THE ANNUALIZED SOCIAL COST OF MOTOR-VEHICLE USE IN THE U. S., 1990-1991: SUMMARY OF THEORY, DATA, METHODS, AND RESULTS

Report #1 in the series: *The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data*

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LIST OF ACRONYMS AND ABBREVIATIONS AND OTHER NAMES

The following are used throughout all the reports of the series, although not necessarily in this particular report

AER = *Annual Energy Review* (Energy Information Administration)
AHS = *American Housing Survey* (Bureau of the Census and others)
ARB = Air Resources Board
BLS = Bureau of Labor Statistics (U. S. Department of Labor)
BEA = Bureau of Economic Analysis (U. S. Department of Commerce)
BTS = Bureau of Transportation Statistics (U. S. Department of Transportation)
CARB = California Air Resources Board
CMB = chemical mass-balance [model]
CO = carbon monoxide
dB = decibel
DOE = Department of Energy
DOT = Department of Transportation
EIA = Energy Information Administration (U. S. Department of Energy)
EPA = United States Environmental Protection Agency
EMFAC = California's emission-factor model
FHWA = Federal Highway Administration (U. S. Department of Transportation)
FTA = Federal Transit Administration (U. S. Department of Transportation)
GNP = Gross National Product
GSA = General Services Administration
HC = hydrocarbon
HDDT = heavy-duty diesel truck
HDDV = heavy-duty diesel vehicle
HDGT = heavy-duty gasoline truck
HDGV = heavy-duty gasoline vehicle
HDT = heavy-duty truck
HDV = heavy-duty vehicle
HU = housing unit
IEA = International Energy Agency
IMPC = Institutional and Municipal Parking Congress
LDDT = light-duty diesel truck
LDDV = light-duty diesel vehicle
LDGT = light-duty gasoline truck
LDGV = light-duty gasoline vehicle
LDT = light-duty truck
LDV = light-duty vehicle
MC = marginal cost
MOBILE5 = EPA's mobile-source emission-factor model.
MSC = marginal social cost
MV = motor vehicle

NIPA = National Income Product Accounts
NO_X = nitrogen oxides
NPTS = Nationwide Personal Transportation Survey
OECD = Organization for Economic Cooperation and Development
O_3 = ozone
OTA = Office of Technology Assessment (U. S. Congress; now defunct)
PART5 = EPA's mobile-source particulate emission-factor model
PCE = Personal Consumption Expenditures (in the National Income Product Accounts)
PM = particulate matter
PM_{10} = particulate matter of 10 micrometers or less aerodynamic diameter
$PM_{2.5}$ = particulate matter of 2.5 micrometers or less aerodynamic diameter
PMT = person-miles of travel
RECS = Residential Energy Consumption Survey
SIC = standard industrial classification
SO_X = sulfur oxides
TIA = *Transportation in America*
TSP = total suspended particulate matter
TIUS = *Truck Inventory and Use Survey* (U. S. Bureau of the Census)
USDOE = U. S. Department of Energy
USDOL = U. S. Department of Labor
USDOT = U. S. Department of Transportation
VMT = vehicle-miles of travel
VOC = volatile organic compound
WTP = willingness-to-pay

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1.1 BACKGROUND

Every year, Americans drivers spend hundreds of billions of dollars on highway transportation. They pay for vehicles, maintenance, repair, fuel, lubricants, tires, parts, insurance, parking, tolls, registration, fees, and other items. These expenditures buy Americans considerable personal mobility and economic productivity.

But the use of motor vehicles costs society more than the hundreds of billions of dollars spent on explicitly priced motor-vehicle goods and services in the private sector. Some of the motor-vehicle goods and services provided in the private sector are not priced explicitly , but rather are *bundled* in the prices of nontransportation goods and services. For example, “free” parking at a shopping mall is unpriced, but it is not costless; the cost is included -- bundled-- in the price of goods and services sold at the mall[1].

In addition to these priced or bundled private-sector costs, there are public-sector costs: the tens of billions of dollars spent every year to build and maintain roads, and to provide a wide range of services that support the use of motor vehicles. These services include police protection, the judicial and legal system, the prison system, fire protection, environmental regulation, energy research and regulation, military protection of oil supplies, and more.

And finally, beyond these *monetary* public and private-sector cost are the *nonmonetary* costs of motor-vehicle use -- those costs that are not valued in dollars in normal market transactions[2]. There are a wide variety of nonmonetary costs, including the health effects of air pollution, pain and suffering due to accidents, and travel time.

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[1]I do not imply that bundling necessarily is inefficient, and that parking, for example, must be priced. This is discussed more later, and in Report #6.

[2]In some cases, one can estimate shadow prices or implicit values of nonmarket goods by using valuation techniques such as hedonic price analysis.

Some of these nonmonetary costs, such as air pollution, are externalities; others, such as travel time in uncongested conditions, are what I will call personal nonmonetary costs[3].

The total national social cost of motor-vehicle use is the sum of all of the costs mentioned previously: explicitly priced private-sector costs, bundled private-sector costs, public-sector costs, external costs, and personal nonmonetary costs. These costs are listed and classified more rigorously in Table 1-1.

Over the past three years, my colleagues and I at the University of California have been doing a detailed analysis of some of the costs of motor-vehicle use in the U.S. In this paper, I explain the purpose of estimating the total social-cost of motor-vehicle use, briefly review recent research, explain the conceptual framework and cost classification, and present and discuss our preliminary cost estimates.

1.2 WHY AN ANALYSIS OF THE SOCIAL COST OF MOTOR-VEHICLE USE IN THE U.S.?

1.2.1 The purpose of a social-cost analysis

Researchers have performed social-cost analyses for a variety reasons, and have used them in a variety of ways, to support a wide range of policy positions. Some researchers have used social-cost analyses to argue that motor vehicles and gasoline are terrifically underpriced, while others have used them to downplay the need for drastic policy intervention in the transportation sector. In any case, social-cost analyses usually excite considerable interest, if only because nearly all of us use motor vehicles.

By itself, however, a social-cost analysis does not determine whether motor-vehicle use is good or bad, or better or worse than some alternative, or whether it is wise to tax gasoline or restrict automobile use or encourage travel in trains. Rather, a social-cost analysis is but one of many pieces of information that might be useful to transportation analysts and policymakers.

A social-cost analysis can provide several kinds of information, which can be used for several purposes. A social-cost analysis can provide: i) general cost data, references, methods, and cost models[4]; ii) marginal unit-cost estimates derived from detailed cost models (e.g., $/kg of pollutant emitted; see Appendix A); and iii) simple estimates of total cost and average cost (which is total cost divided by total quantity). These data, models, unit costs, and results can help analysts: i) evaluate the costs of transportation projects, policies, and long-range scenarios; ii) establish efficient prices

[3]Also, some of the monetary costs included in the $800 billion of private expenditure actually are externalities. I discuss this more below.

[4]Cost models relate total dollar cost to transportation quantities, such as vehicle-miles of travel, trips, vehicles, fuel consumption, highway-miles, or parking spaces, and to non- transportation parameters, such as weather or geography.

for and ensure efficient use of transportation services and commodities; and iii) prioritize research and funding.

Use #1: *Evaluate the costs of transportation projects, policies, and long-range scenarios.* In cost-benefit analyses, policy evaluations, and scenario analyses, analysts must quantify changes to and impacts of transportation systems. The extent to which a generic national social-cost analysis can be of use in the evaluation of specific projects or policies depends, of course, on the detail and quality of the social-cost analysis. At a minimum, a detailed, original social-cost analysis can be mined as a source of data, methods, and models for cost evaluations of specific projects. Beyond this, if costs are a linear function of quantity, and invariant with respect to location, then estimates of national total or average cost, which any social-cost analysis will produce, may be used to estimate the incremental costs for specific projects, policies, or scenarios[5]. (Average-cost estimates are more likely to be useful for long-range, broad-brush scenario analysis than for specific project evaluations.) Otherwise, analysts must estimate the actual nonlinear cost functions for the project, policy, or scenario at hand. Our own social-cost analysis does develop total-cost models for noise, air pollution, accidents, and a few other components of the social cost[6].

It turns out that most total cost functions for transportation services, commodities, and impacts are nonlinear and location-dependent. For example, the nonmonetary costs of air pollution are a nonlinear function of motor-vehicle pollution, and congestion delay costs are a nonlinear function of motor-vehicle travel. Both vary with time and location.

Still, even though most costs of motor-vehicle use are not strictly a continuous linear function of quantity, down to the mile or gram or decibel or minute[7], in at least

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[5]The average unit cost is equal to the total cost of the entire system divided by some measure of total use (quantity, or output), and so is expressed in terms of $/vehicle-mile of travel (VMT), $/trip, $/vehicle, etc. The marginal or incremental unit cost is the cost of an increment to the total system divided by the incremental quantity. Given this, we may scale our estimate of the total social cost of the entire system to an estimate of the cost of an increment to the system only if average unit costs are close to marginal unit costs.

[6]Ideally, we would estimate, for every quantity (pollution, VMT, trips, vehicles, parking spaces..), functions that relate the social dollar cost to the quantity, and that include all the parameters that might be relevant in any situation, so that we could calculate the social cost of any small, realistic, specific change in motor-vehicle use. And in many of the important cases, we actually have done this: for example, we have cost/quantity functions for noise, air pollution, accidents, and some government services. These total cost *functions*, in which a cost such as air pollution is a continuous, often nonlinear function of an "output" such as emissions, can be used directly to estimate the cost of any size change in the output. In some other cases (e.g., the cost of home garages), we have provided an estimate of marginal rates where we know them to be different from average rates. In many other cases, though, we did not estimate total cost functions or total costs based on marginal rates, mainly because we did not have the resources to do so.

[7]Strictly speaking, only the private running costs of motor-vehicle use -- gasoline, oil, tires, and engine wear -- are continuous, immediate, approximately linear functions of mileage.

some scenarios of relatively large changes in motor-vehicle use the average-cost ratio might be a serviceable approximation of the actual *long-run* [8] marginal ratio of interest. For example, our own analysis of the health costs of air pollution, in Report #11, reveals that, in most cases, there is not a great difference between the nonlinear dose-response functions that we use and a linear dose-response function.

Appendix A discusses further the use of social-cost estimates to evaluate the costs of transportation projects, policies, and long-range scenarios.

Use #2: *Establish efficient prices for and ensure efficient use of* those transportation resources or impacts that at present either are not priced but in principle should be (e.g., emissions from motor vehicles) or else are "priced" but not efficiently (e.g., roads).

An efficient price is equal to marginal cost, which is the slope of the total-cost function. Hence, any cost *models* in a social-cost analysis in principle may be employed to estimate marginal-cost prices. (As mentioned above, we have estimated total-cost functions for some of the many cost items in our own social-cost analysis.) Beyond this, the average-cost results of a social-cost analysis might give analysts some idea of the magnitude of the gap between current prices (which might be zero, as in the case of pollution) and theoretically optimal prices, and inform discussions of the types of policies that might narrow the gap and induce people to use transportation resources more efficiently. And to the extent that total-cost functions for the pricing problem at hand are thought to be similar to any simple linear national cost functions of a social-cost analysis, the average-cost results of the national social-cost analysis may be used to approximate prices for the problem at hand.

