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The Annualized Social Cost of Motor-Vehicle Use in the US: Summary of Theory, Data, Methods, and Results

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

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. 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.

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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.

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

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

<u>Use #1:</u> *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

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[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.

[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.

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 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.

<u>Use #2:</u> *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

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[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.

[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.

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 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

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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.

"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 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.

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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.

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.

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].

This annualization method -- whereby the total yearly cost is equal to periodic "operations and maintenance costs" plus annualized capital replacement costs -- is just

[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.

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, 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

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

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 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

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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).

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.

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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.

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].

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].

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[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. 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.

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].

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

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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 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.

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 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

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[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.

[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.

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.

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,

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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.

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 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.

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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.

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 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 cost	assume zero cost
privately owned	assume zero cost	assume zero cost
iv. offstreet residential		
publicly owned	Report #5 (assume zero cost)	Report #7 (assume zero cost)
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 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

[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.

not count free parking for employees as a taxable benefit, the ideal solution is to eliminate the inefficient taxes and standards, and not necessarily to 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 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 is 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.

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

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. (In section 1.4.6 we give a more formal definition.) 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 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 relating to accidents, travel delay, and the macroeconomic costs of oil use.

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

[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.

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 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

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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.

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 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 actually 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.

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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.

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 economic, political, technological, and natural 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.

But 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.

And 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 hard to represent formally.

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 most efficiently 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 ideal 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

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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.

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.

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 modestly to but one of several societal objectives for transportation.

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Personal Costs	Private-sector Costs:		Public-sector Costs	
MPC or MPV might be mis-estimated, because of poor information or irrational behavior	**Prices are not optimal because of imperfect standards (MCC ≠ MDC), distortionary taxes, subsidies, price controls, quotas, imperfect competition (P ≠ MPC), or poor information**	**Bundling decision can be distorted or determined by regulations, taxes, poor information**	**User taxes and fees ≠ MPC, and B/C not maximized, because of non-efficiency objectives**	**These are absence c optimal I**
Nonmonetary	**Monetary costs**			
(1) Personal non-monetary costs of MV use	**(2) MV goods and services produced and priced in the private sector (estimated net of producer surplus and taxes and fees)**	**(3) MV goods bundled in the private sector**	**(4) MV goods and services provided by government**	**(5) Mone use**
• Travel time, excluding travel delay imposed by others, that displaces unpaid activities • Accidental pain, suffering, death, and lost nonmarket productivity inflicted on oneself • Personal time spent working on MVs and garages, refueling MVs, and buying and disposing of MVs and parts	*These kinds of costs usually are included in GNP-type accounts:* • Annualized cost of the fleet (excluding vehicles replaced as a result of motor-vehicle accidents) • Cost of transactions for used cars • Parts, supplies, maintenance, repair, cleaning, storage, renting, towing, etc. (excluding parts and services in repair of vehicles damaged in accidents) • Motor fuel and lubricating oil, excluding cost of fuel use attributable to delay • Motor-vehicle insurance: administrative and management costs • Priced private commercial and residential parking, excluding parking taxes	• Annualized cost of non-residential offstreet parking included in the price of goods and services or offered as an employee benefit • Annualized cost of offstreet residential parking included in the price of housing • Annualized cost of roads provided or paid for by the private sector and recovered in the price of structures, goods, or services	• Annualized cost of public highways, including on-street parking • Annualized cost of municipal and institutional off-street parking • Highway law enforcement and safety • Regulation and control of MV air, water, and solid waste pollution • MV and energy technology R&D	• Moneta imposed consum paid wo • Acciden econom property product adminis • Macroe of GDP • Pecunia paymer non-tra price eff motor v • Moneta of fires a using or services
• MV noise and air pollution inflicted on oneself	*Usually not included in GNP-type account:* • Travel time, excluding travel delay imposed by others, that displaces paid work • Overhead expenses of business and government fleets • Private monetary costs of motor-vehicle accidents, including user payments for cost of motor-vehicle accidents inflicted on others		• Police protection (excl. highway corrections system (net of cost c • Fire protection • Motor-vehicle related costs of o • Military expenditures related to by motor vehicles	

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

Private-sector costs	Bundled private-sector costs	Public-sector infrastructure and services	Externali
	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	Impossibl too costly otherwi undesirab assign a enforc property r to the unp resource effects (he no pric
	Ideal 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 feasib establis property r otherwis few ar involved, do collec bargaini otherwise, a dynamic at the sou equal t margin external c [damage c not accou for], but d compens victim

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 (10^9 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/A3
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 (10^9 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 AND 2002 (10^9 $)

Cost item	10% ΔMVU (1991)		100% ΔMVU (1991)		100% ΔMVU (2002)		Q[a]
	Low	*High*	*Low*	*High*	*Low*	*High*	
A1. Direct expenditures (FHWA)[b]							
Annualized cost of highways (FHWA)	9.0	18.5	90.4	184.9	159.9	335.7	A2
Highway law enforcement and safety	0.45	0.70	7.4	8.7	12.6	15.8	A3
A2. Other direct expenditures[c]							
Collection expenses, LUST, extra m&r	0.46	0.46	4.7	4.7	8.3	8.3	A3
Annualized cost of municipal and institutional offstreet parking	n.e.	n.e.	11.9	19.8	17.5	29.0	A2/3
Deduction for embedded private investment in roads	(0.30)	(0.75)	(3.0)	(7.5)	(6.6)	(16.7)	C
B. Indirect expenditures							
Other police-protection costs (not estimatd by FHWA) related to MV use	0.10	0.47	0.8	4.1	1.9	9.3	A2
Fire-protection costs related to MV use	0.07	0.27	0.7	2.8	1.4	5.5	A2
Emergency-service costs of MV accidents included in police and fire costs	(0.15)	(0.16)	(1.1)	(1.1)	(1.4)	(1.4)	A2/B
Judicial and legal-system costs	0.46	0.59	4.8	6.2	8.9	11.6	A2
Legal costs of MV accidents included under judicial and legal-system costs	(0.09)	(0.12)	(0.9)	(0.9)	(1.2)	(1.2)	A2
Jail, prison, probation, and parole costs related to MV use	0.39	0.61	3.9	6.2	7.0	9.4	A2
Regulation and control of air, water and solid-waste pollution related to MV use	0.17	0.56	2.1	5.9	7.1	15.4	A2
Energy and technology R & D	n.e.	n.e.	0.3	0.5	0.3	0.8	A3
MV-related costs of other agencies	n.e.	n.e.	0.1	0.1	0.1	0.1	D
Military expenditures related to the use of Persian-Gulf oil by MVs	n.e.	n.e.	0.8	8.5	0.8	11.2	B, D[d]
Annualized cost of the SPR	0.00	0.06	0.1	0.7	0.0	0.9	A2
Total	n.e.	n.e.	**122.9**	**243.2**	**216.5**	**433.6**	

Notes: see next page

See Report #7 for details.

ΔMVU = change in motor-vehicle use; MV = motor vehicle; O & M = operation & management.

[a] Q = Quality of the baseline year-1991 estimate (see Table 1-3).

[b] With minor exceptions, these are based on FHWA estimates of government expenditures for highways. The A1 estimates shown here *exclude* user tax-and-fee collection expenses, LUST-fund costs, and extra maintenance and repair (m&r) costs, but *include* the embedded private-sector investment in roads (Table 7-4), because the FHWA expenditure estimates exclude collection, LUST, and extra m&r costs, but include embedded private costs. In part A2 of this table the excluded collection, LUST, and extra m&r costs are added back in, and the included embedded private costs are deducted.

[c] See note b.

[d] A review and analysis of the literature with a good deal of supposition. See Report #15 for details.

TABLE 1-8. MONETARY EXTERNALITIES OF MOTOR-VEHICLE USE, 1991 (10^9 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
Macroeconomic adjustment costs related to oil-price shocks	1.8	31.5	B [A1]
Pecuniary externality: increased payments to foreign countries for oil used in non-motor-vehicle sectors, due to ordinary price effect of using petroleum for motor vehicles	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 (10^9 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]
Climate change due to lifecycle emissions of greenhouse gases (U. S. damages only)	0.0	3.5	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 HERE)

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. Note that all air pollution estimates include costs of air pollution inflicted by drivers on themselves, technically part of personal nonmonetary costs.

[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.

[c]The estimate of lifecycle 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 reports results from detailed model 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.

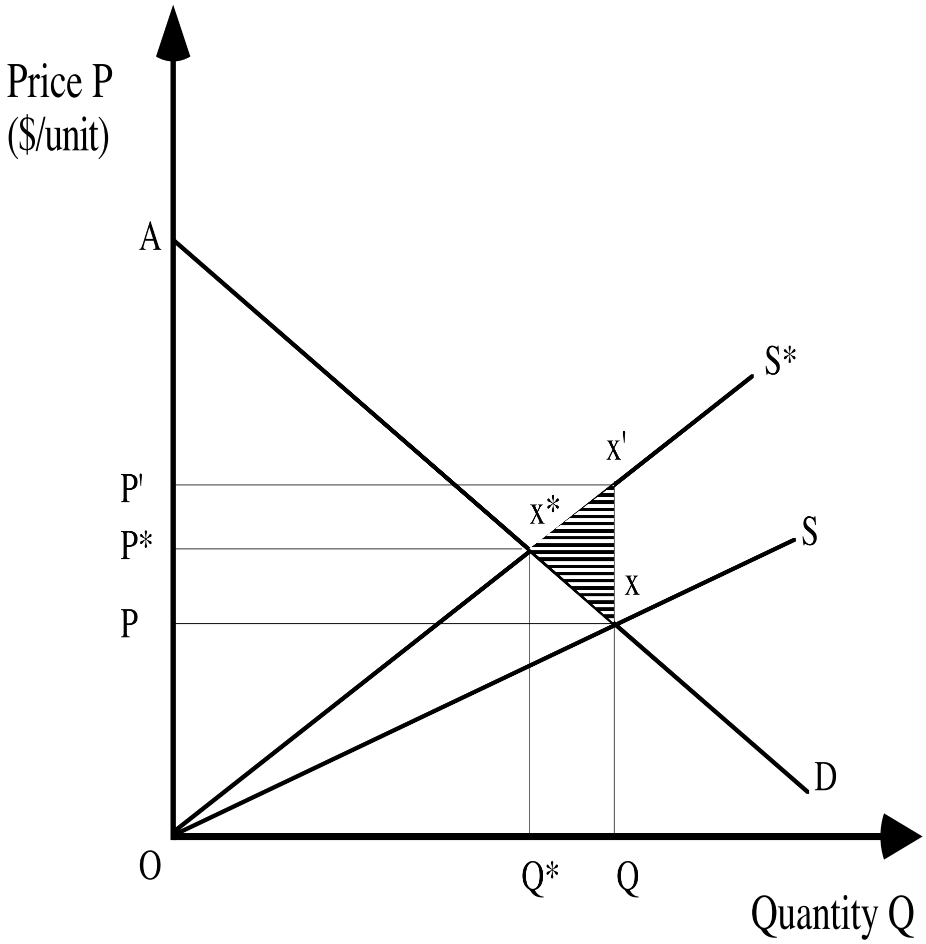
TABLE 1-10. SUMMARY OF THE COSTS OF MOTOR-VEHICLE USE

	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	50%	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]	$123	$243	7%	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	**$1,664**	**$3,304**	**100%**	**100%**
Subtotal: monetary cost only (2+3+4+5)	$1,069	$1,606	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 summarizes the $/kg cost estimates.

These $/kg unit cost figures are useful precisely because they are independent of the kg/mi emission rate of motor vehicles. One can use them to calculate the cost of emissions from, say, alternative-fuel vehicles or super-emitters, both of which have emission rates quite different from the present national average. However, the $/kg figures are proportional to the *exposed* population (of people or crops), which means that if you expect the exposed population to increase by 10% over 1990 levels, then you should increase the pertinent $/kg values by 10%. Similarly, the $/kg estimates are proportional to the assumed value of health effects, crops, and visibility. The $/kg estimates also depend somewhat on the total change in pollution or emissions being considered, because some effects are non-linearly related to pollution levels. However, it turns out that the dependency is not strong: most of the major costs either vary linearly with pollution levels (in which case the $/kg cost is independent of the pollution level), or else nearly linearly.

