds with Nonseparable Public Spending," *Public Finance Quarterly*, vol. 24 (April 1996), pp. 216-236.

[68] The "less progressive" example is from Browning's two rows labelled *dm/dt*=0.8 (Table 2), while the "more progressive" example is from the rows labelled *dm/dt*=2.0; see Browning's discussion on p. 19. In both cases I continue to use his intermediate estimate of the marginal tax rate (*m*=0.43); the range is even wider if we vary that parameter as well.

taxation is in place to meet well understood social objectives, and that any changes in the degree of progressivity caused by financing a transportation project will be factored into overall political decisions about income distribution. (This argument parallels that for macroeconomic effects.) Thus it usually makes sense to treat a given project as being funded without changing the overall progressivity of the tax system. In that case, a reasonable approach is to use an intermediate case, in which a tax proportional to income is added to an existing progressive tax structure.[69] That case leads to an MCF of 1.15-1.30 in the case where benefits are separable, and 1.18-1.44 in the case where they substitute for private goods. In the absence of better information, an intermediate value of 1.25 seems reasonable.

Conclusion: Project Evaluation as a Public Choice Process

This chapter covers many of the technical issues needed to provide sound evaluations of transportation projects. But in the end, project evaluation is performed for decision makers, not technicians. As noted in the introduction, the need for formal tools such as cost-benefit analysis arises because proposed projects create conflicting interests. How then can the tools best be used to promote good decisions?

A pessimistic view would be that project evaluation is inevitably corrupted by the interests of those who sponsor it or carry it out. Certainly, ample evidence supports 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.[70]

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:

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[69]   This is Browning's two rows labelled *dm/dt*=1.0 (Table 2); again, I use his middle three columns.

[70]   J.V. Krutilla and Otto Eckstein, *Multiple Purpose River Development: Studies in Applied Economic Analysis* (Baltimore: Johns Hopkins Press, 1958).

> [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.[71]

One justification of the recent interest in legislation requiring cost-benefit analysis of major regulatory actions is to create some new "conditioned reflexes" so that decision-makers consider the complex direct and indirect effects of a regulation.

Another benefit of formal project evaluation is that it can be used to force explicit consideration of alternatives to a project being proposed. 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.[72]

One danger of formal project evaluation is that the results may be used by interest groups to convey a false sense of certainty to their positions. Even decision makers acting in good faith may mistake professionalism for precision. An important antidote to this tendency is to explore the sensitivity of results with respect to important parameters. Even better is to compute the probability distributions of key results, such as net benefits, given assumptions about the joint probability distribution of key parameters. Such a process, known as "risk analysis," can make use of Monte Carlo simulation. Parameter values are drawn randomly from their assumed distribution and results recalculated; the process is then repeated many times in order that the frequency distribution of calculated results approximate their true probability distribution, thereby faithfully representing the effects of the inherent uncertainty in the analysis. It is important to account for any anticipated correlations among uncertain parameters, for example the correlation between projected

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[71]   János Kornai, ₐAppraisal of Project Appraisal,@ p. 95.

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

employment and average income, so that the results are not distorted by what are highly unlikely combinations of parameter values.[73]

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 public involvement in decision making. It combines the technical steps of cost-benefit analysis with educational and consensus-building tools. Lewis's version emphasizes the graphical presentation of probability distributions of 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. In favorable circumstances, Lewis reports, it leads to a surprising degree of consensus.[74] The risk analysis process can make the role of cost-benefit analysis in decision making more explicit, and can result in analysts adapting their technical tools to make them more transparent.

There is a danger that the risk analysis itself could exacerbate the false sense of certainty by suggesting that technical procedures, such as Monte Carlo simulation, can account for every source of uncertainty. The most sophisticated analysis possible may fail to account for such problems as administrative incompetence, undermining by political opposition, unknown geological features, or new inventions that make a project prematurely obsolete. Indeed, it has been argued recently that for developing nations, it is these kinds of factors, affecting the gross performance of the project, that are more important to project success than many of the technical factors of concern to methodologists - including technical factors that are highlighted in the evaluation methodology of the World Bank.[75] Similarly, formal analysis will often miss significant benefits by failing to foresee the many ramifications of a change. This may especially be a limitation in evaluating research and development projects. Could anyone in the 1890s have predicted the ramifications of inventing the automobile?

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[73] Savvakis Savvides, "Risk Analysis in Investment Appraisal," *Project Appraisal*, Vol. 9 (March 1994), pp. 3-18. For a fuller discussion of risk analysis in transportation project evaluation, see Meyer and Straszheim, *Techniques of Transport Planning, Volume One: Pricing and Project Evaluation*, ch. 13. Monte Carlo analysis is recommended by Transport Canada in its *Guide to Benefit-Cost Analysis in Transport Canada*, pp. 85-86.