Use #3: *Prioritize efforts* to reduce the costs or increase the benefits of transportation. The total-cost or average-cost results of a social-cost analysis can help analysts and policymakers rank costs (is road dust more damaging than ozone?), track costs over time (is the cost of air pollution going down?), and compare the costs of pollution control with the benefits of control (are expenditures on motor-vehicle pollution control devices greater or less than the value of the pollution eliminated?). This information can help people decide how to fund research and development to improve the performance and reduce the costs of transportation. For example, if one is considering funding research into the sources, effects, and mitigation of pollution, it

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[8] I emphasize "long run" because in some cases average cost exceeds marginal cost in the short run. In the short run, lagged costs and fixed costs are not foregone. Consider, for example, the effects on highway-patrol costs of a small reduction in motor-vehicle traffic. If the reduction in travel is very small, it is likely that nobody will notice. Even if public officials notice, they might not care. Even if they care, it will take them a while to act, through the budgetary and political process. And even when they act, they probably will not be able to recover immediately some sunk (but now under-used) capital and infrastructure (some capital can be sold off or converted to other uses immediately, but some can not). Thus, even though one might calculate an overall *average* cost of the highway patrol $X/VMT/year, one cannot expect to save $X if VMT is reduced by one mile in a year.

might be useful to know that road-dust particulate matter might be an order of magnitude more costly than is ozone attributable to motor vehicles.

I present our analysis and estimates with these relatively modest purposes in mind[9], not to promote a particular policy agenda regarding the use of motor vehicles, and certainly not to forward any particular position about what, for example, gasoline taxes "should be", or whether the nation should invest more or less in motor-vehicle use than it is now.

1.2.2 The context

Interest in full social-cost accounting and socially efficient pricing has developed relatively recently. From the 1920s to the 1960s, major decisions about building and financing highways were left to "technical experts," chiefly engineers, who rarely if ever performed social cost-benefit analyses. Starting in the late 1960s, however, "a growing awareness of the human and environmental costs of roads, dams, and other infrastructure projects brought the public's faith in experts to an end" (Gifford, 1993, p. 41). It was a short step from awareness to quantification of the costs not normally included in the narrow financial calculations of the technical experts of the past.

Today, the call for full-social-cost accounting and efficient pricing is being sounded in many sectors of the economy, from transportation to the chemical industry (e.g., Popoff and Buzzelli, 1993). In transportation, discussions of efficient pricing and full-social cost accounting now are routine. For example, in a recent summary of views on high-speed ground transportation in the U. S., two of the four authors suggest that the cost of high-speed rail (HSR) should be compared with the full, unsubsidized costs of the alternatives, including auto and air travel (Stopher, 1993; Thompson, 1993).

Not surprisingly, however, there is little agreement about the proper items in a social-cost analysis, the magnitude of the major components of the social cost, or the extent to which present prices are not optimal. On the one hand, many recent analyses argue that the "unpaid" or external costs of motor-vehicle use are quite large -- perhaps hundreds of billions of dollars per year -- and hence that automobile use is heavily "subsidized" and underpriced (e.g., MacKenzie et al., 1992; Miller and Moffet, 1993; Behrens et al., 1992; California Energy Commission, 1994; Apogee Research, 1993; COWIconsult, 1991; KPMG Peat Marwick Stevenson & Kellog, 1993; Ketcham and Komanoff , 1992; Litman, 1994). But, not unexpectedly, others have argued that this is not true. For example, the National Research Council (NRC), in its review and analysis of automotive fuel economy, claims that "some economists argue that the societal costs of the 'externalities' associated with the use of gasoline (e.g., national security and environmental impacts) are reflected in the price and that no additional efforts to reduce automotive fuel consumption are warranted" (NRC, 1992, p. 25). In support of

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[9]To this list one perhaps might add a fourth: simply to know what the costs are now and were in the past. However, this is an additional purpose only if the knowledge is valued intrinsically, and not instrumentally. If the knowledge is valued instrumentally, then its *use* must be one of the three described above.

this, the NRC cites the following statement by Michael Boskin, chairman of the Council of Economic Advisors at the time (July 10, 1991):

> "With respect to the price of gasoline, the issue is really what the difference is between social cost and private cost. We already have a substantial amount of taxation at the Federal and State levels and there will be phased in increases in the Federal gasoline taxes...The Administration has no belief that externalities or social premiums that ought to be paid go beyond what's already on the books and scheduled to be implemented over the next year or so" (in NRC, 1992, p. 25)[10].

Green (1995) makes essentially the same argument. Beshers (1994) makes the narrower claim that road-user tax and fee payments at least equal government expenditures related to motor-vehicle use. Similarly, in a November 1992 election in California, supporters of a proposition that would have prevented the State of California from charging tolls on toll roads after 35 years argued that the tolls would be superfluous because "gas taxes are set at a level to pay for needed improvements -- but no higher" (Lockyer and Hill, 1992, p. 19). Opponents countered that "subsidies to the automobile total $300 billion in the United States every year. Less than two-thirds of the cost of our federal highway system is paid for by user fees such as gas taxes...Highway users should have to pay for the cost of building, operating, and maintaining the highways" (Thompson and Tomlach, 1992, p. 19). But Dougher (1995) actually argues that road-user payments exceed related government outlays by a comfortable margin.

I could cite other examples. This extraordinary disagreement exists because of the wide range of conceptual frameworks, methods, data, and assumptions. Although there are detailed, original, and conceptually correct analyses of individual cost items (e.g., air pollution [Small and Kazimi, 1995; Krupnick et al., 1997], and accidents [Miller et al., 1991]), analyses of costs in particular localities in the U. S. (e.g., Apogee Research, 1994); original and conceptually correct analyses of the external costs of transport in Europe [e.g., Mayeres et al. [1996]), and detailed but old analyses of the social costs of transportation in the U. S. (e.g., Keeler et al. [1975]), nobody has done a detailed, up-to-date, conceptually sound analysis of all of the major costs in the U.S. With few exceptions, the recent estimates in the current literature are based on literature reviews, often studies that are relatively old, or superficial, or of limited applicability. Moreover, some of the current work is confused about the meaning of "externality," "opportunity cost," and other economic concepts. As a result, the current literature is of limited use to policymakers and analysts.

In light of this, my colleagues and I set out to do original, methodologically sound estimates of many of the major components of the total social cost of motor-vehicle use. We devoted considerable effort to developing a conceptually coherent framework, gathering the best primary data, and using appropriate analytical methods.

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[10]It is doubtful that Boskin or any one else in the Bush Administration could have backed this obviously ideological belief with good analysis -- mainly because the belief most likely is false.

1.3 THE CONCEPTUAL FRAMEWORK

1.3.1 The annualized cost of motor-vehicle use in the U.S.

When I speak of the social cost of motor-vehicle use, I mean *the annualized social cost of motor vehicle use in the U.S. based on 1990-1991 cost levels* [11]. The annualized cost of motor-vehicle use, based on 1990-1991 data, is equal to the sum of:

- 1990-1991 periodic or "operating" costs, such as fuel, vehicle maintenance, highway maintenance, salaries of police officers, travel-time, noise, injuries from accidents, and disease from air pollution; plus
- the 1990-91 replacement value of all capital, such as highways, parking lots, and residential garages (i.e., tems that provide a stream of services), converted into an equivalent stream of annual costs (annualized) over the life of the capital, on the basis of real discount rates[12].

[11]Originally I conceived of this project as "the social cost of motor-vehicle use in 1990-1991," rather than as "the annualized social cost of motor-vehicle use, based on 1990-1991 data". It turns out, however, that it is not straightforward to define what one means exactly by the "social cost of motor-vehicle use *in* 1990-1991," and that the most logical definition of this is too unusual analytically to be useful. In Report # 2, I discuss several frameworks for estimating the social cost of motor-vehicle use, and explain why I did not frame my analysis as "the social cost of motor-vehicle use in 1990-1991".

[12]We use a real (inflation-free) interest rate to amortize capital costs because we want to have the results in terms of 1990-1991 prices. If we had used a nominal (with-inflation) interest rate to amortize capital, then we would have had to have inflated the periodic costs (operation and maintenance costs) to future levels, in accordance with the inflation expectations incorporated into a nominal interest rate. This is because the periodic costs and the amortized capital costs must be in the same terms: either 1990-91 prices, or 1990-91 prices inflated. It is simpler to use a real interest rate, and keep the analysis in terms of 1990-91 prices, than to have to inflate current 1990-91 periodic prices in order to have the analysis in terms of inflated prices.

There is a complication, however. Technically, if we use a real interest rate to amortize capital costs, then we should not estimate any 1990-91 costs on the basis of observed 1990-91 prices, because those prices included a *nominal* (rather than a real) interest component. Consider, for example, the price of gasoline. A part of the price of gasoline is the cost of refining; a part of the cost of refining is amortized capital cost; a part of amortized capital cost is interest cost, determined by the nominal interest rate; and a part of the nominal interest rate is the expected inflation rate. Thus, when we calculate the cost of gasoline on the basis of 1990-91 prices, we incorporate a nominal-interest-rate component. Strictly speaking, this is inconsistent with the use of a real interest rate to amortize 1990-91 capital value. However, to estimate real 1990 costs, on the basis of a real interest rate, we would have had to disentangle the interest component of every 1990 cost (such as gasoline), and then recalculate the cost using an inflation-free interest rate. We did not do this.

This annualization method -- whereby the total yearly cost is equal to periodic "operations and maintenance costs" plus annualized capital replacement costs -- is just the obverse of evaluating the net present value of alternative investment options (in transportation or any other arena). In essence, the yearly social-cost of motor vehicle use, as we estimate it, is the yearly cost stream of the whole motor-vehicle system, analyzed as if it were one large transportation alternative among several. Of course, the *scale* that we have chosen -- all motor-vehicle use -- is just a convenient point of reference. (That is, one just as well could view the analysis presented here as an analysis of a generic motor-vehicle-use project, or alternative, scaled up to the level of all motor vehicle use in the U. S.)

In any event, there is no coherent alternative to the annualization (or net-present-value) approach to estimating the social cost. Either one performs a social-cost analysis as a project evaluation, or one doesn't have a well-defined analysis[13]. If (somehow) we fail to amortize capital costs, or do so incorrectly, or in general don't treat capital and operating costs in an economically consistent fashion, we will not have economically meaningful results, and might then incorrectly evaluate alternatives or mis-price goods and services. Although these concepts are quite elementary, in practice it can be easy to lose sight of them, and misapply widely used data, such as the FHWA data on capital expenditures (see the discussion in Report #2).

1.3.2 What counts as a cost of motor-vehicle use or infrastructure?

In economic analysis, "cost" means "opportunity cost". The opportunity cost of action A is the opportunity you forego -- what you give up, or use, or consume as a result of doing A. For some resource R to count as a cost of motor-vehicle use, it must be true that a change in motor-vehicle use *will result* in a change in use of R. Thus, gasoline is cost of motor-vehicle use because a change in motor-vehicle use will result in a change in gasoline use, all else being equal. But general spending on health and education is not a cost of motor-vehicle use because a change in motor-vehicle use will not result in a change in resources devoted to health or education.

However, for the purposes of planning, evaluating, or pricing, we care not only whether something is a cost of motor-vehicle use, but, if it is a cost, exactly how it is related to motor-vehicle use. For example, pollution is a direct, immediate cost of motor-vehicle use: you change motor-vehicle use a little, and you immediately change pollution a little. But defense expenditures in the Persian Gulf, if they are a cost of motor-vehicle use at all, are an indirect, long-term, and tenuous one. This is discussed more below.

1.3.3 How to interpret "the cost of *all* motor-vehicle use in the U.S."

If one wishes to apply the estimates of the total cost of all motor-vehicle use, or to understand the basis for deciding what is included in our list of costs in Table 1-1,

[13]One can estimate the net present value rather than the annualized cost of a project, but these are economically equivalent methods.

then one might ask what is meant by the cost of *all* motor-vehicle use: all motor-vehicle use compared to what?