As an example, one can calculate the health, visibility, and agriculture value of a 10% reduction in emissions from motor vehicles in the U. S. in the year 2000 with the following formula and data:

$$TPC_{S,A,TY} = VMT_{S,A,TY} \cdot$$

$$\sum_{P} \begin{pmatrix} H_{P,S,A,BY} \cdot \Delta PH_{P,S,A,TY/BY} \cdot \Delta WH_{A,TY/BY} \\ +V_{P,S,A,BY} \cdot \Delta PV_{P,S,A,TY/BY} \cdot \Delta WV_{A,TY/BY} \\ +A_{P,S,A,BY} \cdot \Delta PA_{P,S,A,TY/BY} \cdot \Delta WA_{A,TY/BY} \end{pmatrix} \cdot \frac{ER_{P,S,A,TY}}{1000} \cdot RD_{P,S,A,TY}$$

where:
subscript S = emissions source (in this example, tailpipe and evaporative emissions from all motor vehicles)
subscript A = the area or region (in this example, the U. S.)
subscript TY = the target year of the analysis (in this example, the year 2000)
subscript BY = the year of the baseline damage estimates (1990)
subscript P = pollutant (particulate matter, carbon monoxide, etc.)
subscript TY/BY = target-year TY relative to base year BY
$TPC_{S,A,TY}$ = the total health, visibility, and agriculture cost of air pollution from emission source S in area A in target year TY ($)
$VMT_{S,A,TY}$ = the total vehicle miles of travel by emission source S in area A in target year TY (for this example, assume $2.72 \cdot 10^{12}$ miles in the year 2000 -- a 2.4%/year growth rate from 1990 to 2000)
$H_{P,S,A,BY}$ = the $/kg health cost of pollutant P emitted from emission source S in area A in baseline year BY (for this example, use $/kg estimates for "United States" in Table 11.7-7A of Report #11 [shown in Table 1-A1 below])
$V_{P,S,A,BY}$ = the $/kg visibility cost of pollutant P emitted from emission source S in area A in baseline year BY (for this example, use $/kg estimates for "MVs" in Table 13-3c of Report #13 [shown in Table 1-A1 below])
$A_{P,S,A,BY}$ = the $/kg agricultural cost of pollutant P emitted from emission source S in area A in baseline year BY (for this example, use $/kg estimates for "all gasoline, diesel vehicles," "direct emissions," in Table 12-11 of Report #12 [shown in Table 1-A1 below])

$\Delta PH_{P,S,A,TY/BY}$ = the ratio of the population exposed to health effects from pollutant P from source S in area A in the target year to the population exposed in the base year (for this example, assume 1.10 for all pollutants, sources, and areas -- a population growth of 1%/year from 1990 to 2000)

$\Delta PV_{P,S,A,TY/BY}$ = the ratio of the population exposed to visibility effects from pollutant P from source S in area A in the target year to the population exposed in the base year (for this example, assume 1.10 for all pollutants, sources, and areas -- a population growth of 1%/year from 1990 to 2000)

$\Delta PA_{P,S,A,TY/BY}$ = the ratio of the acreage of crops exposed to air pollution from pollutant P from source S in area A in the target year to the acreage exposed in the base year (for this example, assume 1.00 for all pollutants, sources, and areas -- no change from 1990 to 2000)

$\Delta WH_{A,TY/BY}$ = the ratio of the value of a unit change in health (e.g., $/asthma attack) in area A in the target year to the value of a unit change in the base year (for this example, assume 1.00 -- no change in constant-dollar value)

$\Delta WV_{A,TY/BY}$ = the ratio of the value of a unit change in visibility in area A in the target year to the value of a unit change in the base year (for this example, assume 1.00 -- no change in constant-dollar value)

$\Delta WA_{A,TY/BY}$ = the ratio of the value of a unit change in crop output in area A in the target year to the value of a unit change in the base year (for this example, assume 1.00 -- no change in constant-dollar value)

$ER_{P,S,A,TY}$ = the emission rate of pollutant P from emission source S in area A in target year TY (g/mi) (for this example, assume emission rates 20% lower than the 1990 rates given for "all M.V.s," vehicles only ("V"), in Table 11.7-5 of Report #11 [shown in Table 1-A1 below])

$RD_{P,S,A,TY}$ = the reduction in emissions of pollutant P from emissions source S in area A in target year TY (for this example, 10%, or 0.10)

1000 = g/kg

The relevant data from reports 11, 12, and 13 are shown in Table 1-A1.

Thus, with the formula, data and assumptions above and in Table 1-A1, one can calculate that a 10% reduction in motor-vehicle emissions in the U. S. in the year 2000 ($TPC_{MVs,US,2000}$) is worth $2.0 billion (low $/kg and g/mi values) to $26.8 billion (high $/kg and g/mi values) in foregone health, visibility, and agricultural costs.

In Report #14, we use a detailed model of noise generation and exposure to estimate the cost per mile of noise from motor vehicles. Table 1-A2 shows our base-case estimates of the cost per mile of noise from five different kinds of vehicles traveling on six different kinds of roads, assuming a 10% reduction in noise. One can of course multiply these estimates of $/VMT by any particular change in VMT to obtain a rough estimate of the cost of noise associated with the particular change in motor-vehicle use. Keep in mind, however, that our estimates of the national average cost per mile are a function of many parameters, and may be a poor approximation of costs in any particular area. Furthermore, the low and the high estimates, presented in Report #14 but not here, differ from the base-case estimates shown here by more than an order of magnitude.

In Reports #7 and #8, we estimate the cost of several externalities of using oil in transportation. These costs, expressed per gallon of fuel consumed, are summarized in

Table 1-A3. However, for the following two reasons, one should not simply multiply the average cost per gallon in 1991 by any particular estimated change in fuel use, to estimate the cost of a particular change in motor-vehicle use:

First, in all cases, the total cost, and hence the cost/gallon estimate, depends directly or indirectly on the level of oil imports. Thus, as oil imports change in the future, the estimated $/gallon cost will change.

Second, none of the costs estimated in Table 1-A3 are direct, immediate resource costs of motor-vehicle use. As discussed previously, the cost of defending Middle-East oil, and the cost of the Strategic Petroleum Reserve, are linked but tenuously to motor-vehicle use. The pecuniary externality *is* a direct cost -- to the U. S. -- of motor-vehicle use, but actually is internal to the global economy.

Report #7 also presents cost/quantity functions for some motor-vehicle related government services, such as police protection, fire protection, and corrections. In principle, one can adapt these functions, on the basis of local values, to estimate the cost of marginal changes in motor-vehicle use. However, key parameters in the estimation of those functions are not well known.

In Reports #4 and #5, we estimate the cost of travel time by class of vehicle and travel. The results of that analysis, expressed as cents per person-mile of travel, are summarized in Table 1-A4. Again, one can multiply these $/VMT estimates by any estimated change in VMT to get a rough idea of the change in travel-time costs resulting from any particular change in motor-vehicle use. However, the average $/VMT figures of Table 1-A4 are valid only for the income levels, compensation rates, and vehicle speeds assumed in the national analysis. To estimate locally specific costs, it would be more appropriate to use the cost formulas in Reports #4 and #5, rather than the cost/mile results.

1.A.3 Use of simple average costs

The easiest but least accurate way to use this social-cost analysis in project evaluation is to calculate simple average costs measures and apply them to the transportation quantities estimated for the project at hand. For example, one can divide total public-sector expenditures on police and fire protection related to motor-vehicle use by, say, the amount of travel by motor vehicles, to derive police+fire cost per VMT. One then can multiply this $/VMT figure by the amount of VMT for the project at hand to estimate the police+fire protection cost for the project.

Obviously, the validity of this use depends on the extent to which the actual [unknown] cost function (that is, the relationship between cost and cost-determining transportation parameters) for the project at hand is close to the national average cost rate. It should go without saying that in general the local cost function will not be the national average, and hence that the national average should be used only as a last resort.

In any event, one can construct a variety of simple average cost measures: $/VMT, $/gallon, $/ton-mile, $/vehicle, $/vehicle-ton, and so on. Table 1-A5 provides eight different measures of motor-vehicle use that in principle can serve as the denominator of an average cost measure. As another example: if one believes that highway costs are proportional to ton-miles per axle, then one can divide total highway costs (Table 1-7) by total ton-miles per axle (Table 1-A5) and apply the resultant $/ton-mile/axle measure to ton-mile/axle travel estimated for the project at hand, to estimate highway costs for the project.

Table 1-A5 also provides factors to allow one to allocate total costs to different vehicle classes, as discussed next.

1.A.4 Cost allocation factors

A cost-allocation factor shows the share of a particular vehicle class of some general measure of motor-vehicle use. For example, the cost allocation factors of Table 1-A5 show the share of light-duty gasoline autos of total vehicle miles of travel, and the share of heavy-duty diesel vehicles of total motor-vehicle expenditures for maintenance and repair. Table 1-A5 shows six different vehicle types with respect to eight different measures of motor-vehicle use.

Measure of motor-vehicle use	*Vehicle types*
• vehicle miles of travel	• light-duty gasoline autos (LDGAs)
• total vehicle ton-miles of travel	• light-duty gasoline trucks (LDGTs)
• total vehicle ton-miles of travel where tonnage is raised to the 0.7 power	• heavy-duty gasoline vehicles (HDGVs)
• total vehicle ton-miles of travel per axle	• light-duty diesel autos (LDDAs)
• total fuel use	• light-duty diesel trucks (LDDTs)
• vehicles sold	• heavy-duty diesel vehicles (HDDVs)
• total vehicle-tons manufactured in the U.S	
• total expenditures on maintenance and repair	

The use of these allocation factors is straightforward. For example, the HDDV fraction of total vehicle ton-miles per axle, multiplied by any total motor-vehicle cost that is a function of vehicle ton-miles per axle, tells us the amount of that total cost that is assignable to heavy-duty diesel vehicles. Thus, if we know total expenditures for highway repair, and believe that highway repair costs are related to ton-miles of travel per axle, we can use the ton-mile/axle allocation factors to allocate the total expenditures to individual vehicle classes.

I emphasize, though, that the cost-allocation factors of Table 1-A5 are relatively simple, and most often will be but a fairly crude basis for allocating a total cost. Ideally, one should use more sophisticated engineering and economic models to estimate the marginal costs truly attributable to individual vehicle classes.

TABLE 1-A1. SUMMARY OF THE HEALTH, VISIBILITY, AND AGRICULTURE COST OF EMISSIONS FROM MOTOR VEHICLES

Emitted pollutant --> *Ambient pollutants -->*	**PM_{10}** *PM_{10}*	**VOCs** *organic PM_{10}*	**CO** *CO*	**NOx** *NO_2, nitrate PM_{10}*	**SOx** *sulfate PM_{10}*	**VOCs+ NOx** *O_3*
g/mi -- low (11.7-5)	0.20	3.10	38.20	3.60	0.20	6.70
g/mi -- high (11.7-5)	0.30	3.70	45.30	4.00	0.20	7.70
$-damages/kg-emitted[a]						
Health -- low (11.7-7A)	9.75	0.10	0.01	1.17	6.90	0.01
Health -- high (11.7-7A)	133.78	1.15	0.09	17.29	65.22	0.11
Visibility -- low (13-3c)	0.4	0.0	0.0	0.2	0.9	0.0
Visibility -- high (13-3c)	3.9	0.1	0.0	1.1	4.0	0.0
Crops -- low (12-11)	0.00	0.00	0.00	0.00	0.00	0.19
Crops -- high (12-11)	0.00	0.00	0.00	0.00	0.00	0.30

From Reports 11, 12, and 13 in the social-cost series. Source tables from those reports are shown in parentheses.

[a]Dollar value (in 1991 dollars) of health, visibility, and crop damages due to a change in ambient pollution resulting from a 10% reduction in direct emissions from all motor-vehicles (heavy-duty diesel trucks as well as gasoline passenger cars), in all areas of the U. S. (rural as well as urban), in 1990. Emissions from upstream sources such as refineries, and emissions of road dust, are not included here. (Reports 11, 12, and 13 do present $/kg results including these upstream emissions, and emissions of road dust.) The $/kg cost of a 100% reduction in emissions would be similar but not identical, on account of nonlinearities in the damage models.

