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The Social Cost Calculator (SCC): Documentation of Methods and Data, and Case Study of Sacramento

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**THE SOCIAL-COST CALCULATOR (SCC): DOCUMENTATION OF
METHODS AND DATA, AND CASE STUDY OF SACRAMENTO**

Draft Report

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for

the Sacramento Area Council of Governments (SACOG)

and

the Northeast States for Coordinated Air-Use Management (NECAUM)

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REVISION NOTES

Revision 1, March 2006. Added adjustments to original air pollution \$/kg damage estimates to account for new information about pollution and its effects. Changed parameter values in accident cost model. Made minor changes to assumed \$/gal external costs of oil use. Reformatted and corrected typos.

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INTRODUCTION

Background

Planning agencies, analysts, non-profit organizations, regulatory and legislative bodies, and other organizations develop long-range local, state, regional, and national transportation plans. These plans typically comprise two or more alternatives, or scenarios. These alternatives have different financial costs and different impacts on travel, air quality, noise, safety, and so on. To evaluate and compare these alternatives with their different impacts, planners and analysts often use social cost-benefit analysis (CBA), which estimates the dollar value of all of the major impacts of the plan on society. With social CBA, the different plan alternatives can be compared by the single metric of net dollar benefits.

In support of social CBAs of transportation plans, I have developed an Excel Workbook, called the “Social Cost Calculator,” or SCC. The SCC estimates costs for up to *five different transportation scenarios* for up to *six different geographic areas*, in the following cost categories:

- public-sector goods and services (e.g., highway maintenance and repair, highway patrol)
- climate-change
- external costs of oil use (e.g., supply disruptions, military defense of oil supplies)
- fuel cost (resource cost, taxes, producer surplus, and costs of delay)
- noise
- accidents
- parking
- travel time and congestion
- air pollution from motor-vehicle exhaust
- air pollution from the upstream lifecycle of fuels
- air pollution from road dust, brake wear, and tire wear

For the most part, the categories listed above comprise all of the major social costs of motor-vehicle use *except* those that are efficiently paid or borne directly by motor-vehicle users such as vehicle costs, most operating costs, and some time costs. I exclude those efficiently priced costs for two reasons: i) because they are priced, they are relatively easy to estimate; and ii) because they are more or less efficiently priced, they are of no concern in an analysis of efficient use of transportation systems, and arguably are of only secondary concern in a social CBA. (They are of secondary concern in a social CBA if one believes that net private benefits per mile are likely to be similar across transportation scenarios, and consequently that differences in net social benefits among transportation scenarios are likely to be determined by differences in unpriced or inefficiently priced costs.)

Many but by no means all of the social costs listed above and estimated here are what economists call “external” costs, which can be understood to be inefficiently priced costs of motor-vehicle use (for details, see report # 9 in the UCD social-cost series [described below]). Air pollution, noise, congestion, climate change and *some* of accident, public-sector, oil-use, and fuel-use costs are externalities. Costs that are not directly related to motor-vehicle use (e.g., highway capital costs and defense expenditures), costs that are unpriced but not necessarily inefficiently so (e.g., bundled costs such as parking), and costs that are priced but not necessarily perfectly (e.g., highway maintenance costs and fuel costs), are social costs and may or may not be denominated “external” costs depending on one’s tastes.

Social costs, which include all external costs plus all non-external costs, are used in social CBA, because in social CBA one wishes to compare all of the costs and benefits to society, for each alternative. Social and external costs also are relevant to pricing and hence are useful in analyses of efficient *use* of transportation modes. Thus, social and external costs inform our comparison of alternative transportation plans and our policies for efficient use of transportation systems.

This report documents the data and methods used in the SCC, and applies the SCC to a case study of Sacramento. The Sacramento Council of Governments (SACOG) develops alternative transportation plans for Sacramento as part of its Metropolitan Transportation Plan (MTP). Here, we apply the SCC to estimate the social costs of five

different MTP alternatives (four for the year 2025, and a year-2000 baseline), for the six counties in the SACOG planning area. As part of this case study, parameter values pertinent to Sacramento are documented throughout.