In normal cost-benefit analysis of transportation projects, one estimates costs and benefits relative to a well defined "no-project" alternative, or base case. For example, one might compare a highway-expansion project with a light-rail project relative to a base case of "business as usual" improvement in the management of the existing infrastructure[14]. But if the "project" is all motor-vehicle use, what is the base case -- the world without motor-vehicle use?

In this analysis, the world without motor-vehicle use is presumed to be the same as the world with motor-vehicle use, *except* that in the former people don't use motor-vehicles. This means that the benefits of motor-vehicle use -- the access provided -- are presumed to be the same in both worlds. Put another way, the total social cost of motor-vehicle use is the welfare difference between the present (ca. 1991) motor-vehicle system, and a system that provides exactly the same services (that is, moves people and goods too and from the same places as do motor vehicles) but without time, manpower, materials, or energy -- in short, without cost[15].

This costless transportation baseline is just a frame of reference, a conceptual baseline with respect to which total costs trends can be estimated, or the total costs of one system (say, passenger vehicles) compared with the costs of another (say, passenger trains). Moreover, it is relevant only to understanding the meaning of the total cost estimates themselves; it is not relevant if one is interested specifically in the data, methods, and marginal-cost models of the social-cost analysis, for the purpose of estimating efficient prices (say, for motor-vehicle emissions), or doing cost-benefit analysis of specific projects.

This last point, obvious though it may be, probably cannot be overemphasized. If one is interested in, say, establishing Pigovian taxes to internalize the damages from motor-vehicle emissions, then one probably will wish to examine the details of the damage-function model that produces estimates of the $/kg cost of emissions, as a function of the change in emissions. One will not care about our estimate of the total dollar damages due to air pollution from motor-vehicles in 1990. Thus, insofar as one is interested in the details of our analysis, and not in the total-cost estimates themselves, the question "total cost compared to what?" never arises.

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[14]Of course, one must be more specific about the base case than this, because the estimated costs and benefits will depend greatly on the details. A day-time parking-management plant that reduces VMT by 10% will result in costs and benefits quite different from those of, say, a congestion pricing scheme on a toll bridge that also reduces VMT by 10%.

[15]Of course, if there were a costless transportation system, people would make more and longer trips, and settlement would be more dispersed. Conceptually, I ignore this effect in the baseline "no-motor-vehicle" case.

1.3.4 Benefits versus costs

In this project, we estimate the dollar social cost but not the dollar social benefit of motor-vehicle use. More precisely, we identify, classify, and quantify many of the impacts and resources of motor-vehicle use[16]. The social cost of motor-vehicle use is the value of the resources devoted to motor-vehicle use. (In this context, "resources" should be broadly construed to include health, esthetic, environmental, and similar impacts of motor-vehicle use.) In Figure 1-1, the total social cost is the area under the social supply curve, S* (region O-x*-Q* if we are at the social optimum, with all externalities internalized; region O-x'-Q if we are at the private market optimum, with external costs extant).

The social benefit of motor-vehicle use is the value that beneficiaries ascribe to motor-vehicle use -- in economic parlance, the total "willingness to pay" for motor-vehicle use. Total willingness to pay is the area under the demand curve, D, of Figure 1-1 (region O-A-x*-Q*). The difference between the total benefit and the total cost, region O-A-x* of Figure 1-1, is the net benefit of motor vehicle use. (The net benefit can be negative, of course.) Net social benefit, or the ratio of social benefit to social cost, is the ultimate measure of economic worth. In cost-benefit analysis, the preferred package of policies or investments is the one that generates the highest net benefits for the available budget[17].

Again, ours is a cost analysis, not a cost-benefit analysis. Of course, we have not forgotten that there are benefits of motor-vehicle use[18], and certainly have not presumed that the benefits somehow are less important than the costs. To the contrary, as I discuss in Report #20, it is obvious that motor-vehicle use is enormously beneficial, and that its total social benefit vastly exceeds its cost[19]. The problem is that, although it is possible to estimate the benefits of small changes in motor-vehicle use, it is very difficult to estimate credibly the benefits of *all* motor-vehicle use. The root of the problem is that we do not know what the total demand curve looks like near zero quantity: trips by car for which there are no good substitutes must be extremely valuable, but precisely how valuable we don't know. Because this is a cost analysis only, we are unable to say much about net dollar benefits or cost-benefit ratios, or whether a particular transportation system or plan is worthwhile, or better or worse

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[16]We hope that we have at least *identified* virtually all of the costs of motor-vehicle use.

[17]For a general review of cost-benefit analysis, see Mishan (1976). For a recent discussion of some of the more problematic aspects of cost-benefit analysis, including valuation of non-market goods, ecosystem complexity, the social rate of discount, irreversibilities, and efficiency versus equity, see Hanley (1992).

[18]Social-cost analysts sometimes are accused of ignoring or dismissing the benefits of motor-vehicle use (e.g., Green, 1995;*Science News* , June, 1993) .

[19]Moreover, it is worth noting that in some places automobiles are more environmentally benign than the transportation modes (e.g., horse-drawn carriages) that they have replaced (Button, 1993).

than another system or plan. For example, this analysis indicates that motor-vehicle use might cost us more than people realize; that is, that the total social cost appreciably exceeds the commonly recognized private cost. But even if this is so, it does not mean that motor-vehicle use costs society more than it is worth, or that we should prefer any transportation option that might have near-zero external costs, or even any transportation option that might have lower total social costs. To make such choices, one must estimate the dollar value of all the benefits as well as the dollar value of all the costs, for all of the relevant policies or investment alternatives.

1.3.5 Some minor conceptual issues.

There are other minor conceptual issues worth mentioning. One is that the cost/quantity function for increases in motor-vehicle use might be different than for decreases. Another is that for some of the government services (say, police protection) that support motor-vehicle use, long-run cost might be a non-linear function of some measure of cost-related activity (say, crimes or arrests). In the extreme, cost might be a step-function of activity, such that over some range of activity, the cost of changes in activity might be zero. But one should be careful here, because many small changes in activity, each change by itself not large enough to reach the next cost step, may together create enough additional use to reach the next cost step. Put another way, the problem with assuming that any particular change does not have a cost is that, in the absence of information to the contrary, the starting point for any change is just as likely to be very close to the next cost step as very far, which means that it is just as likely that an infinitesimal change in use will occasion the entire cost of the step as a much bigger change in use will occasion no cost at all. To avoid this mistake, an analyst should treat a step function as a continuous function, which is tantamount to using average cost as a proxy for marginal cost over the relevant range. This is an advantage of an average-cost analysis.

1.3.6 Classification of components of the total social cost

There are *many* components of the social cost of motor vehicles use, and one naturally has the urge to classify them. But should these components be classified or organized in any particular way? It seems sensible to organize cost components in consonance with how the cost estimates will be used. Thus, if one were interested *only* in estimating the total social cost of motor-vehicle use, and did not care at all about how the estimates might be used, then actually one would not need to categorize the components of the social cost. One would just estimate and perhaps add up every component of the social cost. This, however, would not be of much use to anybody.

As discussed above, estimates of total social cost of motor-vehicle use legitimately can be used for three purposes: i) to evaluate the costs of transportation projects, policies, and long-range scenarios; ii) to establish efficient prices for and ensure efficient use of transportation services and commodities; and iii) to prioritize research and funding. Of these uses, only the second one, *efficiency of use* , comes with a set of principle and conditions -- namely, the conditions of efficient resource use -- that can be used to categorize costs. Consequently, if one wishes one's social-cost estimates to be useful to policymakers who want improve the efficiency of the use of the transportation system[20], then one should categorize and analyze cost items with respect to the economic efficiency of their production or consumption. I have done so here.

In Table 1-1, I also use other organizing criteria, such as whether or not a cost is valued in dollars (this is discussed more below), and end up with six categories of costs. Of course, one could come up with other classifications, even using the same general organizing principles. One could, for example, merge or split some of my categories.

Classification with respect to the efficiency condition marginal social value equals price equals marginal social cost. Resources are used efficiently when the marginal value to society (MSV) equals the market price (P) equals marginal cost to society (MSC). However, most real markets do not allocate resources efficiently, according to MSV = P = MSC, because at a minimum most production and consumption involves some sort of externality, and most prices are influenced by distortionary (non-optimal) taxes. In fact, there are a variety of reasons that a market might not allocate resources optimally, or what is worse, why no private market might exist. *These reasons -- the reasons for inefficiencies -- are a natural organizing principle for a social-cost analysis, because there are prescriptions for every kind of inefficiency*. To organize costs with respect to efficiency or inefficiency of allocation is tantamount to organizing costs with respect to prescriptions for maximizing efficiency. This is useful to policymakers.

In Appendix B, I review the conditions required for markets to exist and allocate resources efficiently, and what happens if the conditions are not met. Here, I emphasize an important general point. It is generally true that, for society to use resources efficiently, each individual who makes a resource-use decision must count as a cost of that use everything that in fact is an opportunity cost from the standpoint of society. It does not matter whether or not motor-vehicle users *as a class* pay for a particular cost generated "within" the class; what matters is whether or not each individual decision maker recognizes and pays the relevant social marginal-cost prices. If the responsible individual decision maker does not account for the cost, it does not matter then who actually pays for it, fellow user or non-user; the resource [usually] is misallocated, regardless of who pays.

To account for a cost, a consumer must know its magnitude and be required or feel obliged to bear it. Generally, a *price* accomplishes both of these things: it tells the consumer what he must give up in order to consume the item[21].

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[20]I recognize, of course, that policy makers rarely if ever are concerned solely with maximizing economic efficiency or social net welfare, and often seem utterly unconcerned about it. Unquestionably, matters of distribution -- who gets what, who wins and who loses -- loom larger in the political arena. I leave out such distributional issues not because they are unimportant, but because efficiency is an interesting enough topic itself, and easily distinguished conceptually from equity.

[21]Although a market price on an item is sufficient to make a consumer account for the item in his decision making, in principle it is not necessary. What is necessary is that one way or another the consumer know and bear the cost. A cost can be "borne" abstractly, as, for example, a feeling of guilt.

This emphasis on price, and on individual resource-use decisions, keeps the analysis properly focused on economic efficiency. In an analysis of efficiency, one must not think of motor-vehicle users as a class, and imagine that the distinction between users and non-users *as a class* is relevant. It is not. The class distinction may be relevant to questions of equity, but it certainly is not relevant to questions of efficiency[22].

A methodological organizing criterion. I have included in Table 1-1 a classificatory criterion that has to do not with economic efficiency, but rather with methods of estimating costs: "monetary" versus "nonmonetary" costs. The distinction here is *not* between cost items that "ought" to be valued in dollars and costs that ought not, nor between efficiently and inefficiently priced items, but rather between cost items that are traded in real markets and hence valued directly in dollars, and items that are not.

Although this distinction is not directly relevant to efficiency of resource use, it is relevant to the practical estimation of social cost. Abstractly, the social cost of any item X (tires, roads, disturbance by noise, suffering from asthma caused by air pollution...) is equal to the quantity of X (number of tires, miles of roads, excess decibels of exposure, days of suffering asthma) multiplied by the unit cost of X ($/tire, $/road-mile, $/excess decibel, $/day of suffering). In Table 1-1, the distinction between "monetary" and "nonmonetary" costs pertains to the estimation of the $/unit part of the calculation of social costs. An item is classified as a "monetary" cost if we can observe or estimate its $/unit cost (or value) directly from market transactions. Thus, because we can observe the $/unit cost of tires, and the $/mile cost of building roads, tires and roads are classified as monetary costs. By contrast, we cannot observe directly the unit cost of noise or air pollution ($/decibel, or $/day of suffering), because noise disturbance and suffering per se are not traded and valued in markets[23].