TABLE 1-A2. THE MARGINAL COST OF NOISE FROM A 10% INCREASE IN VMT, FOR DIFFERENT TYPES OF VEHICLES ON DIFFERENT TYPES OF ROADS, IN URBANIZED AREAS: BASE-CASE RESULTS (1991$/1000-VMT)

	Interstate	Other freeways	Principal arterials	Minor arterials	Collectors	Local roads
LDAs	2.96	4.25	1.18	0.57	0.07	0.00
MDTs	8.50	13.20	7.02	5.37	1.05	0.00
HDTs	16.69	30.80	20.07	29.93	4.93	0.00
Buses	6.36	9.77	7.18	6.42	1.22	0.00
Motorcycles	17.15	27.03	8.71	4.67	0.56	0.00

From Report #14 in the social-cost series.

TABLE 1-A3. SUMMARY OF THE EXTERNAL COSTS OF OIL USE (1991$/END-USE GALLON)

Cost category	**Gasoline vehicles**	**Diesel vehicles**	**All vehicles**	**Cost basis**[a]
Strategic Petroleum Reserve - low	0.0004	0.0006	0.0005	Middle-East oil?
Strategic Petroleum Reserve - high	0.0052	0.0064	0.0054	Middle-East oil?
Defense expenditures -low	0.0056	0.0071	0.0059	Middle-East oil
Defense expenditures - high	0.0631	0.0779	0.0661	Middle-East oil
Pecuniary externality - low	0.0285	0.0350	0.0298	U.S. oil use
Pecuniary externality - high	0.0596	0.0730	0.0623	U.S. oil use
Price-shock cost to GDP - low	0.0189	0.0231	0.0198	U.S. oil use
Price-shock cost to GDP - high	0.1889	0.2314	0.1976	U.S. oil use
Water pollution - low[b]	0.0023	0.0026	0.0023	U.S. oil use
Water pollution - high[b]	0.0076	0.0084	0.0078	U.S. oil use
All costs - low	*0.056*	*0.068*	*0.058*	
All costs - high	*0.324*	*0.397*	*0.339*	

The cost is equal to the total cost assigned to each vehicle class (Tables 8-1, 8-2, 7-22, and 15-10), divided by total gallons of fuel consumed by each class, in 1991 (Table 10-3). (For water pollution, see fn b.) Note that in all cases the total costs, and hence the cost/gallon, depend directly or indirectly on the level of oil imports.

[a]*Strategic Petroleum Reserve (SPR):* If the main purpose of the SPR is to buffer against disruprtions in the supply of oil, and if the oil supply from the Middle East is more likely to be disrupted than oil from anywhere else, then one reasonably might say that the SPR is a cost of importing oil from the Middle East. Put another way, if it is true that the U. S. would not have an SPR if it did not import oil from the Middle East, then the SPR is a cost of using oil from the Middle East.

Defense expenditures: We estimate the peacetime and wartime cost of defending oil interests in the Middle East; we do not estimate the cost of defending oil interests anywhere else.

Pecuniary externality: The pecuniary externality is a function of the change in the world price of oil as a result of a change in oil use by U. S. motor vehicles. The world oil price of course is determined by the use of all oil, not just by the use of imported oil.

Price-shock cost to GNP: The exposure of the U. S. economy to oil price shocks depends in part on the total value of oil in the U. S. economy.

Water pollution: The environmental impact of oil used for motor vehicles in the U. S. depends on the amount of oil used by motor vehicles.

[b]In Report #9, I estimate damages from spills of all crude oil used for motor fuels, and damages from leaks of all motor fuels. Here, I multiply total oil spill damages by the fraction attributable to crude used to make gasoline or diesel fuel (from line 4 of Table 10-14), and then

divide by total gasoline or diesel fuel consumption in 1991 (Table 10-3). I assume that the $/gallon damages from leaking tanks are the same for gasoline and diesel fuel.

TABLE 1-A4. THE COST OF TRAVEL TIME IN MOTOR VEHICLES (CENTS/PERSON-MILE)

Type of vehicle and travel	**External cost**		**Total cost**	
	Low	*High*	*Low*	*High*
Private vehicles for personal purposes				
daily travel	0.91	4.01	16.5	27.8
long trips	0.42	1.75	11.4	20.2
Private vehicles for business purposes				
LDAs	0.98	4.56	28.7	43.6
LDTs without paid drivers	1.79	7.09	34.9	54.1
LDTs with paid drivers	2.11	5.29	42.3	42.3
HDTs with paid drivers	2.59	6.48	51.8	51.8
Buses				
intercity and transit	2.44	9.06	34.3	54.5
school	0.27	0.73	4.0	4.7
Public (government) vehicles				
federal civilian	2.79	9.05	54.7	69.6
federal military	2.14	5.82	42.9	46.6
state and local civilian	1.90	6.25	37.1	47.5
state and local police	1.18	3.20	23.6	25.6
All vehicles	*0.96*	*3.94*	*19.1*	*30.0*

From Report #4 in the social-cost series. Includes monetary as well as nonmonetary costs. To obtain costs per vehicle mile, multiply these cost/person-mile by the persons/vehicle occupancy rates estimated in Table 4-1.

TABLE 1-A5. TRANSPORTATION QUANTITIES AND ALLOCATION FACTORS FOR GASOLINE AND DIESEL MOTOR VEHICLES IN THE U.S., 1991

	Gasoline vehicles			Diesel vehicles		
Cost allocation factor	*LDAs*	*LDTs*	*HDVs*	*LDAs*	*LDTs*	*HDVs*
Vehicle travel (10^9 VMT)	1,525	439	24	18	13	154
Fraction of total travel	0.702	0.202	0.011	0.008	0.006	0.071
Weight-travel (10^9 ton-miles)[a]	2,382	853	217	29	28	4,198
Fraction of total ton-miles	0.309	0.111	0.028	0.004	0.004	0.545
Fraction of $ton^{0.7}$-miles[b]	0.466	0.156	0.025	0.006	0.005	0.342
Freight ton-miles (10^9)[c]	0	305	208	0	12	4,191
Fraction of freight ton-miles	0.000	0.065	0.044	0.000	0.003	0.889
10^9 ton-miles per axle[d]	1,191	424	88	15	14	1,047
Fraction of ton-miles/axle	0.429	0.152	0.032	0.005	0.005	0.377
Highway fuel (10^6 gal)	70,227	28,771	3,367	649	714	24,833
Fraction of total highway fuel	0.546	0.224	0.026	0.005	0.006	0.193
Fraction of hwy. gas or diesel	0.686	0.281	0.033	0.025	0.027	0.948
New vehicles sold (10^3)	8,164	4,017	40	11	18	290
Fraction of total number sold	0.651	0.320	0.003	0.001	0.001	0.023
Vehicle-tons made (10^3)[e]	7,703	5,658	327	10	26	2,365
Fraction of total amount made	0.479	0.352	0.020	0.001	0.002	0.147
Spent on m & r (10^6\$)[f]	68,124	27,594	2,264	629	685	16,703
Fraction of total expenditures	0.587	0.238	0.020	0.005	0.006	0.144

Source: see Report #10 of this social-cost series.

All calculations ignore the use of LPG and other alternative transportation fuels, which account for but a tiny fraction of motor-vehicle energy use.

LDA = light-duty automobiles (includes station wagons and motorcycles but not minivans, which are classified as light-duty trucks); LDT = light-duty trucks (those with a gross vehicle weight [GVW] rating of 8,500 lbs or less, and a curb[empty] weight of 6,000 lbs or less; includes passenger vans and jeeps and utility vehicles); HDV = (heavy-duty vehicles; all other trucks, including buses); VMT = vehicle miles of travel; hwy. = highway; m & r = maintenance and repair.

[a]Generally, ton-miles of travel by a vehicle type is equal to vehicle miles of travel (VMT) multiplied by the average weight of the vehicle, including its average payload.

[b]I include this measure of activity because I allocate emissions of particulate matter (dust) from roads on the basis of $ton^{0.7}$-miles of travel (Report #10). This is the same as ton-miles of travel except that the vehicle weight is raised to the 0.7 power. I show only the resulting distribution here because the absolute $ton^{0.7}$-miles are not meaningful.

[c]I assume that only trucks are used to transport freight for business (non-personal) purposes.

[d]Equal to the ton-miles divided by the average number of axles. I assume that all light-duty automobiles have two axles.

[e]Calculated by multiplying the number of vehicles produced by the average curb weight (in tons) of each vehicle, in each category.

[f]I include this measure because I assume that emissions attributable to the use of motor-vehicle services, such as maintenance and repair (m & r), are proportional to the amount of money spent on maintenance and repair (m & r) services.

APPENDIX B. CONDITIONS FOR THE EXISTENCE AND EFFICIENT OPERATION OF MARKETS

Resources are used efficiently when the marginal value to society (MSV) equals the market price (P) equals marginal cost to society (MSC). This is intuitively obvious, and easy to show.

If a consumer is free to choose the amount of an item that she consumes, then she will consume until the marginal value ($/unit) is equal to the price ($/unit) that she faces. At this point, she will be at her optimal level of consumption. Moreover, if the price she faces includes all the costs to society arising from producing or supplying the item, and if she considers all the use-values associated with her consumption, then the marginal social value of consumption (demand) will equal the marginal social cost of production (supply), and such activity summed over all consumers and producers will yield an optimal level of production and use for the whole society.

This optimum, however, is rarely if ever attained. 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. In the following, I review the conditions required for markets to exist and allocate resources efficiently, and what happens if the conditions are not met.

If all of the conditions are met, then in theory a market will exist and price will equilibrate production and consumption at the point where the marginal social value of consumption equals the marginal social cost of production, and the resulting resource allocation and use pattern will be optimal and not susceptible to improvement, except as a result of changes in technology, resource endowment, or tastes.

1.B.1 Conditions for existence of markets

The first five are conditions for the existence of markets (not necessarily in a logical hierarchy):

I). First, property rights must be enforceable: it must be possible (and not too costly) to enforce a price and assign benefits and costs. Mutually beneficial exchange is not possible if the cost and benefits are not assignable.

The absence of property rights is a primary cause of an externality, which I define elsewhere. For example, too much air pollution results, in part, because presently it is impossible to establish ownership of individual molecules of the air. In the absence of optimal regulations or pseudo-markets for air pollution, the air will be overused as a dumping ground, and (all else equal) too many air-polluting items will be produced and consumed.

An externality is a cost or benefit to society that is not accounted for by private markets, and therefore results in a divergence between price and marginal social cost[41]. The case of an external cost is illustrated in Figure 1-1, where the demand for motor-vehicle use, as a function of total price, is the line D, and the marginal private cost of motor-vehicle use, as a function of the amount supplied, is line S. The market clears

[41]In this social-cost analysis, I assume that there are no significant *external* benefits of motor-vehicle use. See Rothengatter (1994), and Report #20 of this social-cost series.

along S -- because [by definition] consumers consider only priced or "accounted-for" costs -- and provides quantity Q at price P. However, unaccounted for costs -- externalities -- cause the total marginal social cost S* to exceed the marginal private cost, S. As shown in Figure 1-1, the marginal social cost of Q, the amount provided by the private market, is P′ (Q intersects S* at x′, which corresponds to P′), which is greater than the private-market price P and hence greater than the marginal value of Q. In fact, every unit consumed beyond Q* costs society more than it is worth, because beyond Q* the social-cost curve rises above the social-value (demand) curve. Therein lies the problem. One solution is to price the externality so that the market clears along the social-cost curve, at Q* and P*.

II). Second, there must be no indivisibility in consumption. If consumption is indivisible, then the marginal cost of an additional consumer is zero, and the efficient price is zero. In this situation either there will be no private market, or else a private market with a non-optimal price -- unless there is perfect discriminatory pricing, in which each user is charged the money value of the utility he derives from the good. Absent perfect price discrimination, the public sector must determine the optimal amount of a public good, and, ideally, finance the good via non-distortionary lump-sum transfers from individuals to the public sector.