[74] 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*. No. 16 of *Searching for Solutions: A Policy Discussion Series* (July 1996), pp. 36-40.

[75] Glenn P. Jenkins, "Project Analysis and the World Bank."

Yet another danger of formal evaluation is that it may assume an unrealistically simple structure for the rest of the economy. For example, many public projects that are subjected to cost-benefit analysis will displace private investments. Often the analysis assumes, explicitly or implicitly, that those private investments would take place under conditions of "perfect competition," so that the marginal social values of resources are measured by their prices. But private markets often embody strategic interactions that are far from the classical competitive model. The airline industry is illustrative. As noted by John Meyer and Mahlon Straszheim, and more recently by Gabriel Roth, a criterion of profit maximization may sometimes allocate resources between private and public sectors better than a criterion of net social benefits.[76] It is wise to scrutinize cost-benefit analyses when markets deviate strongly from perfect competition.

Finally, we must remember that, like it or not, project evaluation exists within a political context. The inevitable conceptual difficulties should be made transparent rather than hidden. 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. The best method of presentation is one that makes it possible to understand and justify political decisions that are in the interests of the citizenry at large, while embarrassing those who would make decisions favoring only narrow interest groups.

Appendix: Calculation of the Shadow Price of Capital

The problem with using the weighted average of interest rates r_c and r_i, applying respectively to private consumption and private investment, is that the benefit or expenditure flows needed to obtain the weights should themselves be discounted. Suppose a project displaces $1 million of private investment at its inception, incurs maintenance costs of $50,000 per year (constant dollars) over its 50-year life, and also creates benefits in the form of additional consumption starting at $100,000 per year and rising thereafter at 1 percent per year until the end of its life. Without discounting these future benefits and costs, we cannot say what proportion of the project's effects should be assigned to consumption and what proportion to investment. But

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[76] John R. Meyer and Mahlon R. Straszheim, *Techniques of Transport Planning, Volume One: Pricing and Project Evaluation,* p. 202; Gabriel Roth, *Roads in a Market Economy* (Aldershot, UK: Avebury, 1996), Section 5.3.

without knowing those proportions, we do not know at what interest rate to do the discounting. Thus, the definition of the weighted average contains a circularity.

This circularity can be eliminated by multiplying each public investment expenditure by a *shadow price of capital*, which measures capital's contributions to future consumption.[77] The shadow price of capital takes into account distortions in market prices due to taxes or other factors, and thereby bridges some of the gaps between various observed market interest rates.

The logic is like that of other shadow prices. Consider, for example, how shadow wages are used to account for distortions in market wages due to labor taxation. Suppose labor is diverted from a competitive private labor market into tax-free employment for an international organization; then its opportunity cost is the value of its marginal product in private employment, which is equal to the market wage rate plus any payroll tax paid by private employers. Similarly, suppose capital is diverted from private investment where it would earn a competitive private net rate of return (i.e., the after-tax rate of return). Then its social opportunity cost - the marginal contribution to production it would have made in the private sector - is the net private return plus any income or other taxes it would have generated.[78] What makes capital more complicated than other factors of production is that the taxes are paid in a stream over many years rather than at the time of the initial investment.

The shadow price of capital has been estimated to be 1.5, with a range from about 1.2 to 2.0, for the U.S. in 1989. The calculation goes as follows. Each dollar of investment displaced by the proposed project is assumed to provide an infinite stream of 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 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 of the capital stock, then

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77   This approach was pioneered by David F. Bradford, AConstraints 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, AThe 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, AThe 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.

78   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 income taxes, property taxes, and perhaps sales taxes; but the point applies equally well to all forms of capital. See 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.

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:

- The original capital depreciates to a fraction $1-\delta$ of its value;
- The gross return results in new investment equal to sw;
- The 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 $(1+r_c)^{-1}$ gives the original shadow price V. Thus V is the solution to the equation:

$$V = [(1-\delta+sw)V + (1-s)w]/(1+r_c),$$

which gives the following formula for the shadow price of capital:[79]

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

This value is greater than one, assuming the rate of time preference r_c is less than the net private return $r_i = w-\delta$.

Using a rough estimate of 10 percent for the depreciation rate δ, and 15 percent for the savings rate s,[80] along with our earlier estimates $r_c=0.04$ 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. Recalculating for r_c between 2 and 6 percent and $w-\delta$ between 8.6 and 10.6 percent, we find that 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 $r_i = w-\delta$, a similar argument results in the following shadow price of capital:

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

[79] This equation is given by Randolph M. Lyon, AFederal 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.

[80] As suggested by Boardman et al., *Cost-Benefit Analysis*, p. 172.