Thus, in principle, pollution could be satisfactorily accounted for in consumer decisions if everyone knew all the costs of pollution and cared enough to act as though they paid the costs in dollars.

[22]Indeed, thinking in terms of classes often will lead one to the wrong answer. For example, it might seem at first glance that because congestion costs are "internal" to -- borne entirely by -- motor-vehicle users as a class, there is no imperative to do address them. However, when one person slows down another and does not account for the imposed delay, the resulting congestion, or delay, is an externality, and hence a source of economic inefficiency. In an analysis of efficiency, it does not matter that in this case motor-vehicle users as a class might bear all of the consequences; the point is that if there is a delay externality, then the motor-vehicle users *themselves* are using their motor vehicles inefficiently, and can improve their total welfare if each person has to account for his or her effect on the travel time of others. To maximize the net social benefits of motor-vehicle use we must eliminate *all* externalities, not just those that affect the class of "non users" (however defined).

[23]However, protective or ameliorative measures, such as ear plugs or asthma medicine, often are valued in markets. Ideally, one would distinguish these as monetary externalities. Moreover, the entire cost of crop loss due to motor-vehicle air pollution, which I have classified as a nonmonetary cost, actually is a market cost, and hence should be classified as a monetary externality. However, not only is it difficult in most cases to quantify the monetary-cost components of air-pollution and noise, it seems more natural to classify all of the costs of pollution in one place, as non-monetary externalities. And in any

The distinction is methodologically important because (obviously) it is much more difficult to estimate the $/unit cost of nonmonetary items than of monetary items[24]. Although economists have a variety of techniques (e.g., hedonic-price analysis and stated-preference analysis) to estimate the $/unit costs of (or demand curves for) nonmonetary items, all of the techniques can be problematic, and as a result the social nonmonetary costs of motor-vehicle use often are very uncertain -- typically, much more uncertain than are the monetary costs[25].

Other conceptual and methodological issues are explored in more detail in Report #2 of this social-cost series (see the list at the beginning of this report). I turn now to the six general cost categories of Table 1-1.

1.4 COMPONENTS OF THE SOCIAL COST OF MOTOR-VEHICLE USE

1.4.1 Column 1 of Table 1-1: Personal nonmonetary costs of motor-vehicle use.

Personal nonmonetary costs are those unpriced costs of motor-vehicle use that a person imposes on herself as a result of her decision to travel. The largest personal costs of motor-vehicle use are personal travel time in uncongested conditions, and the risk of getting into an accident that (loosely speaking) involves nobody else.

Note the distinction between personal nonmonetary costs (column 1) and externalities of the same sort (column 6). Personal costs are caused and borne by the same party, whereas externalities are imposed by one party on another but not accounted for by the imposing party. The [expected value of the] risk that I will cause an accident and injure myself is a personal nonmonetary cost; the risk that someone else will injure me is an external risk, if the other person does not account for it. The congestion delay that others impose on me is an external cost; the *rest* of my travel time

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event, failure to distinguish all monetary costs does not undermine the classification with respect to economic efficiency, because from the perspective of efficient resource allocation and proper pricing there is little difference between a monetary externality and a non-monetary externality.

Why then bother to distinguish monetary from non-monetary externalities at all? One reason, explained in the text, is that non-monetary externalities usually are harder to estimate and more uncertain. A second reason is that some public-sector infrastructure and service costs can be considered to be monetary externalities, and hence to straddle the public-sector and the monetary-externality categories. If we do not distinguish monetary from non-monetary externalities, then some of the public infrastructure and service costs, such as fire protection, will straddle the category that includes environmental externalities, such as global warming. This seems too much of a stretch; it is better to separate public-sector costs from environmental externalities by having an intermediate category called "monetary externalities".

[24]It also may be that monetary costs are more significant politically because they are more tangible economically.

[25]Of course, some monetary costs also are difficult to estimate and very uncertain. An example is the GNP loss due to a sudden change in the price of oil.

is a personal nonmonetary cost. These distinctions are relevant to policy making because personal costs are unpriced[26] but efficiently allocated if consumers are informed and rational, whereas externalities are unpriced and inevitably a source of inefficiency[27]. As discussed below and indicated in Table 1-2, the usual prescription for externalities is a Pigovian[28] tax, whereas the "prescription" for a personal cost (whether caused by the affected party or not) is just that the affected party be fully aware of it. Thus, any individual should be charged for the accident or travel time costs he imposes on others, *and* be fully aware of the costs that he himself faces as a result of using a motor-vehicle.

If an individual does not correctly assess the personal costs to himself, then he will consume more or less than he would have had he been fully informed and rational. For example, there is evidence that most drivers overestimate their alertness and driving skill, and underestimate their chances of getting into an accident (DeJoy, 1989). To the extent that they do, they underestimate the expected personal cost of driving, and make more trips, or more risky trips, then they would if they were properly apprised of their abilities and chances.

Report #2 in this series contains further discussion of the classification and interpretation of personal nonmonetary costs. In that report, I note that it is more sensible to classify the costs of drunk driving and motor-vehicle crime not as external costs within a framework of economic efficiency, but as costs of immoral and illegal behavior, within a broader framework that classifies costs by non-efficiency as well as efficiency concerns.

Personal nonmonetary costs are estimated in Report #4 of this social-cost series. Appendix C of this report provides an overview of some of the concepts, data, and estimation methods for some of the cost items in this column.

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[26]Explicit prices, which mediate transactions between buyers and seller, obviously are not necessary if the "buyer" and "seller" are one and the same -- that is, if there is no exchange, or no market, as in the case of personal nonmonetary costs. Thus, the absence of an explicit price is not relevant. (One might say that personal costs are implicitly or "internally" priced by travelers.)

[27]I recognize, though, that the distinction between personal nonmonetary costs and nonmonetary externalities is awkward to the extent that it is not realistic psychologically. In reality, if a motor-vehicle user accounts for, say, exposure to noise and the risk of an accident, she does not necessarily distinguish between the noise or risk that she is responsible for and the noise and risk imposed by others. Rather, she probably makes a qualitative judgment about overall exposure to noise and risk.

[28]Named after the English economist A. C. Pigou, who made significant contributions to the economic analysis of social welfare.

1.4.2 Column 2 of Table 1-1: Motor-vehicle goods and services priced in the private sector (estimated net of producer surplus and taxes and fees).

The economic cost of motor-vehicle goods and services supplied in private markets is the area under the private supply curve: the value of the resources that a private market allocates to supplying vehicles, fuel, parts, insurance, and so on.

However, we do not observe the supply curve itself, and so cannot estimate the area under the supply curve directly. Rather, we must estimate this area indirectly, starting from what we can observe: total price-times-quantity revenues. Thus, the private-sector resource cost under the supply curve is equal to price-times-quantity revenues minus producer surplus and taxes and fees. We deduct producer surplus[29] because it is defined as revenue in excess of economic cost, and hence is a non-cost wealth transfer from consumers to producers[30]. We deduct taxes and fees assessed on producers and consumers because in no case are they marginal-cost prices that can be used in a price-times-revenue calculation of costs[31].

Note that this is not merely theoretical twaddle: it bears directly on comparisons of alternatives. For example, in comparing the cost of oil with the cost of alternative energy sources, it will not do to count all price-times-quantity oil revenues as the cost, because the true private resource cost is much less than this, on account of the enormous producer surplus that accrues to some oil producers.

The prices and quantities that obtain in private markets rarely are optimal -- that is, the actual prices (P) paid rarely satisfy MSV = P = MSC -- not only because of distortionary taxes and fees, but because of imperfect competition, standards and regulations that affect production and consumption, price controls, subsidies, quotas, externalities, and poor information. For example, the market for crude oil is not always competitive. The reason, of course, is that the Organization of Petroleum Exporting

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[29]In most cases, we do not have good data on producer surplus, and simply estimate it as a fraction of price-times-quantity revenues. Often, our estimate of this fraction is little more than our educated guess.

[30]However, a net (equilibrium) transfer from U.S. consumers to foreign producers is a real cost to the U.S.

[31]Recall that the point here is to estimate private-sector resource cost. The cost of the private-sector resources devoted to, say, making gasoline, does not include the federal and state gasoline tax, because that tax is a charge for the use of the roads, not part of the marginal-cost price of making gasoline. But why not then use the gasoline tax as an estimate of the cost of the roads, just as one uses price-times-quantity payments (less producer surplus) to estimate private-sector resource cost? There are two reasons. First, we have data on expenditures on road construction and maintenance anyway, and so do not need to use price-times-quantity to approximate cost.

Second, even if we did want to use price-times-quantity to approximate the infrastructure cost, we would not treat the gasoline tax as a price, because it is not a marginal-cost price, but rather is a charge that bears no obvious resemblance to an efficient price. We can use price-times-quantity data to estimate cost (the area under the supply curve) only if we know the relationship between price and cost. Because we do not know the relationship between the gasoline tax and cost, gasoline tax data are useless information in an analysis of cost.

Countries (OPEC) sometimes manages to restrict oil output and thereby raise oil price above marginal cost. This is inefficient from the standpoint of the world because it cuts off production of oil that could be produced for less than the [formerly] prevailing market price and hence from a social-efficiency standpoint *should* be produced and consumed[32] (see Figure 1-B2). One also can argue that other industries, such as the automobile manufacturing industry, at times look oligopolistic[33].

Standards and regulations also can be economically inefficient. For example, the cost of vehicles and fuels includes items, such as catalytic converters and airbags and perhaps lightweight materials, used to meet government standards for emissions, safety, and fuel economy. Now, if the government standards are not the most efficient corrective, then the corresponding resources (for catalytic converters, air bags, etc.) are not efficiently allocated. Of course, it is well known that, transaction costs and uncertainty aside (and these admittedly are *big* asides), Pigovian taxes indeed are more efficient than are standards. However, Pigovian taxes can be more expensive to administer, less predictable, and more difficult to change on short notice, to the point that standards might be preferable in some and perhaps many situations (Baumol and Oates, 1988). It thus is not necessarily always the case that in the real world standards and regulations are less efficient than Pigovian regulations[34].

Finally, consumers can be ignorant and irrational. For example, some and perhaps many people routinely underestimate the probability that they will be in an accident, and as a result undervalue safety equipment in motor vehicles.

In sum, then, it certainly is not true that all private markets are perfect and should be left alone. Rather, there are a variety of imperfections, in every sector of the economy, including the most competitive, unregulated private sectors. As a result, we

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[32]This also results in an increased transfer of wealth from consumers to producers (who are receiving a price above their marginal cost), and can be a real loss to heavy oil importers like the U.S. Note, though, that this extra wealth transfer is not in addition to price-times-quantity payments; to the contrary it already is part of price-times quantity payments. Rather, the extra wealth transfer is with respect to the total transfer in a competitive market (see Greene and Leiby, 1993). The total resource cost of fuel use to the U.S., competitive market or not, is equal to price-times-quantity payments less *domestic* producer surplus, which is a non-cost transfer from U.S. consumers to U.S. producers.

[33]In light of this, one might distinguish those resources provided in [occasionally] non-competitive markets, and place them in a separate column labeled "subject to non-competitive pricing: MSV = p _ MSC". For simplicity, I have not.