III). Third, indifference curves must be convex; i.e., there must diminishing marginal utility in consumption, so that the last unit is worth less than the previous. If this does not hold, the demand curve might not intersect the supply curve, and if it does not, there will be no market equilibrium.

IV). Fourth, there must not be economies of scale over the relevant range of output; i.e., average cost must not decline with output. If the average-cost curve is declining, then the revenue from a marginal-cost price will not cover total cost. This is illustrated in Figure 1-B1, where the demand curve D′ intersects the marginal cost (MC) curve in a region where average total cost (AC) is declining. The result is that the total cost of producing the quantity Q′ exceeds the revenues from selling Q′ by the amount (Pac′-P′)·Q′. [In the "normal" case where demand D* intersects MC in a region of increasing costs, total revenues exceed total cost and provide a producer surplus equal to (P*-Pac*)·Q*]. This situation precludes a competitive market, and might give rise to a "natural monopoly."

V). Fifth, there must be no institutional or transactional barriers to the formation of markets. This condition is self-explanatory.

1.B.2 Conditions for efficiency

The next five are efficiency conditions:

VI). Sixth, there must be *many buyers and sellers*. The most well-known violation of this condition, monopoly power, results in an undersupply relative to the competitive equilibrium. This is easy to show. A firm, whether a monopoly or competitor, maximizes its profit when the marginal cost (MC) of the last unit equals the marginal revenue (MR) gained from selling it. In any industry, whether competitive or comprising a single firm, $MR = P + Q\,(dP/dQ)$, where dP/dQ, the change in price with output, is negative because of diminishing marginal utility of consumption. Now, in a competitive market, the output of a single firm does not affect price appreciably, and hence for the competitive firm dP/dQ is zero, and MR = P. However, the monopolists' output affects price, so that for it, $dP/dQ < 0$, and MR < P. This is shown in Figure 1-B2.

As a result, the monopolist produces less than society is willing to pay for (Q < Q*), and so causes a real loss in social surplus (the triangle x-x*-x').

VII. Seventh, everyone must have information on the prices and quality of goods, services, and factors of production, and individuals must appreciate the value to themselves of their own consumption. These conditions are obvious. If a person is uninformed, or does not know his "true" preferences, then he cannot be sure that the something is worth what he pays for it; that is, he cannot be sure that MV = P. In transportation, for example, it is likely that some drivers underestimate their risk of getting into an accident, and consequently drive more than is optimal for them and for society.

VIII. Eighth, everyone must be free to choose the amount of every product or resource that he or she uses. (This condition, broadly construed to include noise, pollution, and the like, also is tantamount to stipulating that there are no externalities, according to some definitions of "externality".) If individual consumers are *not* free to choose the amount they pay and/or consume, then, even if they account for all the costs of their consumption, and face full marginal social-cost prices, it will be purely coincidental if for their [forced] choice, P = MV. In the case of bundled items, which are not priced explicitly but are part of a package that is priced, the requirement is that the consumer be free to choose the whole package, assuming that the bundling is efficient because of high costs of unbundling.

IX. Ninth, there must be no distortionary taxes on production or consumption. Taxes drive a wedge between demand price and supply cost; the wedge reduces output and thereby results in a "deadweight loss" of social welfare. In Figure 1-B3, government levies a fixed percentage tax on output, which effectively rotates the supply curve upward from S to Stax. As a result, the market price increases from P* to Ptax, and the quantity demanded contracts from Q* to Qtax. Government collects tax revenues equal to (Ptax-P')·Q', but the revenues are a transfer from consumers and producers, and on balance society loses the consumer and producer surplus on the foregone output -- the deadweight triangle x-x*-x'.

In a first-best world, government revenues are collected by "lump-sum" taxes -- fixed per-capita assessments that are independent of any particular production or consumption. If this is impossible, then a second-best solution is to tax so as to minimize the deadweight losses, by reducing all outputs by approximately the same proportions (Baumol and Bradford, 1970). Generally, the [second-best] optimal tax will cause prices to deviate from true marginal cost in inverse proportion to the price elasticity of demand, so that the tax will be very high where the demand is very inelastic. The rationale for this is intuitively clear: if demand is inelastic, then even a large tax will reduce demand only slightly, and cause but a small deadweight welfare loss (in Figure 1-B3, the steeper the demand curve D, the smaller the area x-x*-x').

X. Tenth, there must be no distortionary regulations or standards. Unless standards are designed to be economically optimal, it is unlikely that the marginal cost of the resources devoted to meeting the standards (e.g., the cost of catalytic converters required by emissions standards) will equal the marginal economic value provided (a reduction in emissions).

If all of these conditions are met, then in theory a market will exist and price will equilibrate production and consumption at the point where the marginal social value of consumption equals the marginal social cost of production, and the resulting resource allocation and use pattern will be optimal and not susceptible to improvement, except as a result of changes in technology, resource endowment, or tastes[42].

[42]It is worth noting that in the real world, in which many of these conditions are violated, we cannot be sure that we will improve things by removing some but not all of the violations. So says the "general theory of the second best," which is presented by Lipsey and Lancaster (1956-57), Davis and Whinston (1965), and Laffont (1990), and briefly in Report #2 of this social-cost series.

FIGURE 1-B1. THE PROBLEM OF DECLINING LONG-RUN MARGINAL COST

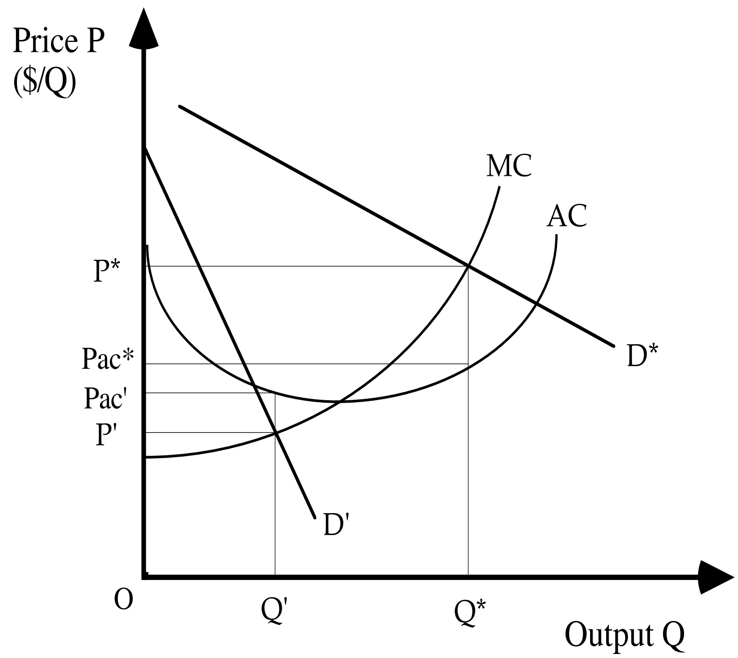


FIGURE 1-B2. EFFICIENCY LOSS DUE TO MONOPOLY

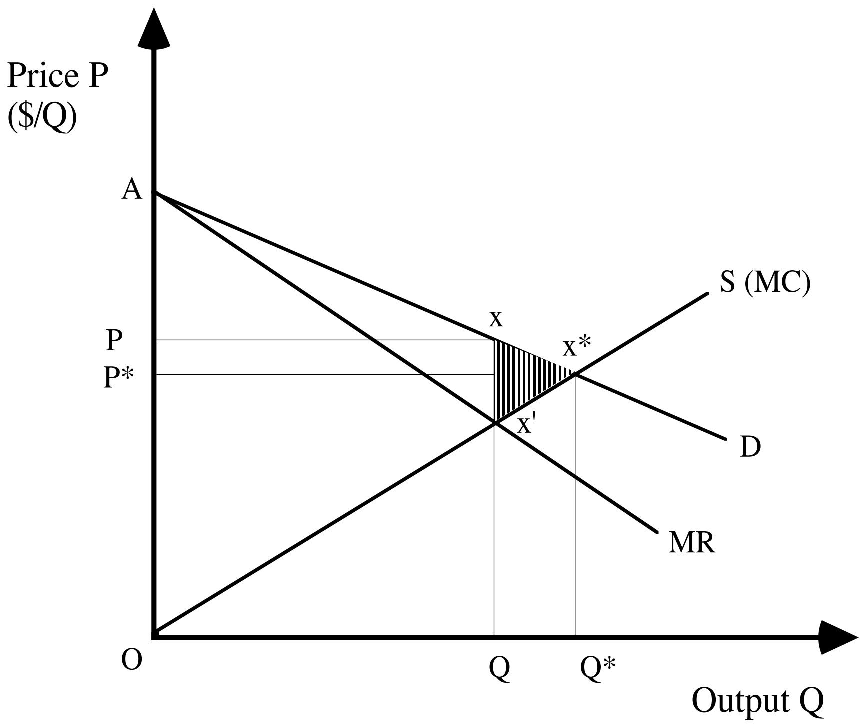
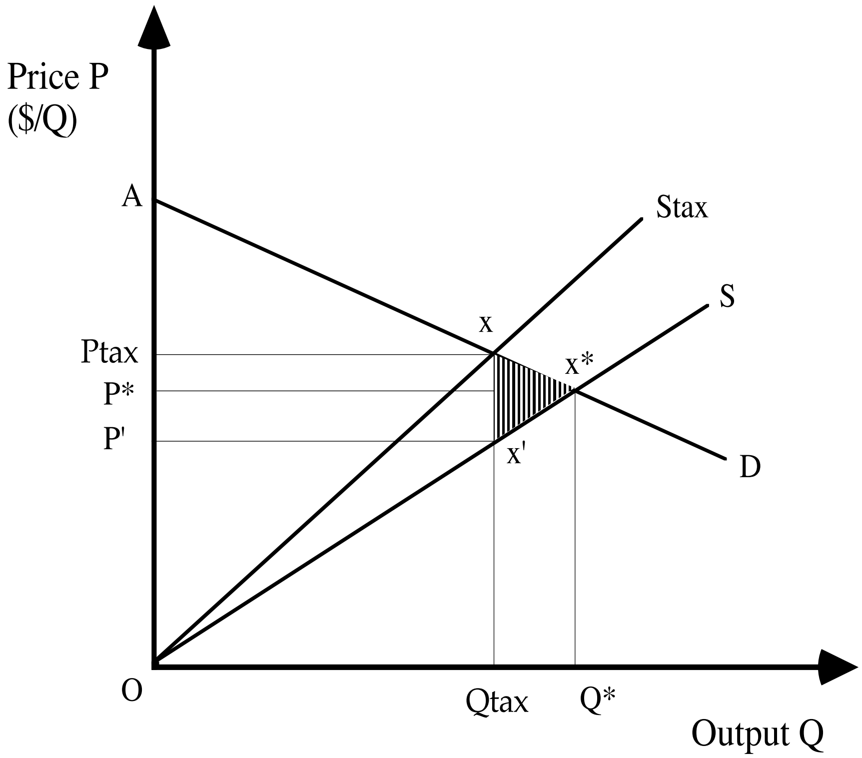


FIGURE 1-B3. EFFICIENCY LOSS DUE TO TAXES



APPENDIX C. OVERVIEW OF CONCEPTS, DATA, AND ESTIMATION METHODS FOR SOME OF THE COST ITEMS IN TABLE 1-1.

1.C.1 Column 1 of Table 1-1

• *Travel time, excluding travel delay imposed by others, that displaces unpaid activities.* I estimate the total cost of nonmonetary personal travel time as a function of total person-hours of travel, average speed in uncongested conditions, the fraction of travel time that displaces unpaid activities, the opportunity cost of travel time, the hedonic cost of travel time, and other factors. The opportunity cost of travel time is equal to the value of activities foregone while in the car. (By definition, the opportunity cost of nonmonetary travel time is *not* paid work, but rather leisure or unpaid work.) The hedonic cost is the pure utility or disutility of the driving experience itself. We use the data tapes from the *Nationwide Personal Transportation Survey* (FHWA, 1991) to analyze travel time as a function of income, mode, and trip purpose.