Underlying source of data and methods

Most of the data and methods are derived from the comprehensive analysis of the social cost of motor-vehicle use in the United States, performed by me and my colleagues at the University of California Davis (UCD) and documented in a series of reports published over the last 10 years (www.its.ucdavis.edu/people/faculty/delucchi/). That analysis, which I refer to here as “the UCD social-cost series,” produced estimates of unit costs (e.g., \$/mi; \$/kg-pollutant; \$/gal-fuel) in each of the impact categories for “average” urban or urban-and-rural situations in the U. S in 1991. (In a few cases, for example in the case of public-sector costs, the UCD social-cost analysis produced estimates for the year 2002.) For the SCC, these unit costs originally developed for U. S. national or average urban prices and quantities in 1991 are adjusted to regional prices in 2002 and regional quantities of actual or projected levels of travel, emissions, fuel use, or population for each of the scenario alternatives (Sacramento MTP alternatives, in the case study presented here). These adjustments often are done in two steps: from U. S. 1991 to U. S. 2002, and from U. S. to the region of interest (e.g., Sacramento). This documentation details all adjustments to the original UCD national unit cost estimates, but does not reproduce any details of the development of the original U. S. 1991 unit costs. For those details, the reader is referred to the documentation reports in the UCD social cost series.

OVERVIEW OF THE SOCIAL COST CALCULATOR (SCC)

The SCC has separate sheets for each of the cost categories listed above, plus a sheet for general data inputs and sheets presenting cost summaries:

- Model inputs

- Public sector costs
- Climate change costs
- Oil use costs
- Fuel costs
- Noise costs
- Accident costs
- Parking costs
- Congestion costs
- Air pollution costs
- Upstream air pollution
- PM dust
- Cost per gal and cost per mi
- Summary of results

The “Model inputs” sheet contains general input data that characterize the transportation scenarios and the region of interest. The “Summary of results” presents total costs by cost category and transportation scenario for the region of interest, in millions of year-2002 dollars. The “Cost per gal and cost per mi” sheet gives intermediate summaries of costs per gallon of gasoline or diesel fuel and costs per mile of travel by LDVs and HDVs, by individual area and cost category, for one of the transportation scenarios. The other sheets contain the methods and data used to calculate costs in each category. These methods and data are discussed in the sections below.

Because there is a good deal of uncertainty in even detailed estimates of social costs, for most data categories in the SCC there is a “low-cost” value and a “high-cost” value. A macro called “Low_cost” reads all of the low-cost values into “active” calculation cells and runs the spreadsheet calculations and presents the results (in the “Summary of results” sheet) as pertaining to the low-cost case. A macro called “High_cost” is analogous.

MODEL INPUTS

The purpose of the SCC is to estimate social costs and external costs for different *transportation scenarios* for a particular geographic *region* of the U. S. The SCC will analyze costs for up to five different transportation scenarios, including a year-2000 baseline. The region to be analyzed in the SCC may comprise up to six individual geographic areas. As discussed more below, the transportation scenarios and individual areas are characterized by different amounts of vehicle travel, fuel use, emissions, etc. The names of the transportation scenarios, the individual areas, and the overall region are input in the “Model inputs” sheet and are used by the SCC throughout the model. (Note that the first transportation scenario must be the “main” scenario to be analyzed, and the second must be the year-2000 baseline.)

The individual geographic areas may be anything that the user wishes to analyze and has data for: cities, counties, user-delineated areas, states, or regions of the U. S. The overall region is simply the aggregation of the individual areas, and hence may be a part of a state, a whole state, a group of states, or the whole U. S. Each of the up to five transportation scenarios is simply a separate series of data sets characterizing the individual areas. For example, an analysis of transportation scenarios for the Sacramento region may contain separate data sets (VMT, fuel use, emissions, etc.) for up to six individual counties in the Sacramento region.

The “Model inputs” sheet contains general data that characterize the individual geographic areas and transportation scenarios to be analyzed. The following data are input for each of the six individual areas and five transportation scenarios:

- vehicle miles of travel (VMT) by vehicle class (light duty autos [LDAs], medium-duty trucks [MDTs], heavy-duty trucks [HDTs], buses, and motorcycles);
- fuel consumption (gallons of gasoline or diesel fuel);
- mass emissions rates of urban air pollutants, by vehicle class, scenario, and pollutant (g/mi of nitrogen oxides [NO_x], sulfur oxides [SO_x], volatile organic

compounds [VOCs], carbon monoxide [CO], and particulate matter of 10 microns or less [PM₁₀):

- average vehicle speed (mph) on all roads except local roads.

Other input data are for the year-2000 baseline scenario only, for each of the up to six individual areas:

- vehicle-minutes/day travel time
- vehicle occupancy
- person-miles of travel by mode
- bus fractions of transit, by trip purpose
- population density
- number of households
- median household income
- traffic fatalities, and
- traffic injuries.

In the case study of Sacramento, these data are from SACOG or the Bureau of the Census (2004). Finally, there are two general price inputs:

- median housing value in each county in 2002 (based, as discussed below, on U. S. Census data for 2000), and
- an input for a generic ratio of regional prices to U. S. national average prices, for use when item-specific price ratios aren't available.