[34]I emphasize that the question here is not whether the resources used to meet government standards should be counted as a cost of motor-vehicle use -- certainly they should be -- but whether they are efficiently allocated. Catalytic converters are a cost of motor-vehicle use today, and barring unforeseen changes in regulations, will continue to be a cost of motor-vehicle use, regardless of whether or not there would be catalytic converters in a Pareto-optimal world. Furthermore, regardless of whether standards or taxes are used to address an externality, the relevant total cost is the resource cost of whatever control measures are used (including "defensive" behavior broadly construed) *plus* the estimated cost of the residual (uncontrolled) effects, such as emissions.

face a range of analytical and policy issues pertaining to pricing, taxation, regulation, and so on.

The costs of priced private-sector goods and services are estimated in Report #5 of this social-cost series. Appendix C of this report provides an overview of some of the concepts, data, and estimation methods for some of the cost items in this column.

1.4.3 Column 3 of Table 1-1: Motor-vehicle goods and services bundled in the private sector

Some of the motor-vehicle goods and services provided in the private sector are not priced explicitly , but rather are *bundled* in the prices of nontransportation goods and services. For example, "free" parking at a shopping mall is unpriced, but it is not costless; the cost is included -- bundled-- in the price of goods and services sold at the mall. Similarly, residential garages are not sold as separate commodities, but rather are included in the total price of a home. In the United States, nearly all parking, commercial and residential, is bundled. Some local roads also are bundled, usually with the cost of a home.

Parking. The typical motor vehicle is driven less than one hour every day. The rest of the time, it is parked. In the U.S., a considerable amount of resources are devoted to providing parking for nearly 200 million vehicles parked for 23 hours a day. As estimated in Appendix A of Report #6, parking spaces for vehicles consume on the order of 2,000 to 3,000 square miles of land. More importantly, most of the roughly $100-billion resource cost of parking is not priced as a separate charge for parking, but rather is bundled with other goods, such as items at a shopping center, or a family's home, and priced as a package.

There are several ways to classify and analyze parking: on street versus offstreet, commercial versus residential, publicly versus privately owned and operated, parking garage versus parking lot, and more. In this social-cost series, parking costs are classified and estimated as follows:

Type of parking space	*a. Priced*	*b. Unpriced (bundled)*
i. on-street parking		
publicly owned	Report #7 (included with cost of public roads)	Report #7 (included with cost of public roads)
privately owned	Report #5 (assume zero, or with private roads)	Report #6 (private roads)
ii. off-street loading ramp or commercial driveway		
publicly owned	not estimated	not estimated
privately owned	not estimated	not estimated
iii. unimproved land[35]		
publicly owned	assume zero	assume zero
privately owned	assume zero	assume zero
iv. offstreet residential		
publicly owned	Report #5 (assume zero)	Report #7 (assume zero)
privately owned	Report #5	Report #6
v. offstreet nonresidential		
publicly owned	Report #7	Report #7
privately owned	Report #5	Report #6

Bundled private-sector parking costs (i-b, iv-b, and v-b) are classified in column 3 of Table 1-1, and estimated in Report #6. In that report we develop our estimates in detail, with special attention to important and uncertain parameters, such as the number of offstreet, non-residential parking spaces, the cost of parking spaces, the number of residential garages and parking spaces, the fraction of residential parking space actually used by cars, and maintenance and repair expenditures for garages. We also discuss the reasons for and efficiency implications of the practice of bundling parking.

Other bundled costs. Report #6 also presents rough estimates of the cost of local roads funded by private parties and included in the price of homes.

Although there are benefits to unbundling a commodity and pricing it explicitly, there also can be costs, and as a result it is not necessarily true that bundling is inefficient. For example, although priced parking generally is supplied and used more efficiently than is unpriced (bundled) parking, there is a cost to actually administering a pricing system, and this transaction cost may exceed the benefit of more efficient use

[35]The cost of parking in, say, a dirt field is just the foregone stream of rent from alternative uses of the land. In areas where such parking occurs, this generally will be small; certainly, it will be small compared to the land, capital, and operating costs of improved parking spaces.

of parking. One must do a complete social cost-benefit analysis, in which transaction costs are included, to determine if bundling is superior to pricing. If the decision to bundle can be distorted by such things as minimum parking requirements and tax laws that do not count free parking for employees as a taxable benefit, the ideal solution is to eliminate the inefficient taxes and standards, and not necessarily force parking costs to be unbundled. See Report #6, and Gomez-Ibanez (1997) for further discussion.

Appendix C of this report provides an overview of some of the concepts, data, and estimation methods for some of the cost items in this column.

1.4.4 Column 4 of Table 1-1: Motor-vehicle infrastructure and services provided by the public sector.

The public sector provides a wide range of infrastructure and services in support of motor-vehicle use. I use data on government expenditures for capital and operations and maintenance, and estimates of motor-vehicle-related activity in various cost categories (police protection, fire protection, and so on), to estimate the long-run annualized capital cost and annual operating and maintenance cost of this motor-vehicle-related infrastructure and service. I categorize these public-sector costs separately because governments, unlike private firms, do not charge efficient prices for their goods and services.

Note that some cost items straddle columns 4 and 5. In at least one respect, the distinction between column 4 and column 5 is somewhat arbitrary: items in column 4 are priced but not priced efficiently (or as efficiently as is possible), whereas items in column 5 are not priced at all. The distinction is somewhat arbitrary because whether there is an inefficient charge or no charge at all, the result is similar: inefficient use of resources[36]. Nevertheless, for several reasons, it is useful and natural to distinguish improperly priced from unpriced items. In the first place, analyses of social cost often are framed around the distinction between private costs and external costs, wherein external costs are unpriced and completely unaccounted for by consumers. Thus, to identify pure externalities, one must distinguish unpriced from improperly priced items. Second, analysts and policymakers need to know which items are being charged for already, but incorrectly, versus which items are not being charged for at all, because generally it will be easier to correctly charge for the former group than the latter. Third, much of the motor-vehicle-related infrastructure and service provided by the public sector is priced, but not efficiently. Thus, if one wants to identify public infrastructure and service costs charged at least partly to motor-vehicle users -- and it certainly seems natural to do so -- one must distinguish improperly priced from unpriced costs.

This distinction does make for a messy classification, though, because it is difficult to decide which taxes or fees are payments for which public services. For example, as I argue in Report #17, the portion of the motor-fuel tax that is officially dedicated to deficit reduction should be counted as a payment by motor-vehicle users for motor-vehicle use, regardless of the actual legislative earmarking. But to which

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[36]Of course, this statement does not apply to pure public goods, for which the optimal price is zero.

publicly provided motor-vehicle services does it apply? Fire protection related to motor-vehicle use? Highway construction only? Defense of oil interests? The answer is a matter of judgment, and as a result, whether a particular public service is priced inefficiently or instead is completely unpriced also a matter of judgment. I have placed in column 4 those public infrastructure and service items that by law are funded at least partly by taxes fees on motor-vehicle use. The rest of the items -- those that are not definitely and universally understood to be funded by motor-vehicle users -- straddle columns 4 and 5.

Of course, whereas all government expenditures on highways and the highway patrol are a cost of motor-vehicle use, only a portion of total government expenditure on local police, fire, jails, and so on, is a cost of motor-vehicle use. I have estimated the portion of these expenditures that, in the long run anyway, is a cost of motor-vehicle use. This sort of allocation is valid for expenditures (such as for police protection) that arguably are opportunity costs of motor-vehicle use. (For example, using or having motor-vehicle goods, services, and infrastructure has some effect on crime, which requires police-protection services.)[37]

Note that our estimates of total public-sector costs include the annualized cost of the capital stock. Because capital is foregone (liquidated, not replaced, or not expanded) only in the long run, and only as a result decisions by public officials, the costs estimated here are long-run costs of public decision making.

Government expenditures are estimated in Report #7 of this social-cost series. Appendix C of this report provides an overview of some of the concepts, data, and estimation methods for some of the cost items in this column.

1.4.5 Column 5 of Table 1-1: Monetary externalities of motor-vehicle use.

An external cost of motor-vehicle use is a cost of motor-vehicle use that is imposed on person A by person B but not accounted for by person B (but see the more formal definition in the next section). A *monetary* external cost is one that happens to be valued monetarily by markets, in spite of being unpriced from the perspective of the responsible motor-vehicle user. The clearest example, shown in column 5 of Table 1, is accident costs that are paid for by those *not* responsible for the accident. These repair costs, inflicted by uninsured motorists, clearly are unpriced in the first instance -- that is, unpriced from the perspective of the uninsured motorist responsible for the accident -- but nevertheless are valued explicitly in dollars in private markets. With respect to

[37]Another point: for at least three reasons, it is likely that expenditure data do not represent purely economic cost (area under the supply curve). First, even if competitive bidding forces each contractor to offer no more than his minimum willingness to supply, the amounts that the highway contractors themselves pay for materials and services (and which they incorporate into their bids) may include producer surplus. Second, as Lee (1992) notes, "it is possible to argue that kickbacks from corrupt contractors and [a portion of] politically inflated labor rates are transfers, not costs" (p. 19; bracketed comments mine). Third, to the extent that highway expenditures are financed from incremental tax revenues, the economy suffers deadweight losses of consumer and surplus due to the contraction of consumption and production caused by price distortion by the incremental taxes.

economic efficiency, the concern here is that the costs in this category are not priced at all, and hence are larger than is socially optimal.

The largest monetary externalities are those resulting from accidents and travel delay.

Monetary externalities are estimated in Report #8 of this social-cost series. Appendix C of this report provides an overview of some of the concepts, data, and estimation methods for some of the cost items in this column.

1.4.6 Column 6a of Table 1-1: Nonmonetary externalities of motor-vehicle use.

I follow Baumol and Oates (1988), and state that a nonmonetary externality is present when agent A chooses the value of [a] nonmonetary variable[s] in agent B's utility or production relationships without considering B's welfare. Thus, by this definition, "externality" is synonymous not with "damage," but with "unaccounted for cost". A nonmonetary externality is one that is not valued directly by economic markets. Environmental pollution, traffic delay, and pain and suffering due to accidents are common examples of nonmonetary externalities.

Environmental costs include those related to air pollution, global warming, water pollution, and noise due to motor vehicles. To estimate these costs, one must model complex physical processes and biological responses, and then estimate the dollar value of the responses.

The economic problem created by externalities is the classic divergence between private cost and social cost, discussed above and illustrated in Figure 1-1. As indicated in Table 1-2, the usual prescription for nonmonetary externalities is to assign property rights, bargain, or apply a dynamic Pigovian tax on the perpetrator or emissions source[38], with no direct compensation of the victim. The definition, treatment, and estimation of external costs is discussed in more detail Report #9 of this social-cost series.

In this report, I have distinguished nonmonetary externalities, which are nonmonetary costs inflicted, even if only indirectly, by motor-vehicle user A on party B and not accounted for by A, from personal nonmonetary costs, which are inflicted by a motor-vehicle user on herself. I also might have distinguished a third kind of nonmonetary or environmental-damage cost: that inflicted by motor-vehicle user A on party B but accounted for by A as a marginal cost of motor-vehicle use. When an

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[38]The Pigovian tax must be levied on the immediate damaging activity, and not on some related activity. In the case of air pollution, the tax should be levied on the source of the emissions. For example, the environmental damages from pollution from petroleum refineries should be internalized by a tax on refinery emissions, not by a tax on the final uses of the fuel products of the refinery. This remains true even if there is a clear economic and physical linkage between the final use of the refinery products and the emissions from the refinery. Now, if there is such a linkage, we may say that refinery pollution is a cost of motor-vehicle use -- because motor-fuel use does, through a chain of events, give rise to the environmental costs of the refinery -- and one way or another, whether via the Pigovian tax or a separate calculation of marginal damages, we must count the refinery pollution as a cost of motor-vehicle use. However, linkage or no, we should levy the pollution tax at the refinery stacks.

externality is properly taxed, it becomes this third type of cost. (One perhaps could argue that once a [formerly] nonmonetary cost is properly taxed, it becomes a monetary cost, but this is merely semantics.) Thus, the third category would consist of true Pigovian taxes.