• *Accidental pain, suffering, death, and lost nonmarket productivity inflicted on oneself.* In general, I distinguish three kinds of pain, suffering, and lost productivity costs of motor-vehicle accidents. Those inflicted by an individual on himself are personal nonmonetary costs, and are included in column 1. Those inflicted but also paid for by another, via liability insurance or out-of-pocket payments, become priced pain and suffering (etc.) and are included in column 2. Finally, those inflicted and not paid for by another are nonmonetary externalities, and are included in column 6[43].

I use total social-cost functions and marginal social cost functions to estimate the nonmonetary (and monetary) personal and external costs of motor-vehicle accidents. Costs are estimated as a function of vehicle miles of travel, vehicle occupancy, the injury or accident rate, and the cost per injury or accident. The injury or accident rate and the cost per injury or accident are specified separately for eight different kinds of injury accidents (Blincoe, 1996, Miller, 1997). Marginal external costs are estimated as the difference between the marginal social cost and the marginal private cost, less estimated user liability payments. The cost functions are derived, and the parameter values documented, in Report #19.

• *Motor-vehicle noise and air pollution inflicted on oneself (included with external costs of column 6).* Noise costs and air pollution costs in principle can be disaggregated into

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[43]An accident cost incurred by driver D is an externality if the cost could have been avoided had another person not driven, and if that other person has not paid the cost, either out of pocket or through insurance. It matters not who is liable *legally* for the cost, or whether D's insurance covers the cost. That is, even if the insurance company of the party *not* economically responsible for the cost pays the cost, the cost still is external, because it is not accounted for by the responsible party. The necessary and sufficient condition for a monetary externality is that the responsible party does not face a price and pay the cost; beyond that, it does not matter who actually ends up paying the cost..

This treatment of accident externalities is not ignorant of Vickrey's (1968) "paradox," which is that the full cost of an accident involving two parties is attributable to both parties, because had *either* not driven there would not have been an accident. Vickrey's observation is correct, but not preclusive of a simple, optimal pricing strategy: namely, charge each driver for the expected damage (risk) inflicted on the other, and let each driver bear as an unpriced personal nonmonetary cost the risk that he faces. In this way, the externalities are properly (but not doubly) priced, and all of the risks are properly accounted for as risks imposed and risks faced.

costs inflicted by motor-vehicle users on themselves (personal nonmonetary costs), and costs inflicted on others (external costs). Usually, however, this distinction is not made, on the presumption that the personal nonmonetary costs are trivial compared to the external costs. This assumption most likely is correct in the case of air pollution, because the exhaust plume is directed away from the vehicle, and most pollutants disperse widely (although researchers have found that levels of carbon monoxide (CO) inside vehicles are much higher than ambient levels [Ott et al., 1994]). In the case of noise, though, it is not immediately obvious that personal nonmonetary costs are trivial compared to external costs, because vehicular noise is intense at the source, and diminishes rapidly with distance. Nevertheless, we have followed the usual practice, and have not estimated personal noise or air-pollution costs apart from the external costs. We report the total external+personal-nonmonetary cost as an externality, in column 6. The analysis is summarized in Report #9, and presented in full detail in Report #14.

1.C.2 Column 2 of Table 1-1

I have included in this column several items that most other analysts and most GNP-type accounts usually do not include as costs of owning and operating motor-vehicles. The "User Operated Transportation" categories of the National Income and Product Accounts (NIPA) of the United States (e.g., Bureau of Economic Analysis, 1990; *Survey of Current Business*, July, 1992), the FHWA's *Cost of Owning and Operating Automobiles, Vans, and Light Trucks* (1984, 1992), the U. S. Department of Labor's Consumption Expenditure Surveys (e.g., Bureau of Labor Statistics, 1992), Runzheimers' (1992) *Survey & Analysis of Business Car Policies and Costs 1991-1992*; and the financial profile of automobiles in *National Transportation Statistics* (1992; their data are from the NIPA and the FHWA's *Highway Statistics*) do *not* include in their transportation accounts the following costs: compensated work travel time; the overhead expenses of business, commercial, and government fleets; accident costs paid for by responsible party, but not through automobile insurance; vehicle inspection by private companies; or the cost of legal services and security devices. They do not include them either because they have overlooked them, or because (in the case of the NIPA and Consumer Expenditure Surveys) they classify them elsewhere, as legal costs, medical costs, housing costs, and so on, rather than as personal transportation costs.

There is no doubt, however, that these are costs of motor-vehicle use. For example if there were no motor vehicles, there would be no vehicle inspection costs, and no out-of-pocket costs of motor-vehicle accidents. With regards to economic efficiency, the issue here is whether or not motor-vehicle users *recognize* that these are costs of motor-vehicle use. That is, even though these costs are explicitly priced, they might be overlooked and omitted from the decision calculus. The out-of-pocket costs of motor-vehicle accidents *might* be an example of this sort of unaccounted-for cost.

• *Annualized cost of the motor-vehicle fleet.* The annualized replacement cost of the motor-vehicle fleet is the market value of the present fleet, less producer surplus, annualized over the life of the fleet at relevant interest rates. The market value is equal simply to the unit price (excluding sales taxes) multiplied by the number of units, in each of six classes of motor vehicles. All producer taxes are deducted en masse in a separate line in this column.

The annualized replacement cost so estimated is equivalent to: i) the annualized cost of doubling the present fleet at present prices; ii) the annualized cost, in the long run, of maintaining the present fleet by replacing vehicles as they retire; and iii) the annualized cost, in the short and long run, of maintaining the present fleet and of failing to liquidate the present fleet, if its liquidation value is inversely proportional to its life.

If a vehicle is totaled in an accident, and the party economically responsible does not pay, either out of pocket or through insurance, the replacement cost is an externality (see above for my definition of accident externality). Such external replacement costs are included in column 5.

• *Cost of motor fuel*. This is equal to the pre-tax cost per gallon of motor fuel, multiplied by the number of gallons of motor-fuel consumed, less a detailed estimate of producer surplus accruing to oil producers, and less the cost of excess motor-fuel consumed as a result of travel delay. The last is a monetary externality, included in column 5.

• *Part, supplies, maintenance, repair.* All such costs paid for by the economically responsible party, either out of pocket or through automobile insurance, are included here. (The cost of normal wear and tear, and the cost of accidental damage covered by the insurance of the responsible party, are examples.) All external property damage due to accidents is included in column 5, as a monetary externality.

• *Automobile insurance: administrative and management costs and profit only.* I count as a cost of insurance per se only the administrative and management cost and profit of providing the insurance service. All of the costs actually paid by insurance companies either are "Private monetary costs of motor-vehicle accidents...", itemized separately in this column, or else monetary externalities, in column 5.

• *Private monetary costs of motor-vehicle accidents.* Here, I include all of the monetary costs of motor-vehicle accidents that are not externalities: property damage, medical care, legal and other services, and so on. Included, and itemized separately, are payments (such as insurance liability payments) by motor-vehicle users for costs that they inflict on others. The cost of administering and managing insurance also is itemized separately, in this column. Costs not paid for by the responsible party are monetary externalities, in column 5. Report #19 gives the details of the estimates of accident costs.

• *Travel time, excluding travel delay imposed by others, that displaces paid work.* We estimate the total cost of travel time in this category as a function of total person-hours of travel, the ratio of uncongested speeds to congested speeds, the fraction of travel time that displaces paid activities, the opportunity cost of travel time, and other factors. By definition, the opportunity cost of monetary travel time is paid work, not leisure or unpaid work. If the travel displaces leisure or unpaid work, then the travel time has a nonmonetary cost and belongs in column 1 or 6, not in column 2 or 5.

Note that, in determining whether the travel-time cost is "monetary," we do *not* care whether the traveler is reimbursed for travel; rather, we care whether the activities that are foregone because of the travel are themselves directly valued in dollars. For example, if "business" travel displaces paid work, then the cost of the travel time is the value of the foregone productivity, which I assume is the full compensation rate in current employment (see the discussion in Report #5). In this case, business travel has a monetary cost and belongs in column 2 or 5, regardless of whether or not the traveler is reimbursed explicitly for travel time per se. However, if business travel actually displaces leisure time, then the travel time has a nonmonetary cost and belongs in column 1 or 6, even if the traveler is paid a salary during the travel or is reimbursed, because leisure time, which is the opportunity cost, is not valued directly in dollars.

• *Overhead expenses of fleets*. Business, government, and commercial vehicle fleets have overhead expenses for administrative staff, garage and repair facilities, and motor-vehicle related equipment. These expenses are costs of motor-vehicle use, and are not included in any other cost item in this table.

• *Vehicle inspection by private companies.* I include here only those payments to private inspection stations, because payments to government-run stations presumably are included in expenditures for the highways reported in the Federal Highway Administration's annual *Highway Statistics* report. Also, privately run inspection stations presumably charge marginal costs, whereas government stations might not.

• *Deduction of taxes and fees embedded in price-times-quantity estimates.* The preceding estimates of the supply cost of motor-vehicles goods and services exclude retail sales taxes, and federal, state, and local excise taxes on motor fuels. However, because they are price-times quantity estimates, they still include taxes "embedded" in the price: namely, excise, income, or property taxes paid by producers. For example, our estimate of the supply cost of gasoline excludes retail sales taxes and the motor-fuel excise tax, but it includes the cost of corporate income taxes paid by oil companies, and environmental excise taxes paid by oil producers. Similarly, our estimate of the supply cost of motor vehicles excludes sales taxes, but includes gas-guzzler taxes and emission-certification fees.

These embedded taxes and fees should not be included in an estimate of the true private-sector resource cost of motor-vehicle goods and services, because they either are transfers from the private sector to the government, or else inefficient charges for government services[44]. If they are the latter, then they do not properly represent the cost of the services. In this case, the best way to do the accounting is to eliminate the taxes from the private-sector ledger and perform a separate estimate of the actual cost of the government services and record the estimated cost in public-sector ledger.

1.C.3 Column 3 of Table 1-1

• *Annualized cost of non-residential offstreet parking.* The annualized replacement cost of all off-street nonresidential parking in private lots and garages is equal simply to the average annualized capital+land[45] cost per space plus the annual operating and maintenance cost per space, multiplied by the total number of spaces.

In this calculation, the most difficult parameter to specify is the total number of offstreet, nonresidential, improved private parking spaces. To estimate this parameter, we use two independent approaches and data sets. In the first method, the total number of spaces is equal to the number of offstreet nonresidential parking spaces for employees plus the number of privately owned parking spaces for others. In the second method, we use data on parking requirements and building areas to estimate the total number of spaces as $\Sigma\, P_t \cdot F_t$ where P_t is the number of parking spaces, required by

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[44]If any of the environmental excise taxes actually were correctly calculated and applied Pigovian taxes, equal to marginal residual environmental damages, then it would reasonable to leave the taxes and the damages that they represented embedded in the private cost. In this case, there would be no externality (because the cost would be correctly internalized), and hence no cost estimated in column 6 of Table 1-1. However, none of the environmental excise taxes (not even the charge for the Oil Spill Liability Trust Fund) appear to be correctly calculated and applied Pigovian taxes.

[45]Because land yields services in perpetuity, the rent, or annualized cost, is equal simply to the value multiplied by the relevant discount rate.

ordinance, per square foot of building type t, and F_t is square feet of building or activity type t. Happily, these two methods yield similar results.

As a check on our estimate of average-cost/unit multiplied by the number of units, we have made an estimate of the potential revenues that could be collected from all users at the current prices and level of demand for parking. In theory, the estimated potential revenues should at least equal the estimated total cost. As shown in Report #6, they do.

• *Annualized cost of home garages, carports, and other residential offstreet parking.* This is the annualized replacement cost of all residential parking spaces, given the distribution of parking places (carport, 1-car garage, 2-car garage, parking lot space, etc.) at new homes, plus 1990-91 maintenance and repair costs, and average annual alteration and addition costs. Generally, we multiply the total square footage in garages, carports, or other offstreet parking spaces, by the annualized construction cost and annual operations, maintenance, and repair cost per unit area or space. We use data from recent, comprehensive surveys of characteristics of housing (e.g., Bureau of the Census, *American Housing Survey for the United States in 1993*, 1995) to estimate the area or number of parking spaces, and the fraction of spaces devoted to motor vehicles.