I have assumed that the "generic regional/US price ratio" is 1.00 to 1.10. In the case study of Sacramento, the high is based on the ratio of median housing prices in Sacramento to the median housing price in the U. S. in 1999 (Bureau of the Census, 2004; SACOG, 2004).

Global vs. regional toggle. In most cases, the costs generated by the use of motor-vehicles in the region of interest are confined to the region of interest. For

example, the costs of noise, motor-vehicle-exhaust air pollution, accidents, and congestion due to the use of motor-vehicles in a particular metropolitan area are borne mainly or entirely by the people of that metropolitan area. However, in a few cases, some of the costs attributable to the use of vehicles in a particular region are borne by people outside of that region. For example, regional emissions of so-called “greenhouse gases” (GHGs) affect the global climate, and hence generate external costs worldwide. Similarly, the regional use of motor fuel can affect fuel taxes, oil profits, and oil markets nationally and globally. Finally, regional demand for fuel can affect the production and transport of fuels outside of a region, and hence be responsible for “upstream” fuel-cycle air-pollution damages outside of the region.

In the cases where the regional use of motor vehicles results in costs that are borne outside of the region, there is a question as to whether one should take a regional perspective, and count only those costs actually borne within the region, or a global perspective, and count all costs, no matter where they occur, attributable to the regional use of motor vehicles. Because either perspective is reasonable, the SCC has a toggle that allows users to count costs under either the “regional” or “global” perspective. If the global perspective is chosen, then the SCC uses global \$/kg damages for GHG emissions and U. S. national-average \$/kg damages for “upstream” emissions in the petroleum lifecycle, and takes a national or international perspective on oil markets and fuel taxes. If the regional perspective is chosen, then the SCC uses regional \$/kg damages for GHG emissions and “upstream” air pollution and takes a regional perspective on oil markets and fuel taxes. Details are given in the pertinent sections on climate-change costs, oil-use external costs, fuel costs, and upstream air pollution costs.

Note that a single regional/global toggle applies to climate-change costs, upstream air pollution costs, and oil markets and fuel taxes. If the global perspective is taken, and costs outside of the region of interest are counted, then climate-change damages increase but the so-called pecuniary externality of oil use disappears, and excess fuel-use costs due to delay decrease. Conversely, if only regional costs are counted, then the climate-change cost is virtually zero, but the pecuniary externality is present, and excess fuel-use costs due to delay are higher.

PUBLIC SECTOR COSTS

Definition

Public-sector costs include the full social cost of goods and services provided by federal, state, and local governments. The major items included here are highway construction and land, highway maintenance and repair, unpriced public parking (because priced public parking is a directly and efficiently paid cost, and hence not included in this analysis), and highway patrol and safety services. (The Strategic Petroleum Reserve [SPR] also can be classified as a public-sector cost, but in this analysis it is classified and estimated as an oil-use cost.) Other less important items include the motor-vehicle related portion of the following services: police-protection services other than the highway patrol, fire-protection services, the court system, the prison system, and pollution regulatory agencies. The cost of private roads is estimated in this section of the SCC, because the methods are similar to those used to estimate highway construction costs, but it is classified in the “summary of results” sheet as a bundled cost.

Other services (non-highway patrol police, fire, etc.) and unpriced public parking can be considered external costs of motor-vehicle use, although the link between motor-vehicle use and the cost of other police and fire services is not direct. The capital cost of the highway is not a cost of motor-vehicle *use*, and hence is not an external cost. Highway maintenance and patrol are paid for out of user fees, but these fees are far from efficient prices. Hence, whether to classify these maintenance and patrol costs as “externalities” is a matter of judgment. (I prefer to classify them as external costs.)

Methods

The total cost in each category is calculated simply as the product of an estimated cost-per-mile (CPM) and VMT. The CPM term is the product of the CPM in the U. S. in 2002 (1991, in the case of unpriced public parking), a U. S. 2002/US 1991 price scalar (applied to parking only), and a regional/US price scalar. Note that by applying *price* scalars only I am assuming that the relevant *quantity* – the amount of public goods or services per unit of travel – is the same in the region of interest in 2002 as it was

estimated to be for the U. S. in 1991. I make this assumption because I have no basis for assuming anything else.

The U. S. 2002 CPM in each category is estimated within the SCC as a nonlinear function of changes in travel. Complete documentation of these U. S. 2002 national cost functions is provided in report #7 in the UCD social cost series. These functions produce within the SCC estimates of the change in the CPM, in each public-sector cost category, associated with a given change in VMT. As mentioned above, these initial U. S. 2002 CPM estimates are multiplied by regional/national scaling factors to get from U. S. to regional price levels.