However, there are at most only three quasi-Pigovian taxes related to motor-vehicle use: 1) the portion of the oil-spill environmental excise tax that covers costs other than clean-up costs; 2) the tax, which Barthold (1994) says is "Pigovian," on ozone-depleting chemicals; and 3) the gas-guzzler tax, which arguably is partly a tax on energy-security costs. However, the oil-spill tax and the gas-guzzler tax probably are not equal to marginal expected damages, and hence probably are not true Pigovian taxes, and the tax on ozone-depleting chemicals now is largely irrelevant because new automobiles use a more ozone-friendly refrigerant that is not subject to the tax. For these reasons, I have not created a separate category called "properly taxed, efficiently allocated environmental damages".

Note that, if one were tallying the marginal social cost and found that there were optimal Pigovian taxes, one would count either the tax or the value of the actual marginal damage, but not both, because if the tax had been calculated correctly it would equal the damage[39]. Note too that the cost of pollution control equipment cannot be construed as a Pigovian tax: the economic cost of pollution-control equipment is the value of the resources used to make and operate control equipment, whereas a correct Pigovian tax is equal to the marginal cost of the remaining [post-control] pollution. In a social-cost analysis control costs and post-control damage costs are additive, not equivalent.

Nonmonetary externalities are estimated in Report #9 of this social-cost series. Appendix C of this report provides an overview of some of the concepts, data, and estimation methods for some of the cost items in this column.

1.4.7 Column 6b of Table 1-1: Nonmonetary costs of infrastructure

Note that I have classified the nonmonetary social and environmental impacts of the motor-vehicle infrastructure in part b of column 6, separate from the non-monetary

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[39]Suppose that we wish to estimate the social cost (private cost plus external cost) of using motor gasoline. We know that there is a relationship between the amount of motor fuel consumed and the amount that refineries produce, and a relationship between the amount of fuel that refineries produce and the amount of pollutants they emit. We therefore may count as a cost of using motor gasoline the value of the environmental damages from emissions from petroleum refineries making gasoline. In a world without true marginal-cost Pigovian taxes -- i.e., in the real world of today and tomorrow -- we can make an independent estimate the value of the environmental damages from making motor gasoline, and add to it the refineries' actual private cost (exclusive of taxes) of making gasoline, as part of our estimate of the social cost of motor gasoline. This is what we do here. But what if the emissions from refineries actually were assessed a Pigovian charge equal to the marginal damage that they caused? In that case, the damage cost would be internalized at the refineries (which, as pointed out above, is where it should be internalized), and the refineries' private cost would include the cost of environmental damage. To add to this private cost an independent estimate of the environmental damages in this case would double-count the damages.

externalities of motor-vehicle use. Although these infrastructure costs ultimately are a long-run cost of total motor-vehicle use, they are not a cost of marginal or incremental motor-vehicle use, because they do not vary with each mile or trip. Hence, infrastructure costs are not externalities of motor-vehicle use, according to our definition of "externality", and for this reason are categorized separately from external costs. Note too that we we have not estimated any of these environmental costs of infrastructure. (One should not presume, though, that omitted costs necessarily are trivial.)

1.4.8 Summary observations regarding Table 1-1

Divergence between price and marginal social cost increases from left to right. One perhaps can argue that, in general terms, the "typical" divergence between the marginal social cost and the actual price (or the marginal social value) in each column of Table 1-1 increases as one moves from column 1 to column 6. For the items in the first column, there is little or no divergence between marginal social cost and marginal social value; for those in the last column, the price is zero but the marginal social cost can be considerable.

Long-run vs. short run and direct vs. indirect costs. In order to keep Table 1-1 manageable, I have not distinguished in the table between costs incurred immediately as a result of motor-vehicle use (one might call these "direct short-run" costs), and costs incurred in the long run, or only indirectly, as a result of motor-vehicle use. However, these distinctions are important.

Motor vehicle use does not give rise to costs "automatically," according to some immutable laws of physics or to the logic of mathematics, but rather is linked to costs -- to particular effects, or changes in actual resource consumption -- by physical, economic, or political processes. Some links are direct and almost immediate. For example, motor-vehicle use is linked directly by combustion processes to motor-vehicle emissions of CO, emissions of CO in turn are linked directly by atmospheric processes to ambient levels of CO, and ambient levels of CO are linked statistically, by behavioral and biological processes, to headaches. In this case, the linkage between use and cost (headaches) is largely physical, and almost immediate.

Of course, linkages can be much more attenuated than this. For example, the linkage between motor-vehicle use and a change in refinery emissions is more complicated than the linkage between motor-vehicle use and a change in motor-vehicle tailpipe emissions, because there are intervening economic as well as physical processes. In theory, a change in motor-vehicle use will change quantity and hence price in the market for gasoline, which in turn will affect price in the market for crude oil, which in turn will affect price in the market for other petroleum products (such as heating oil). In theory, refinery owners will adjust to the price changes by changing the mix and amount of refinery products. This economically induced change in output will be linked physically to changes in refinery emissions, which in turn will be linked to ambient pollution and then to health effects. And all of this is a theoretical simplification: in reality, political factors and economic variables other than price will be important too.

But the linkages between motor-vehicle use and cost can be even more tenuous: they can depend not only price changes, which at least in economic theory are "mechanisms," but on the decisions of public policymakers as well. Consider the links between motor-vehicle use and defense expenditures in the Middle East. First, the change in motor-fuel use will change demand for oil, but not barrel for barrel, because prices of and hence demand for other petroleum products will change. The change in demand for oil might change demand for oil imported from the Middle East, depending on the price of domestic versus imported oil, sunk costs, contractual arrangements, political conditions, and other factors. Congress then *might* notice any change in oil imports from the Middle East, and then *might* decide that it means that the U.S. cares less about the region and need not devote as many resources to policing it. Such government decisions make the link between motor-vehicle use and military expenditures especially remote.

Although Table 1-1 does not make these distinctions, they nevertheless are important because the more tenuously linked costs are harder to estimate, often are lagged considerably with respect to the causal changes in motor-vehicle use, and often depend greatly on the specific characteristics and amount of the change in motor-vehicle use. The upshot is that it is *especially* dubious to use willy-nilly, in any context, our estimates of the total or average cost of the more tenuously linked costs.

1.4.9 The quality of the estimates

Table 1-1 lists nearly 50 individual components of the total social cost of motor-vehicle use. For some of these cost components, we were able to develop original, reasonably detailed estimates. However, in many other cases we simply took estimates from the literature or made educated guesses. Thus, there is quite a wide range in the quality of our estimates. In order to provide an overview of the quality of our estimates, and help readers understand initially which estimates are sound and which are little better than guesswork (and of course which are in-between), we have rated each of our estimates. The rating system is delineated in Table 1-3, and the ratings are presented in Tables 1-4 to 1-9. (Note that the rating system presented in Table 1-3 is very similar but not identical to the rating system used in the literature review of Report #3.)

1.5 THE RESULTS OF THE ANALYSIS

The results of this analysis are shown by individual cost item in Tables 1-4 to 1-9, and summarized by aggregate cost category in Table 1-10. The cost items correspond to those in Table 1-1. I show the aggregated totals here in order to provide a sense of magnitudes, not because such aggregated totals are themselves useful. Indeed, as discussed next, one must be careful to avoid misusing estimates of the total social-cost of motor-vehicle use.

As stated in the notes to Tables 1-4 to 1-9, the estimates are detailed in the other reports of this social-cost series (listed at the beginning of this report).

1.5.1 Allocation of costs to individual vehicle categories

All of the costs shown in Tables 1-4 to 1-9 pertain to all motor vehicles: all autos, trucks, and buses. Although it can be interesting to estimate the cost of all motor-vehicle use, it typically will be more useful to estimate the cost of different classes of vehicles or of different fuel types, because analysts, policymakers, and regulators typically are interested in specific classes of vehicles, and specific fuels, rather than all motor-vehicles as a group. (For example, pollution regulations are set for individual classes of vehicles, not for all motor vehicles as a class.)

For some cost items, such as the some of the costs of air pollution, we have estimated marginal costs by individual vehicle class (see Report #9 in this social-cost series). In most cases, though, we have not actually estimated costs by vehicle class. However, we have developed simple *cost-allocation factors*, which can be used to apportion or disaggregate some total costs to specific vehicle and fuel classes. These factors are developed in Report #10 of the social-cost series, and summarized here in Appendix A and Table 1-A5.

1.5.2 How the results of this analysis should *not* be used

Earlier in this report, I explain the proper uses of a social-cost analysis. In this section, I caution against several common misuses of estimates of the total social cost.

First, one should resist the temptation to add up all of the unpriced costs, and express the total per gallon of gasoline, as if the optimal strategy to remedy every inefficiency were simply to raise the gasoline tax. Rather, as indicated in Table 1-2, the various kinds of inefficiencies, or market failures or imperfections, require various kinds of remedies. In fact, it turns out that there is not a single external cost, with the possible exception of CO_2 emissions from vehicles, that in principle is properly addressed by a gasoline tax.

In the first place, some sources of inefficiency, such as imperfect competition and distortionary income tax policy, are not externalities, and hence should be addressed not by Pigovian taxation, but by ensuring that the markets are competitive and only minimally distorted by taxation. Similarly, it is not theoretically ideal (in a first-best world), to force privately provided free parking to be priced; rather, one should amend any tax and regulatory policies that distort the pricing and bundling decisions of private suppliers.

Even where Pigovian taxation is called for, a tax on gasoline is not the proper application. For example, an optimal air pollution tax would be a function of the amount and kind of emissions, the ambient conditions, and the size of the exposed population; it would not be simply proportional to gasoline consumption. Similarly, an optimal congestion charge would be a dynamic function of traffic conditions. Costs that arise from the use of particular sources of oil, such as oil imported from the Middle East, should be addressed at the source, not at the level of all gasoline end use. And in any case, it is not even necessarily true, in the real and far-from-first-best world of regulations, standards, taxes, imperfect taxes, poor information, imperfect competition, and so on, that the optimal emissions tax is equal to the cost of the marginal residual emissions (Burtraw et al., 1993)[40].

Second, I caution that it might be misleading to compare the total social cost of motor-vehicle use with the Gross National Product (GNP) of the United States, because the GNP accounting is quite different from and generally more restricted than our social-cost accounting. For example, the GNP does not include any non-market items, which constitute a substantial portion of the social cost estimated here.

Third, one should properly represent and interpret the considerable uncertainty in any estimate of social cost. Uncertainty can be represented by low-high ranges, scenario analyses, probability distributions, and other techniques. Our analysis presents low and high estimates of cost. Yet, strictly speaking, these estimates are not lower and upper bounds, even where the high is much higher than the low, because we did not estimate every conceivable component or effect of every cost, and did not always accommodate the entire span of data or opinions in the literature. Moreover, we do not know how probable the higher and lower values are, or even if the higher is more probable than the lower; in fact, we do not know anything about the probability distribution of the estimated total cost. We can not even offer a “best” guess between our low and high estimates.

Fourth, as discussed in Appendix D, it is not *economically* meaningful to compare estimates of user tax and fee payments for public motor-vehicle goods and services with estimates of government expenditures for same. Most emphatically, it simply is not true that, in order to have the economically optimal amount and use of public motor-vehicle goods and services, the revenues collected from the present system of user charges must equal government expenditures. It is not true because the present taxes and fees look nothing like efficient marginal-cost prices, and because in any case it is not a necessary or sufficient condition of economic efficiency that the government collect from users of the highway infrastructure revenues equal to expenditures. Comparisons between present user payments and present government expenditures are relevant only to concerns about equity (See Appendix D for further discussion.)