1.C.4 Column 4 of Table 1-1

• *Annualized cost of public highways.* My estimate is based on a detailed analysis of expenditure data reported in FHWA's *Highway Statistics* (various years; e.g., FHWA, 1993). However, there are considerable differences between my estimate of the annualized cost, and the FHWA's estimate of total expenditures. Most importantly, I estimate the annualized replacement cost of the entire capital stock, and add this to the annual operating and maintenance costs, whereas the FHWA adds annual capital expenditures to annual operating and maintenance expenditures. In essence, I have included an interest charge on all capital, whereas the FHWA counts only the interest actually paid on borrowed funds.

I also have added several costs not included in the FHWA's summaries: i) the states' costs of collecting and administering highway user fees; ii) the cost of the Leaking Underground Storage Tank Trust Fund; iii) the cost of under-maintenance (actually, the additional expenditures required to maintain conditions, or the *additional* future time and travel cost to drivers of the deteriorating conditions) (Memmot et al., 1993); and iv) land costs not included in the outlay data reported to FHWA.

On the other hand, I exclude most of what the FHWA classifies as debt retirement and interest, because most of this cost is accounted for by the annualization of the capital cost. Also, I classify the cost of highway police separately, below, rather than as a cost of highways per se.

As discussed in Report #7, FHWA statistics on highway expenditures might include expenditures that are really a cost of bicycle or pedestrian use of roads. I have made a minor, ad-hoc adjustment to account for this.

• *Police protection, fire protection, judicial and legal system, corrections, energy and technology R & D, and regulation and control of pollution,* Generally, I estimate the motor-vehicle-related cost of these services as some fraction of the total cost: $MVC = \left(1 - AF_{noMV}{}^{K}\right) \cdot AC_{91}$, where MVC is the motor-vehicle-related cost of the government service, AC_{91} is the total annualized cost of the service in 1991 (annualized cost of the capital stock, plus operating and maintenance costs) (Bureau of the Census, *Government Finances: 1990-1991*, 1993), AF_{noMV} is the activity level in the absence of motor-vehicle use (expressed as a fraction of the total activity in 1991), and the exponent K determines the shape of the nonlinear cost vs. activity function. The activity measures are related to the cost of providing the service: crimes, arrests, fires, time spent hearing cases, prisoner-months of incarceration, or pollution. In the case of crimes as a measure of the activity, the estimation of AF_{noMV} considers the extent to which crimes not nominally related to motor-vehicle use (e.g., robberies in parks) might substitute for crimes that nominally are related to motor-vehicle use (e.g., robberies in parking lots). However, my estimates of this "substitute" fraction, as well as my estimates of the shape exponent K, are my judgment.

• *Military expenditures related to the use of Persian-Gulf oil by motor vehicles.* We start with an estimate of total military expenditures to defend all U.S. interests in the Persian Gulf, and estimate and subtract the portions of that total expenditure that we believe are meant to protect interests other than the use of oil by motor vehicles. First, we estimate and subtract expenditures to protect non-oil interests (e.g., general strategic interests, and the interests of non-petroleum businesses) in the Persian Gulf. Then we estimate and subtract expenditures meant to protect against Persian-Gulf-born oil price shocks that might cause a world-wide recession. We estimate these costs irrespective of U.S. production or consumption of Persian-Gulf oil, because the U.S. would be affected by such a recession even if it did not produce or consume oil from the Persian Gulf. Next, we estimate and subtract expenditures to protect the investments of U.S. producers in the Persian Gulf, apart from the interests of U.S. oil consumers. Finally, we estimate and subtract expenditures to protect the use of oil by all except motor-vehicle users. What is left, in principle, is the military cost of the *use* of Persian-Gulf oil by motor vehicles specifically. Mostly our analysis is illustrative, not quantitative. All of the steps (including the first, the estimate of expenditures to defend the gulf) are uncertain and difficult to estimate, because of joint production and other problems. The analysis is presented in Report #15.

Note that we have not estimated the military cost of defending oil or infrastructure interests in other parts of the world. Nor have we estimated the potential costs of whatever threats to U. S. interests remain in spite or perhaps even because of U.S. defense expenditures (except to the extent that the threat of an oil supply disruption, which we do estimate, is a "residual" of U. S. defense efforts).

Not included: tax subsidies. Note that I have *not* included here as a cost "general government services," "social-overhead," or "tax-subsidies." Some analysts (e.g., Lee, 1994; Litman, 1994) have classified as a social cost the difference between some baseline rate of taxation and the actual rate of taxation applied to the production and use of motor-vehicle goods, services, or infrastructure. Their reasoning is that general government services, such as health, education, and defense, must be paid for by general taxes, set at a "fair" or "economically neutral" baseline rate, and that any deviation from this baseline rate -- for example, the exemption of gasoline sales from the sales tax -- constitutes a cost to society.

I object to this on two grounds. First, the general government services that are financed by general taxes are not a cost of motor-vehicle use in the economic sense of "opportunity cost". If one expands motor-vehicle use a lot, one eventually may devote more resources to fire protection, and perhaps even to the military defense of foreign oil supplies, but one will not devote more resources to education or to non-specific national defense, all else equal, because these are public goods. (Strictly speaking, no portion of the money cost of any public good is a cost of any particular transportation system.) In principle, public goods should be handled in a separate account, and financed by minimally distortionary taxes, such as lump-sum charges.

Second, any tax payment, whether greater or less than some arbitrary baseline, is in the first instance a transfer from producers or consumers to the government, and not representative of a net resource cost. Even if the *only* distortion in the U.S. tax system were the exemption of gasoline from the sales tax, the true money welfare cost to society of failing to tax gasoline would *not* be the amount of the tax not collected, but rather the probably much smaller difference between the total deadweight loss with and without the gasoline sales tax (given a fixed tax collection). And given that the U.S. tax system is distorted -- non-optimal -- in myriad ways, one cannot even be sure that failing to tax gasoline in this wildly distorted system is on balance costly rather than beneficial.

Of course, an analysis of tax subsidies might be pertinent to an analysis of the equity of various financing schemes. I do not consider equity in my cost analysis.

1.C.5 Column 5 of Table 1-1

• *Accident costs not accounted for by economically responsible party.* See the discussions of accidents in column 2.

• *Macroeconomic adjustment costs due to oil-price shocks*. The inability of the macro economy to adjust efficiently to rapid changes in the price of oil can cause a real decrease in economy-wide output, manifest as a reduction in Gross Domestic Product (GDP). This “macroeconomic adjustment cost” (MEAC) is a function of the total level of petroleum consumption, the magnitude of the price change, the substitutability of oil in the economy, and other factors. To the extent that the MEAC is a real resource cost, a function of oil consumption, and not reflected in the price of oil, it is a marginal external cost of oil use.

To estimate the MEAC of using oil, I first specify a a total cost function that estimates the MEAC as a function of oil use and other factors. With this function we can estimate the $/bbl MEAC of any change in motor-vehicle use. To calculate the total MEAC we simply multiply the $/bbl MEAC by the quantity of crude oil embodied in highway fuels. This method includes crude oil embodied in imported gasoline and diesel fuel, as well as crude oil imported as such and made in the U.S. into gasoline and diesel fuel, but does not include any non-crude components of gasoline, such as natural-gas liquids and alcohols. It also does not count oil consumed “upstream” by petroleum refineries, motor-vehicle manufacturing plants, and so on..

Although some early research (e.g., Bohi, 1991) argued that the apparent macreconomic-adjustment losses of GDP are due to [bad] government policies (such as tight monetary policy) rather than oil price spikes per se, more recent research seems to reject the hypothesis that the economic downturns that follow oil price shocks can be attributed solely to monetary policy (Paik, 1996; Leiby et al., 1997; Jones et al., 2004).

It is important to keep in mind that here we are interested here in the cost to society *in addition* to the actual price-times-quantity payment for oil. That is, in this analysis, I estimate the economic cost that: 1) would not be incurred if motor vehicles did not use oil, and 2) is in addition to the price-times-quantity payment for oil, which, net of producer surplus, taxes and fees, and externalities, is a private-sector cost included in column 2 of Table 1-1. This is not the same as the cost to society of the world oil price being higher than it would be if the world oil market were perfectly competitive (which is what Greene and Leiby [1993] estimate).

• *Pecuniary externality: ordinary price effect of using petroleum fuels.* This is a pecuniary externality -- a wealth transfer between consumers and producers -- and not a true resource cost to the world economy. However, if a particular class of producers (e.g., foreign oil producers) is excluded from the cost analysis, then consumer loss is not balanced by producer gain, and so is a real net welfare loss within the restricted scope of such an analysis.

I count as a loss to the U. S. the extra payments from nontransportation sectors to foreign oil producers, due to the effect on oil price of demand for motor fuels. I multiply the increase in the price of crude oil, due to the use of highway gasoline and diesel fuel, by the quantity of foreign crude oil consumed in non- transportation sectors in 1991. The key parameters in this calculation are the price elasticities of supply and demand, and the amount of foreign crude oil embodied in petroleum consumed by non-transportation sectors.

I have not considered pecuniary externalities outside of the oil industry, and have not counted the positive pecuniary externality of higher prices for oil exports[46]. I also have not accounted for the possibility that the foreign producers might return some of their oil wealth by purchasing domestic goods and services with a high domestic producer surplus.

• *Monetary, non-public-sector losses from net crimes related to using or having motor-vehicle goods, services, or infrastructure.* Included here are medical costs, lost productivity, and the cost of legal and social services other than government police, fire, legal and correctional services, which are in column 4. I include these non-public-sector costs of crimes (etc.) because they are in some sense costs of motor-vehicle use: if there fewer motor vehicles, or less motor-vehicle infrastructure, there would be less net monetary welfare loss due to crimes such as motor-vehicle theft, arson of gas stations, and even rape in parking lots. I do not, however, count as a social cost any portion of the victim's property loss, or forced transfer. Although usually there will be a social cost to allocating resources by forced transfer rather than by price-mediated, voluntary transactions, the cost typically will not be the market value of the stolen property.

In the subtitle, "net" means net of substitute crimes; see the brief discussion of police, fire, and related government costs in column 4, and the longer discussion in Report #7.

As discussed in Report #2, and in the note to Table 1-1**,** even though these costs are related to using or having motor-vehicle goods, services, or infrastructure, they probably should be classified not as externalities, within an economic framework, but rather as costs of immoral and illegal behavior, within a broader framework.

Not included: urban sprawl. Some analysts claim that motor-vehicle use adversely affects urban form, and creates a cost loosely referred to as "urban sprawl" (e. g., Litman, 1994). A specific manifestation of this cost might be the extra cost of building water and sewage infrastructure to serve low density communities.

That there are relationships between the spatial characteristics of urban areas and the cost and service attributes of transportation systems is beyond dispute. Indeed, several land-use/transportation models quantify these relationships and tell us how changes in the attributes of transportation systems eventually affect locational decisions

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[46]In 1995, crude oil exports were less than 1% of consumption of crude oil (Energy Information Administration, 1996).

and thus certain characteristics of urban areas. Why then have I not listed "urban sprawl" as an external cost of motor-vehicle use?

The short answer is that the "sprawl" is an effect of *locational decisions*, which are determined partly by characteristics of transportation systems, but not an effect of motor-vehicle use per se; and that even if sprawl were an effect of motor-vehicle use, there would be no reason to believe that the net effect would be undesirable, and thereby a *cost* of motor-vehicle use. For example, it is true that if we add a $3/gallon tax to motor fuel, we will change the cost of using motor vehicles relative to the cost of using other forms of transportation, and thereby affect the locational decisions of firms and households. Ultimately, these locational choices will change the total cost of urban infrastructure, such as sewage. But the urban-form effect here -- a change in infrastructure cost -- results not in any sense from the *use* of motor vehicles, but from locational decisions that are influenced by the cost of all transportation options.

We also should be clear that the question of the relationship between motor-vehicle use and urban form is not relevant to the question of optimal *pricing* of public resources, although it is relevant to cost-benefit analysis of transportation options or policies. Regardless of the relationship between motor-vehicle use and sprawl, the efficient pricing policy of course is not to tax or control motor-vehicle use, but rather to price at marginal cost all of the relevant urban form resources themselves -- infrastructure, esthetics, and so on.