Finally, given that ours is an analysis of the *total* social cost of motor-vehicle use, whereas any particular policy or investment decision will involve costs incremental or decremental to the total, one should not use our average-cost estimates in marginal analyses, unless, as discussed above, one believes that the total-cost function is approximately linear and hence that any marginal-cost rate is close to the average rate. Certainly, our results will become less and less applicable as one considers times and places increasingly different from the U.S. in 1990 and 1991. However, I note that, even if our results per se are irrelevant, our data, methods, concepts, and cost models might be useful in an analysis of specific pricing policies or investments.

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[40]Against this, however, Freeman (1997) notes that even if the emissions standards results in lower emissions than is consistent with economic efficiency, there still should be a tax on miles equal to the residual marginal damages.

1.6 SUMMARY

We have classified and estimated the social costs of motor-vehicle use in the U. S., on the basis of 1990-1991 data. Our analysis is meant to inform general decisions about pricing, investment, and research. It provides a conceptual framework for analyzing social costs, develops analytical methods and data sources, and presents some detailed first-cut estimates of some of the costs.

By now it should be clear that a social-cost analysis cannot tell us precisely what we should do to improve our transportation system. There are several kinds of inefficiencies in the motor-vehicle system, and hence several kinds of appropriate correctives. Many of our estimates are simply too generic or uncertain to be of much use -- as hard numbers -- to policymakers and analysts faced with specific problems. Moreover, society cares at least as much about equity, opportunity, and justice as it does about economic efficiency. At the end of the day, a total social-cost analysis contributes only modestly to but one of several societal objectives for transportation.

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TABLE 1-1. CLASSIFICATION OF THE COSTS OF MOTOR-VEHICLE USE

TABLE 1-2. EFFICIENT PRICING OF MOTOR-VEHICLE GOODS AND SERVICES

Private-sector costs	Bundled private-sector costs	Public-sector infrastructure and services	Externalities
Factors affecting efficient marginal-cost pricing			
General taxes and subsidies; controls on quantity or price; non-optimal standards; imperfect competition	High transaction costs of unbundling and establishing prices; tax and regulatory disincentives to charging for parking; perceived economic benefits of free parking and roads	Possible indivisibility in consumption (MC = 0; e.g., defense); decreasing long-run costs (e.g., some roads); government is concerned with generating revenue, encouraging or discouraging certain behaviors, distributing benefits, providing security and justice, and other things besides economic efficiency	Impossible, or too costly, or otherwise undesirable to assign and enforce property rights to the unpriced resources or effects (hence, no price)
Prescriptions			
Set taxes to minimize deadweight losses (or use lump-sum transfers instead of taxes); set standards such that MCC = MDC; remove controls on price and quantity; break up monopolies and oligopolies; and so on	If there are no external benefits to unbundling, and no distorting taxes, and if transaction costs cannot be lowered and private assessments are not wrong, then do nothing; otherwise, remove tax and regulatory disincentives to unbundling, and remove any institutional barriers to private ownership and operation of roads	Turn ownership over to private sector, where possible and efficient; short-run marginal-cost pricing, where possible (highway use charges set equal to marginal wear and tear plus congestion costs; registration and license fees set at marginal administration costs; parking priced at marginal cost; etc.); lump-sum transfers to finance any "public good" portion of highway infrastructure and services	If feasible, establish property rights; otherwise, if few are involved, then do collective bargaining; otherwise, levy a dynamic[a] tax, at the source, equal to marginal external costs [damage costs not accounted for], but do not compensate victims

Notes: see next page.

Notes to Table 1-2.

See also Appendix E of FHWA (1982), the Congressional Budget Office (1992), and Gillen (1997) The Federal Railroad Administration (1993) lists many pricing and mitigation strategies to address environmental externalities and "social costs" of transportation systems. MC = marginal cost; MCC = marginal control cost; MDC = marginal damage cost.

Note that the prescriptions generally all must be satisfied at once in order to achieve Pareto-optimal resource use. The general theory of the "second best" tells us that, in the real world in which many of the conditions for Pareto optimality are not satisfied, it is not necessarily best to satisfy just one additional condition. For example, given non-optimal emissions standards, emissions regulations, and fees and taxes on automobile producers, it is not necessarily true that it is most efficient to assess a Pigovian tax equal to the marginal cost of the residual emissions.

[a]In most cases, damage is a nonlinear function of output, with the result that the marginal damage rate (the slope of the total damage function) changes with the level of output. In these cases, the Pigovian tax will have to be iterated to stay equal to the marginal damage rate, because the initial application of the Pigovian tax will change the output and hence the marginal damage. Such an iterated tax is a "dynamic" tax.

TABLE 1-3. DESCRIPTION OF OUR RATINGS OF THE QUALITY AND COMPLEXITY OF OUR ANALYSIS

Quality of our analysis	Rating
Detailed and largely original analysis, with extensive calculations based mainly on primary data. Primary data include: original censuses and surveys of population, employment and wages, government expenditures, manufacturing, production and consumption of goods and services, travel, energy use, and crime; financial statistics collected by government agencies, such as the Internal Revenue Service and state motor-vehicle departments; measured environmental data, such as of ambient air quality and visibility; surveys and inventories of physical infrastructure, such as housing stock and roads; and the results of empirical statistical analyses, such as epidemiological analyses of air pollution and health.	A1
Detailed and original analysis based mainly on primary data, but less involved than level A1 analysis (see A1 for examples of primary data).	A2
Straightforward analysis based partly or mainly on primary data, with few and relatively simple calculations. Less involved than A2 analysis.	A3
Direct use of a few primary data, with no significant analysis, calculations, or adjustments. A simple citation of primary data.	A4
Review and analysis of existing estimates of the whole cost or its major components. The difference between B work and A work is that A work is based mainly on primary data, such as from government surveys or data series or physical measurements (see above), whereas B work is more dependent on the secondary literature (i.e., on someone else's original analysis of some major components of the social cost). However, the analysis in B work can be more extensive than that in A3 and certainly A4 work.	B
Review of a few existing estimates, with little or no analysis. This is essentially a literature review.	C
Estimate or simple, illustrative calculation based ultimately on supposition or judgment. Whereas C work cites a substantive analysis or estimate of the cost under consideration, D work is based on judgment without reference to any direct estimate of the cost or its major components.	D

TABLE 1-4. PERSONAL NONMONETARY COSTS OF MOTOR-VEHICLE USE, 1991 (BILLION 1991$)

Cost item	*Low*	*High*	*Q*[a]
Travel time, excluding travel delay imposed by others, that displaces unpaid activities	406.8	629.0	A2
Accidental pain, suffering, death, and lost nonmarket productivity inflicted on oneself	70.2	227.0	A2 / B
Personal time spent working on motor vehicles and garages, and refueling motor vehicles	49.5	109.6	A3
Personal time spent buying and selling and disposing of vehicles, excluding dealer costs	0.8	2.6	A3
Motor-vehicle noise inflicted on oneself	included with external noise costs		
Motor-vehicle air pollution inflicted on oneself	included with external pollution costs		
Total	**527.3**	**968.2**	

See Report #4 for details.

[a]Q = Quality of the estimate (see Table 1-3).

TABLE 1-5. MOTOR-VEHICLE GOODS AND SERVICES PRICED IN THE PRIVATE SECTOR (COST ESTIMATED NET OF PRODUCER SURPLUS AND TAXES AND FEES), 1991 (BILLION 1991$)

Cost item	*Low*	*High*	*Q*[a]
Usually included in GNP-type accounts			
Annualized cost of the entire motor-vehicle car and truck fleet, excluding sales taxes[b]	269.2	350.2	A3
Cost of transactions for used cars	12.7	12.7	A3
Parts, supplies, maintenance, repair, cleaning, storage, renting, towing, etc.[b]	159.9	188.1	A3
Motor fuel and lubricating oil, excluding excise and sales taxes and fuel costs attributable to travel delay	74.9	82.2	A2
Motor-vehicle insurance: administrative and management costs	36.7	36.7	A4
Priced private commercial and residential parking, excluding parking taxes	3.2	3.2	A3
Usually not included in GNP-type accounts			
Travel time, excluding travel delay imposed by others, that displaces paid work	190.1	229.1	A2
Overhead expenses of business, commercial, and government fleets	90.3	112.9	A3
Private monetary costs of motor-vehicle accidents, excluding user payments[c]	65.7	65.6	A2 / B
Motor-vehicle user payments for the cost of motor-vehicle accidents inflicted on others	55.7	58.8	A4 / D
Deduction for property damage, and motor-vehicle insurance administration costs counted elsewhere (as private monetary costs here, or as external monetary costs)	(65.2)	(74.8)	A2 / B
Deduction for embedded taxes included in the price-times-quantity estimates above	(59.8)	(57.6)	A2 / A 3
Deduction for bundled parking costs included in cost of any industries above, but counted separately here as a bundled parking cost	(6.4)	(26.6)	D
Total	**826.9**	**980.4**	

See Report #5 for details.

[a]Q = Quality of the estimate (see Table 1-3).

[b]These figures include costs related to motor-vehicle accidents. Because these costs also are counted in the line "private monetary costs of motor-vehicle accidents", they are deducted in a separate line ("Deduction for property damage..."), to avoid double counting.

[c]The figure under "Low" might be higher than the figure under "High" because a total estimated accident cost is allocated to the different cost categories on the basis of low and high externality fractions, whereby "Low" means low external cost -- and hence high private or personal cost -- and "High" means high external cost.

TABLE 1-6. MOTOR-VEHICLE GOODS AND SERVICES BUNDLED IN THE PRIVATE SECTOR, 1991 (BILLION 1991$)

Cost item	*Low*	*High*	*Q*[a]
Annualized cost of non-residential offstreet parking included in the price of goods or services or offered as an employee benefit	48.5	162.2	A2
Annualized cost of home garages, carports, and other residential parking included in the price of housing	15.4	40.6	A2
Annualized cost of roads provided or paid for by the private sector and recovered in the price of structures, goods, or services	11.8	75.9	A3, D[b]
Total	**75.7**	**278.7**	

See Report #6 for details.

[a]Q = Quality of the estimate (see Table 1-3).

[b]A simple calculation involving some solid numbers and some guesswork.

TABLE 1-7. MOTOR-VEHICLE INFRASTRUCTURE AND SERVICES AND SERVICES PROVIDED BY THE PUBLIC SECTOR, 1991 (10^9 $)

	10% _MVU[a]		100% _MVU[a]		
Cost item	*Low*	*High*	*Low*	*High*	*Q*[b]
Annualized cost of public highways, including on-street parking and private off-site investment in roads	9.99	18.66	99.9	186.6	A2
Annualized cost of municipal and institutional offstreet parking	n.e.	n.e.	11.9	19.8	A2/3
Highway law enforcement and safety, as estimated by FHWA	0.45	0.70	7.4	8.7	A3
Other police-protection costs (not included in FHWA estimates) related to motor-vehicle use	0.10	0.47	0.8	4.1	A2
Fire-protection costs related to motor-vehicle use	0.07	0.27	0.7	2.8	A2
Emergency-service costs of motor-vehicle accidents included in police and fire costs above	(0.17)	(0.17)	(1.1)	(1.1)	A2/B
Judicial and legal-system costs related to motor-vehicle use	0.46	0.59	4.8	6.2	A2
Jail, prison, probation, and parole costs related to motor -vehicle use	0.39	0.61	3.9	6.2	A2
Regulation and control of air and water pollution and solid waste, related to motor-vehicle use	0.17	0.56	2.1	5.9	A2
Energy and technology research and development related to motor-vehicle use	n.e.	n.e.	0.3	0.5	A3
Motor-vehicle related costs of other government agencies	n.e.	n.e.	0.1	0.1	D
Military expenditures related to the use of Persian-Gulf oil by motor vehicles	n.e.	n.e.	0.6	6.8	B, D[c]
Annualized cost of the SPR: investment, operation and management, and oil-holding costs	0.01	0.06	0.1	0.7	A2
Total	n.e.	n.e.	**131.4**	**247.1**	

[a]Costs are shown for a 10% reduction in motor-vehicle use, and a 100% reduction (Report #7).

[b]Q = Quality of the estimate (see Table 1-3).

[c]A review and analysis of the literature with a good deal of supposition.

TABLE 1-8. MONETARY EXTERNALITIES OF MOTOR-VEHICLE USE, 1991 (BILLION 1991$)

Cost item	*Low*	*High*	*Q*[a]
Monetary costs of travel delay imposed by others: foregone paid work	9.1	30.5	A2
Monetary costs of travel delay imposed by others: extra consumption of fuel	2.3	5.7	A2
Accident costs not accounted for by economically responsible party: property damage, medical, productivity, legal and administrative costs	26.0	28.0	A2 / B
Expected loss of GNP due to sudden changes in the price of oil	1.8	31.5	C [A1]
Price effect of using petroleum fuels for motor vehicles: increased payments to foreign countries for oil used in other sectors	3.8	8.0	A3
Monetary, non-public-sector costs of net crimes related to using or having motor-vehicle goods, services, or infrastructure	0.1	0.4	A3
Monetary costs of injuries and deaths caused by fires related to motor-vehicle use	0.0	0.1	A3
Total	**43.1**	**104.2**	

See Report #8 for details.

[a]Q = Quality of the estimate (see Table 1-3). Ratings in brackets refer to the quality of the analysis in the literature reviewed.

TABLE 1-9A NONMONETARY EXTERNALITIES OF MOTOR-VEHICLE USE, 1990-91 (BILLION 1991$)

Cost item	*Low*	*High*	*Q*[a].
Accidental pain, suffering, death, and lost nonmarket productivity not accounted for by economically responsible party	9.5	97.7	A2 / B
Travel delay, imposed by others, that displaces unpaid activities	22.5	99.3	A2
Air pollution: human mortality and morbidity due to particulate emissions[b] from vehicles	16.7	266.4	A1
Air pollution: human mortality and morbidity due to all other pollutants from vehicles	2.3	17.1	A1
Air pollution: human mortality and morbidity, due to all pollutants from upstream processes	2.3	13.0	A1
Air pollution: human mortality and morbidity, due to road dust	3.0	153.5	A1
Air pollution: loss of visibility, due to all pollutants attributable to motor vehicles	5.1	36.9	A1
Air pollution: damage to agricultural crops, due to ozone attributable to motor vehicles	3.3	5.7	A1
Air pollution: damages to materials, due to all pollutants attributable to motor vehicles	0.4	8.0	B [A1]
Air pollution: damage to forests, due to all pollutants attributable to motor vehicles	0.2	2.0	B [A2]
Global warming due to fuel-cycle emissions of greenhouse gases (U. S. damages only)	0.5	9.2	A1, B [A1][c]
Noise from motor vehicles	0.5	15.0	A1
Water pollution: health and environmental effects of leaking motor-fuel storage tanks	0.1	0.5	D
Water pollution: environmental and economic impacts of large oil spills	0.2	0.5	C [A1]
Water pollution: urban runoff polluted by oil from motor vehicles, and pollution from highway deicing	0.7	1.7	D[d]
Nonmonetary costs of net crimes related to using or having motor-vehicle goods, services, or infrastructure	0.7	2.8	A3

Nonmonetary costs of fires related to using or having motor-vehicle goods, services, or infrastructure	0.0	0.2	A3

TABLE CONTINUED. (COSTS NOT ESTIMATED).

Air pollution: damages to natural ecosystems other than forests, due to all pollutants attributable to motor vehicles	n.e.	n.e.	n.a.
Environmental and esthetic impacts of motor-vehicle waste	n.e.	n.e.	n.a.
Vibration damages from motor vehicles	n.e.	n.e.	n.a.
Fear and avoidance of motor vehicles and crimes related to motor-vehicle use	n.e.	n.e.	n.a.
Total	**68.0**	**729.6**	

TABLE 1-9B. NONMONETARY ENVIRONMENTAL AND SOCIAL COSTS OF THE MOTOR-VEHICLE INFRASTRUCTURE

Cost item	*Low*	*High*	*Q*[a]
Land-use damage: habitat destruction and species loss due to highway and motor-vehicle infrastructure	n.e.	n.e.	n.a.
The socially divisive effect of roads as physical barriers in communities	n.e.	n.e.	n.a.
The esthetics of highways and service establishments	n.e.	n.e.	n.a.
Total	**n.e.**	**n.e.**	

See Report #9 for details. n.e. = not estimated; n.a. = not applicable.

[a]Q = Quality of the estimate (see Table 1-3). Ratings in brackets refer to the quality of the analysis in the literature reviewed.

[b]Includes secondary PM, formed from direct emissions of SO_X, NO_X, and NH_3.

[e]The estimate of fuelcycle emissions of greenhouse-gases is original and detailed (A1), whereas the estimate of the $/ton cost of emissions is based on a review of literature (B) that features detailed original calculations ([A1]).

[d]This is my estimate of the cost as of 1997. As discussed in the text, the cost probably was higher in 1991, because the leakage-prevention and clean-up programs were not in place everywhere. I speculate that the external costs in 1991 were three times the costs today.

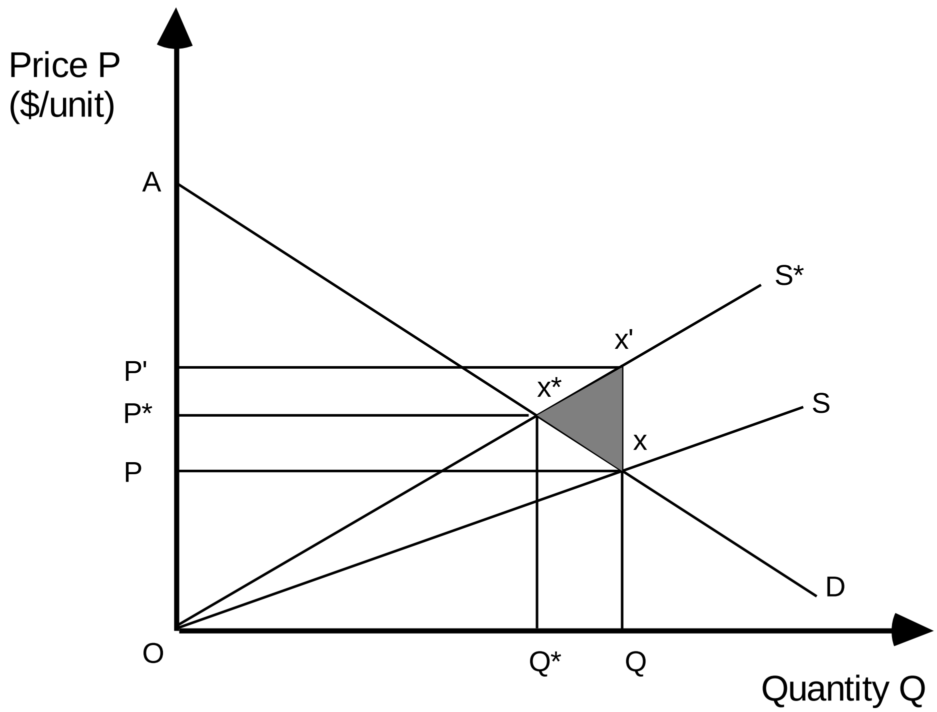
TABLE 1-10. SUMMARY OF THE COSTS OF MOTOR-VEHICLE USE

	Total cost (10^9 $)		Percentage of total	
	Low	*High*	*Low*	*High*
(1) Personal nonmonetary costs of motor-vehicle use	$527	$968	32%	29%
(2) Motor-vehicle goods and services produced and priced in the private sector (estimated net of producer surplus, taxes, fees)	$827	$980	49%	30%
(3) Motor-vehicle goods and services bundled in the private sector	$76	$279	5%	8%
(4) Motor-vehicle infrastructure and services provided by the public sector[a]	$131	$247	8%	7%
(5) Monetary externalities of motor-vehicle use	$43	$104	3%	3%
(6) Nonmonetary externalities of motor-vehicle use	$68	$730	4%	22%
Grand total social cost of highway transportation	**$1,673**	**$3,308**	**100%**	**100%**
Subtotal: monetary cost only (2+3+4+5)	$1,077	$1,610	64%	49%

For details, see other summary tables in this report, the text in this report, and other reports in the social-cost series.

[a]Includes items in Table 1-1 that straddle columns 4 and 5.

FIGURE 1-1. SOCIAL COST-BENEFIT ANALYSIS OF MOTOR VEHICLE USE



APPENDIX A. USE OF SOCIAL COST ESTIMATES TO EVALUATE THE COSTS OF TRANSPORTATION PROJECTS

In an evaluation of the costs of specific transportation projects, the social-cost analysis presented here may be used in three ways:

1). The concepts, data, methods, and models of this analysis may be used to develop specific, marginal-cost estimates or functions for a particular project. This in principle is the best use of our analysis.

2). The marginal (but "generic") unit-cost results (e.g., $/kg-pollutant) derived from detailed cost functions or models in this analysis may be used directly to calculate total costs for a particular project, as delineated below. However, the greater the divergence between the conditions to which the "generic" marginal unit-cost estimates of our analysis apply and the conditions of the particular project at hand, the less appropriate it is to use the unit-cost results directly.

3). Least preferably, and generally only given an inability to do 1) or 2), an analyst may calculate simple average-cost figures (e.g., $/mile) from the results presented here, and use them to estimate total costs for the project hand (e.g., by multiplying $/mile by VMT). This usually will not be not defensible for anything other than broad-brush planning.

1.A.1 Use of concepts, data, methods, and models

If one wishes to make detailed, accurate cost estimates for the project at hand, then one should not use the cost *results* of this social-cost analysis at all, but rather should use this series of reports as an analytical guide, and source of data and references, for the construction of project-specific cost models and functions. For example, one can use Report #14 to construct a model of noise damages, Report #12 to construct a model of agricultural costs, the travel-time data and functions of Report #4 in an analysis of the cost of congestion, the accident rate and cost functions of Report #19 in an analysis of accident costs, and the cost functions of Report #7 to estimate the cost of government services related to motor-vehicle use.

1.A.2 Use of unit-cost results derived from detailed cost functions.

In some cases, we have derived marginal unit-cost measures from our detailed cost models. Because these are marginal measures derived from detailed models, they generally will be more accurate, or representative, than will simple, average-cost measures (such as $/mile).

In Reports 11, 12, and 13, we use detailed cost models to estimate the health, agricultural, and visibility costs of air pollution per kg of pollutant emitted from motor vehicles. Because the $/kg value depends to some extent on the level of pollution (because of the nonlinearity of the damage functions), we estimate these $/kg figures for a 10% reduction and a 100% reduction in motor-vehicle emissions. The $/kg estimate multiplied by a kg / mi emission rate and then by total VMT will generate an estimate of total cost. Table1-A1