For these reasons, I think it makes little sense to list "urban sprawl" as a cost of motor-vehicle use. This is discussed more in Report #8.

1.C.6 Columns 6a and 6b of Table 1-1

• *Accidental pain, suffering, death, and lost nonmarket productivity, not accounted for by the economically responsible party*. See the note pertaining to nonmonetarty accident costs in column 1[47]. Accident costs are detailed in Report #19.

My estimate of the nonmonetary costs of accidents includes costs inflicted upon pedestrians and cyclists and other non-users of motor-vehicles, but it does not include the cost of fear and avoidance of motor vehicles.

• *Travel delay, imposed by other drivers, that displaces unpaid activities*. The nonmonetary travel-time cost of motor-vehicle congestion is equal to the value of unpaid activities foregone by drivers during travel delay, plus the pure hedonic cost of time spent in congestion. The hedonic cost is a function of several factors, including comfort, safety, privacy, available space, amenities, and the amount of effort and attention required to control a vehicle. See also the item note for travel time in column 1.

• *Air pollution inflicted on others*. Motor vehicles and their related emission sources, such as petroleum refineries, emit many different kinds of air pollutants, which can affect human health, agricultural production, visibility, materials, forests, and so on. We have performed detailed estimates of the health costs (Report #11), agricultural costs (Report #12), and visibility costs (Report #13) of motor-vehicle air pollution. In the following paragraphs, we discuss the estimate of the health costs, which are the largest of the three. The methods of estimating the agricultural costs and visibility costs are similar in many respects to the methods for estimating the health costs.

[47]See also the discussion in Report #2 of this social-cost series, about rational decision making and efficient outcomes as regards the personal non-market costs of accidents. That discussion also is pertinent to the setting of proper prices in order to internalize external non-market costs of accidents.

The relationship between changes in emissions related to motor-vehicle use and changes in health welfare (measured in dollars) can be modeled in three steps:

1) relate changes in emissions to changes in air quality;
2) relate changes in air quality to changes in physical health effects; and
3) relate changes in physical health effects to changes in economic welfare.

We have made a detailed model of this sort to estimate the cost of the health effects of motor-vehicle air pollution.

1). We estimate air quality with and without motor vehicles and their related emissions, in the year 1990. Air quality *with* motor vehicles and related emissions is of course just the status quo, which we represent with measurements of actual ambient air quality at air-quality monitoring sites in every metropolitan area of the U.S. in 1990. This data set (EPA, 1993) is discussed in Report #11. We estimate air quality without motor-vehicle related emissions with a relatively simple model of emissions, dispersion, and atmospheric chemistry, developed in Report #16.

Our analysis includes emissions directly and indirectly attributable to motor vehicles: evaporative and tailpipe emissions from vehicles; emissions from refueling vehicles; emissions from the production, storage, and distribution of gasoline and diesel fuel; emissions from the manufacture and assembly of materials for vehicles; emissions from re-entrained road dust; and emissions from other sources and activities related to the use of motor vehicles and motor-vehicle fuels (see Report #10.) It includes emissions of toxic air pollutants (e.g., benzene) as well as emissions of the "criteria" pollutants (or precursors to criteria pollutants) regulated by the U.S. Clean Air Act (hydrocarbons [a precursor to ozone], nitrogen oxides, sulfur oxides, carbon monoxide, and particulate matter).

2). The second major step is to determine the health effects of the estimated exposure to air pollution due to motor vehicles. We reviewed hundreds of clinical, animal, and epidemiological studies of the health effects of various pollutants, and constructed exposure-response functions for each criteria pollutant (ozone, carbon monoxide, etc.) and each of a variety of health effects (for example, asthma, or headaches). These functions relate the change in health effects to the change in exposure. We have developed mortality-risk estimates for those pollutants, such as fine particles, which according to some studies are associated with mortality. We also have constructed unit-risk functions, which relate the probability of getting a particular type of cancer (e.g., leukemia) to the amount of exposure to a particular toxic air pollutant (e.g., benzene), for exposure to several toxic air pollutants. For many pollutants and health effects we have established upper and lower-bound estimates of the effects of exposure.

Our estimate of the health effects of particulate matter, which is the most damaging pollutant, accounts for the likelihood that smaller particles are more damaging than larger particles, that geological material is less damaging than combustion material, and that particulate-matter emission inventories are seriously mis-estimated.

3). In the last step, we estimate the economic value of the estimated health effects. Our estimates of the dollar value of health effects are derived from studies of the value of lost work days, of restricted activity, of tolerating certain symptoms, and so on (Report #11). When we estimate the value of life, which is the most important valuation parameter in the analysis, we distinguish future deaths from current deaths, and deaths that would have occurred soon anyway even if there were no pollution from deaths that would not have.

With these estimates, the total health cost is equal to the change in the effect of interest (e.g., number of deaths due to motor-vehicle particulate air pollution) multiplied by the dollar value per effect (e.g., the value of life). In Report #11, we estimate total dollar health costs for the whole U.S., for urban versus rural areas of the U.S., and for eleven different metropolitan areas. We also present the costs in terms of $/vehicle-mile traveled and $/kg-pollution-emitted (see Appendix A).

For a recent review of the literature on the air pollution damages of transportation, see Krupnick et al. (1997). See also the recent methodological reviews by Krupnick (1993) and Cifuentes and Lave (1993). For a recent estimate of air-pollution damages in Los Angeles, see Small and Kazimi (1995).

• *Global warming* . Most atmospheric scientists believe that an increase in the concentration of "greenhouse gases" --- primarily carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs) -- will increase the mean global temperature of the earth. Recently, an international team of scientists, working as the Intergovernmental Panel on Climate Change (IPCC), has concluded that "the balance of evidence suggests that there is a discernible human influence on global climate" (IPCC, 1995a, p. 5). In the long run, this global climate change might affect agriculture, coastal developments, urban infrastructure, human health, and other aspects of life on earth (IPCC, 1995b).

In principle, the "damage" cost to the U. S. of global warming can be estimated simply as the product of fuelcycle greenhouse gas emissions, and warming damages per unit of emissions. I review the literature to estimate damage costs per unit of emissions, and then use a detailed greenhouse-gas emissions model (DeLuchi, 1991) to estimate fuelcycle emissions.

Note that I count only the cost to the U.S. of U.S. greenhouse-gas emissions; I do not count the cost to other countries. If one chooses to take a worldwide perspective and count the cost to the entire world of U.S. greenhouse-gas emissions, then one cannot count as a cost the "Price effect of using petroleum fuels..." in column 5, because that is a transfer from the U.S. to foreign oil producers and hence not a cost in the global market (Gomez-Ibanez, 1997).

• *Noise.* In Report #14, we develop and document a model of the total external damage cost of motor-vehicle noise. Our general cost model is conceptually straightforward: the dollar cost of noise is equal to dollars of damage per excess decibel (HV), multiplied by: the annualized value of housing units exposed to motor-vehicle noise above a threshold (P); the density of housing units exposed to motor-vehicle noise above a threshold (M); the amount of motor-vehicle noise over a threshold (AN); and a scaling factor to account for costs in non-residential areas ((To+Ti)/Ti).

We find that the external damage cost of direct motor-vehicle noise could range from less than $1 billion per year to tens of billions per year, although we believe that the cost is not likely to much exceed $10 billion. In sensitivity analyses presented in Report #14, we show that this wide range is due primarily to uncertainty regarding the cost of noise per decibel above a threshold, the amount of noise attenuation due to ground cover and intervening structures, the threshold level below which damages are assumed to be zero, average traffic speeds, and the cost of noise outside of the home. Our estimates do not include the cost of "indirect" motor-vehicle noise, such as from highway construction, or the cost of controlling noise related to motor-vehicle use, or the loss of use of property that is unused because of motor-vehicle noise. Also, our estimates assume that motor vehicles are the only source of noise.

• *Water pollution*. It is especially difficult to model the national cost of groundwater pollution from leaking underground storage tanks and urban runoff. Instead of developing a formal model, I reviewed some of the relevant literature, and made educated guesses as to the likely magnitude of the cost. As shown in Table 1-9, I estimate that the external damage costs are rather small, in part because regulations passed in 1988 required tank owners to retrofit existing tanks with release-detection systems and maintain financial assurance to cover the costs of clean up and third-party liability.

I also have not formally modeled oil-spill costs, and instead have based my estimate on a review of some of the literature. One potential modeling difficulty here is that, technically, in order to attribute the cost of oil spills to motor-vehicle use, one must trace through how a change in demand for motor fuels affects the world market for oil and the production and shipping decisions of oil producers. At the margin, oil spills that affect the U.S. may or may not be a cost of motor-vehicle use in the U.S.; the outcome depends on details of producer behavior that we have not modeled. (See Report #9 for further discussion.)

• *Nonmonetary costs of net crimes and fires related to using or having motor-vehicle goods, services, or infrastructure.* The costs estimated here include pain and suffering and lost nonmarket productivity due to crimes and fires related to using or having motor-vehicle goods, services or infrastructure. See the note regarding monetary losses from motor-vehicle-related crimes, in column 5.

• *Costs not estimated.* All of the costs not estimated, including all of the non-monetary costs of the motor-vehicle infrastructure, are real costs of highways and vehicles, and in principle should be estimated and included in the social-cost totals. However, we were not able to make even remotely credible estimates. Of course, one should not infer therefore that these costs necessarily are trivial.

APPENDIX D. PAYMENTS BY MOTOR-VEHICLE USERS FOR THE USE OF THE HIGHWAY INFRASTRUCTURE AND PUBLIC MOTOR-VEHICLE SERVICES

There is a good deal of argument about whether motor-vehicle users "pay" fully for government-provided motor-vehicle infrastructure and services. Lee (1994), MacKenzie et al. (1992), and others have argued that payments by users fall well short of outlays by the public for roads and related services. But Beshers (1994) and Lockyer and Hill (1992) claim that road-user tax and fee payments at least equal government expenditures related to motor-vehicle use, and Dougher (1995) argues that road-user payments exceed related government outlays by a comfortable margin.

The disagreement, of course, results mainly from different opinions about how to count "user payments", although there also is disagreement about the other side of the ledger, public-sector expenditures. Some of the arguments about user payments stem from confusion about the purpose of and proper conceptual approach to whole exercise. In Report #17, I attempt to clear up some this confusion. In this Appendix I summarize briefly the results of that analysis.

I emphasize that, properly understood, the debate here is about *equity* -- whether users pay a "fair" amount -- and not about economic *efficiency*. Simply put, a comparison of current tax and fee payments, however defined, with current motor-vehicle-related costs, however defined, tells us nothing at all about optimal pricing, optimal revenues, optimal expenditures, or optimal use of public or private transportation resources. The reason for this is two-fold: i) none of the current user taxes and fees of Table 1-D1 are marginal-cost prices or optimal departures from marginal-cost pricing; and ii) efficiency does not require that revenues from user charges equal or exceed government expenditures[48].

1.D.1 Current user taxes and fees are not efficient charges for government-provided motor-vehicle infrastructure and services.

The most important condition of economic efficiency is short-run marginal-cost pricing (Table 1-2; see also Gillen [1997] and the Congressional Budget Office [1992]), which when applied to highways and public motor-vehicle services would result in a charge structure that would look nothing like the present charge structure, and which would not *necessarily* generate revenues equal to government expenditures. An efficient highway-user charge would have two components: a variable-cost charge, equal to the cost of wear of the highway per mile of travel, and a congestion charge, equal to the cost of delay imposed on all other travelers as a result of an additional mile of travel by each. (Of course, there also should be charges for environmental externalities, but I do not call these "highway user" charges.) The congestion toll can be viewed as a "capacity"

[48]If current user charges had the incidence and structure (but not necessarily the magnitude) of correct marginal-cost prices, and if it were *necessary* that optimal pricing of government-provided transportation goods and services generated user revenues at least equal to costs, then the difference between user revenues and government expenditures would indicate the minimum amount by which user charges would have to be increased in the aggregate. But even this would not be useful information, because it would not tell us how much to increase which charges.

charge, because the congestion creates “pressure” on highway capacity, and under certain conditions the congestion toll finances the optimal expansion of the highway[49].

Clearly, none of the present highway user taxes and fees are marginal-cost prices[50] as outlined above. Consider the most prominent of the present user fees, the fuel tax. The excise tax on fuel is a charge per gallon consumed. The public service and infrastructure being charged for is highway construction and maintenance. Obviously, there is no correspondence between the amount of fuel that a vehicle uses, and the amount of congestion that it causes and hence the amount of “pressure” that it places on capacity. The gasoline tax looks nothing like an optimal congestion toll.

There is a better correspondence between fuel consumption and wear and tear of the highways, because the weight of a vehicle affects both its fuel consumption and the damage it causes to the road. However, neither relationship (between weight and fuel economy, and between weight and road damage) is one of strict proportion, because many factors other than total weight affect fuel economy and road damage, with the result that a heavier vehicle may have lower fuel consumption and cause less road damage than does a lighter vehicle.

The upshot, as the FHWA (1982) notes, is that “the relationship of the fuel tax to [highway damage] costs is negligible. To impose anything approximating efficient highway user charges, new pricing instruments will need to be developed” (p. E-64; brackets mine). The Congressional Budget Office (1992) agrees, noting that “fuel taxes...do not correlate closely with the actual costs imposed by specific users” (p. 15), a problem which has “led planners to seek taxes or charges that do” (p. 11). Finally, Button (1993) remarks that “charges levied on road users relate very little to the costs of providing and maintaining the infrastructure provided let alone to wider notions of optimizing its use either from a purely traffic perspective or from a much wider social perspective” (p. 99).

The same could be said about other user fees: they certainly are not set at marginal cost[51]. Beyond this, it is clear that with efficient pricing of highways and related services, price-times-quantity revenues need not cover costs. An efficient variable-cost charge for wear and tear will cover the cost of highway maintenance and repair, but an optimal congestion toll may or not cover the optimal long-run capital cost of the highway. Indeed, the congestion toll will cover the capital cost only if: a) the road is in fact congested (even at its optimal size, it need not be)[52], and b) the cost/capacity-

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[49]The discussion of the relationship between optimal congestion tolls and optimal long-run capacity of roads can be found in texts on transportation economics (e.g., Mohring, 1976) or urban economics (e.g., Mills and Hamilton, 1984), and in articles on pricing of infrastructure (e.g., Gillen, 1997).

[50]Some road tolls, probably by coincidence, may be efficient prices. Similarly, some fines, and charges levied on producers, may be efficient (equal to marginal cost), but again most likely only by coincidence.

[51]Complicating matters in many cases is the difficulty of determining what exactly is the marginal opportunity cost of motor-vehicle use.

[52]The optimal capacity of the road is that at which the marginal cost of providing an additional unit of capacity is just equal to the total willingness to pay for the additional unit of capacity. If capacity can be added in infinitesimal increments starting at zero, then generally, willingness to pay for additional capacity will be greater than zero only if there is congestion. Thus, if all roads were perfectly malleable all the way down to nonexistence, all (are nearly all) optimally sized roads would have some congestion. (There still would be exceptions: an optimally sized road for one user could not be congested.) But roads are not perfectly malleable; they must be built in discrete units. The most important discrete jump is that

unit of the highway is constant or rising with additional capacity[53]. If these conditions are not met, there will be a revenue shortfall or surplus. Ideally, any revenue shortfall will be made up by lump-sum wealth transfers from individuals (non users as well as users) to the public sector.

1.D.2 An estimate of tax and fee payments

Table 1-D1 shows my estimates of tax and fee payments towards government provided motor-vehicle infrastructure and services. Although my estimates result in a small deficit of payments relative to expenditures (shown in Table 1-7) , there is a wide enough range of reasonable opinion about what to count as a tax and fee payment by motor-vehicle users (and for that matter, about what to count as a government expenditure), that the outcome can range from payments falling modestly short of expenditures to payments exceeding expenditures. Specifically, the outcome depends on how one defines what is "fair", and how one treats general sales, income, and property taxes on vehicles, fuels, and so on. As regards equity, or fairness, the central question is this: do we care only that people who use motor vehicles should pay for the government expenditures, in any way, and that people who don't use motor vehicles should not pay, or do we also care *how* the users pay? If our concern is only that non-users should not pay, then we will count as a "fair" payment any general sales taxes and personal income taxes, paid by motor-vehicle users, that might fund government expenditures on motor-vehicle infrastructure and services. In this accounting, all but a minuscule amount of the total government expenditures will be covered by user payments, because virtually everybody uses motor vehicles in one way or another. The tiny (and perhaps zero) portion that will not be covered will be the very small contribution of non-users, via general taxes, to the minor fraction of infrastructure and service expenditure that is financed out of general taxes rather than special user charges such as the gasoline tax.

We might, however, feel that it is not fair *enough* to require only that users pay and non-users don't, and that we should require further that users pay through their actual *use.* Put another way, we might feel that the net revenues generated by taxes and fees on vehicles, fuels, drivers, etc. should cover the net government expenditures on motor-vehicle infrastructure and services. (The ethical core of this view might be that a "fair" treatment of all transportation modes requires that each mode recover its full costs through direct user charges.) With this view, we will not count any general tax and fee payments that are made by persons who use motor vehicles but that are unrelated to the actual use.

In either view of fairness, the tally of revenues versus expenditures depends on how one treats general sales, income, and property taxes on vehicles, fuels, and so on. There are two ways to put the issue here. One is: Are these general taxes reasonably

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between no road and a one-lane road. Often it will be the case that the total willingness to pay for a one-lane road will equal or exceed its cost, but that the resultant road never will be congested. In this case, a congestion toll will generate no revenues, and the road capital cost will have to be financed by other means.

[53]There has been much debate over whether cost/capacity-unit for highways increases, decreases, or remains constant with increasing capacity. Anderson and Mohring (1997) cite studies that found constant cost, but Mills and Hamilton (1984) cite studies that found increasing or decreasing costs. If the cost/capacity is decreasing, then as discussed in Appendix B, the marginal-cost price, multiplied by quantity, will not cover total cost.

counted as payments towards government expenditures on motor-vehicle infrastructure and services, or should they be counted as payments for other general government services? The other way to put it, which I prefer, in principle can be answered formally: If vehicle ownership, fuel use, roadway mileage, and so on, increased, what *on balance* would happen to general tax revenues to government? On the assumption that the money spent on the additional vehicle use would have been spent on something else, the government would receive more general-tax revenue from the motor-vehicle sector, but less general-tax revenue from other sectors. How this would balance would depend on how much of which goods and services would be used in the two scenarios ("more motor-vehicle use" versus "the same motor-vehicle use and more use of something else"), and on the tax rates on the various goods and services.

I believe that it is most reasonable to treat general tax payments as payments for all general government services -- which include motor-vehicle-related services, but also much more (health, education, welfare, defense..) -- rather than as payments for government motor-vehicle infrastructure and services exclusively. Similarly, in my estimation, it is not likely that the government would get more general tax revenue from increased use of vehicles, fuels, and so on than from increased use of other goods and services. As a result, I prefer not to count general sales taxes, income taxes, or property taxes as payments towards government expenditures on motor-vehicle infrastructure and services.

Therefore, the accounting of Table 1-D1 includes only those tax and fee payments that are levied on or embedded in the cost of motor vehicles, motor fuels, and related goods and services. This does include a portion -- albeit a fairly small portion -- of general sales, income, and property taxes levied on or embedded in the cost of motor vehicles, motor fuels, and related goods and services. The portion that I count is the portion of general taxes that *on the average* end up funding government motor-vehicle infrastructure and services as opposed to other general government services. In any case, in Report #17 I present the full amount of most if not all conceivable tax and fee payments for motor-vehicle infrastructure and services, so that readers may make their own estimates of "fair" payments.

TABLE 1-D1. PAYMENTS BY MOTOR-VEHICLE USERS FOR THE USE OF THE HIGHWAY INFRASTRUCTURE AND PUBLIC SERVICES RELATED TO MOTOR-VEHICLE USE (10^9 1991$)

Payment item	*Low cost*	*High cost*	*Q*[a]
A1. Special taxes and fees targeted to vehicles and fuels and used for MVIS			
A1.1. FHWA-estimated federal, state, and local tax, license, and toll payments by highway users	50.4	50.4	A3
A1.2. Interest earnings on payments invested to cover highway and other capital	29.6	141.1	A3
A2. Other taxes, fees specifically related to motor-vehicle use.			
A2.1. Taxes and fees dedicated to nonhighway purposes, including collection expenses	15.3	15.3	A3
A2.2. Property-tax-like fees specifically related to motor-vehicle use	6.5	6.5	A3/4
A2.3. Extra $ due to Oct. 93 $0.043/gal tax increase[b]	--	--	A3
A2.4. The amount extra that would have been collected had there been less, or no, tax evasion[b]	--	--	C [A2]
A2.5. Air-quality, environmental fees on motor vehicles	0.0	0.0	A3
A2.6. Environmental excise taxes on petroleum[c]	0.4	0.4	A3
A2.7. Gas-guzzler taxes, luxury taxes, other minor taxes	0.3	0.3	A4
A2.8. Traffic fines and parking fines	6.0	4.0	A2
A2.9. Public parking fees and all parking taxes	4.2	5.1	A3
A2.10. Miscellaneous taxes, fees not counted elsewhere	0.0	0.0	D

Summary table continued on next page.

TABLE 1-D1, CONTINUED.

Payment item	*Low cost*	*High cost*	*Q*[a]
B. Selective taxes, fees on limited commodities and activities.[d]			
B1. Severance taxes paid on oil and gas (attributed to MV use)	1.8	0.0	A3
B2. Special property taxes	0.1	0.0	A3
B3. Special sales taxes	0.8	0.0	A3
B4. Other selective taxes and fees	0.7	0.0	A3
C1. General taxes on a wide range of commodities, activities			
C1.1. Portion of general sales taxes on motor vehicles, fuels, parts, and services	0.3	0.8	A2
C1.2. Portion of corporate income taxes paid by motor-vehicle related industries	0.2	0.6	A3
C1.3. Portion of personal income taxes paid by employees in motor-vehicle related industries	0.6	1.9	A2
C1.4. Portion of general property taxes paid on motor vehicles and by motor-vehicle related industries	0.2	0.4	A3
C2. Tax expenditures			
C2.1. Tax expenditures: corporate income taxes	0.0	(2.7)	A2/3
C2.2. Tax expenditures: general sales taxes	0.0	(3.0)	A2/3
C2.3. Tax expenditures: property taxes on highways	0.0	(5.9)	A3

See the Report #17 for details. "Low cost" means "low social costs net of user payments" and hence can have the numerically higher user payments; "high cost" means "high social costs net of user payments" and hence can have the numerically lower user payments. See Appendix 17-A.3 of Report #17 for further discussion of "low" and "high" user payments in this context.

[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] In the original version of this analysis I counted the amount extra that highway users would have paid in 1991 had the October 1993, $0.043/gal increase in the Federal excise tax and post-1991 increases in state and local highway-user taxes been in effect. I also estimated how much additional tax revenue would have been collected had there been less tax evasion. However, because the analysis now has been updated to include public costs and user payments through the year 2003, I no longer include these items for the year 1991. (Note that I estimated that the post-1991 tax increases generated about $7 billion in additional user payments, and

that the post-1991 reduction in tax evasion generated $1 to $3 billion in additional user payments. See Report #17.)

[c] Most of the environmental excise taxes are for public control and clean up of hazardous waste sites and oil spills. However, the oil-spill liability trust fund also is used to compensate for oil-spill damages. Technically, whatever amount compensates for damages should not be included here, but rather in a separate table called "payments for environmental damages", or "Pigovian taxes". These environmental charges would then be netted against environmental damages. However, the amount is too small to worry about.

[d] In the low-cost case I count all of these taxes as payments by motor-vehicle users specifically for motor-vehicle use (weight of 1.0). In the high-cost case I treat these taxes as general taxes, like a sales tax or an income tax, and count as a user payment for motor-vehicle use only the portion that on average goes into general funds and comes out as an expenditure related to motor-vehicle use.