Because the CPM depends on the VMT change, the SCC first estimates the CPM for a 100% reduction in VMT from year 2000 levels, and then multiplies this by year-2000 VMT to produce an estimate of the total cost for the year 2000. To estimate the cost for year 2025 alternatives, the SCC first calculates the change in VMT from 2000 to 2025, and then multiplies the resulting CPM by the difference in VMT between 2000 and 2025, to produce an estimate of the total cost of the additional VMT beyond the year 2000. The total cost for a year 2025 alternative is equal to the year 2000 cost plus the cost of going from year 2000 to year 2025 VMT.

Data

U. S. average 2002 CPM. The parameter values used in the SCC functions that calculate the U. S. average 2002 CPM are taken directly from report #7 in the UCD social cost series.

U. S. year 2002/US year 1991 prices. This is applied only to unpriced public parking costs, which is the only public-sector cost item estimated in 1991 dollars. For the purpose of estimating this price ratio for parking, the ratio of the 2002 PPI to the 1991 PPI in the following categories is relevant (BLS, 2004a):

- 1.21 Highway and street construction
- 1.19 Maintenance and repair construction
- 1.16 Other heavy construction
- 1.19 Non-residential buildings

Regional 2002 /US 2002 prices. All costs are scaled by the “generic regional/US price ratio” specified in the “Model inputs” sheet.

VMT. The model user provides data on VMT by vehicle class and individual area within a region, for each transportation scenario (in the “Model inputs” sheet).

CLIMATE CHANGE COSTS

Definition

Climate-change costs are the dollar value of the damages from climate change attributable to emissions of greenhouse gases (GHGs) from the use of motor-vehicles. There are several distinct parts to this definition:

Damages are the monetary value of the actual impacts of climate change, as opposed to the monetary costs of controlling emissions of GHGs.

The *impacts of climate change* are global, but as a matter of policy analysts might be interested only in the damages in a particular region or country. Hence, in the SCC, the user may estimate damages globally or damages only in the overall region of interest.

GHGs comprise all air emissions that have any effect on climate, directly or indirectly.

Emissions from the use of motor vehicles include emissions related to producing transportation fuels as well as emissions from direct combustion of fuels. (See Delucchi’s [2003] Lifecycle Emissions Model [LEM] for a complete discussion of GHGs and the lifecycle of fuels.)

The use of motor-vehicles refers to the use of motor vehicles in the particular region of interest (e.g., Sacramento, California, or the Northeast States.) Thus, the analysis here encompasses much more than just CO₂ from fuel combustion by vehicles: it is a multi-gas, lifecycle analysis, covering all sources of emissions of all climate-relevant gases. It also distinguishes between regional and global damages.

Methods

The total climate-change damage cost is calculated as the product of three terms:

- CO₂ emissions from the combustion of gasoline and diesel fuel;
- the ratio of lifecycle emissions of CO₂-equivalent emissions to CO₂ emissions from the combustion of gasoline or diesel fuel; and
- the damage cost per unit of CO₂-equivalent GHG emitted (discussed more below).

CO₂ emissions from the combustion of gasoline and diesel fuel, in turn, are calculated by multiplying the carbon content of the fuel, the fuel density, and the fuel quantity consumed.

The ratio of lifecycle emissions of CO₂-equivalent emissions to end-use CO₂ emissions scales the end-use emissions to account for emissions of GHGs other than CO₂ and for emission sources other than end use. For a complete discussion of lifecycle emissions analysis, see the documentation to the LEM (Delucchi, 2003).

The damage cost of CO₂. As indicated above, the measure “the damage cost per unit of CO₂-equivalent GHG emitted” is defined more precisely as “dollar damages from climate change in *either* the world *or* in the region of interest, per unit of lifecycle CO₂-equivalent GHG emitted from the use of motor-vehicles in the region of interest.” I make this distinction because even though emissions of GHGs attributable to the use of motor vehicles in the region of interest (e.g., the Sacramento region) affect climate worldwide, the analyst may be interested only in damages within the particular region of interest. To accommodate this possibility, the SCC has a toggle that allows the user to select whether damages are calculated for the whole world or just for the region of interest.

The estimation of the damage cost of climate change per unit of CO₂ therefore begins with an estimate of global damages/kg. If the user specifies that global damages are to be counted, then the SCC uses this input global \$/kg value. However, the user also can input the ratio of damages in relevant regions and subregions of the world to damages globally. From these ratios the SCC calculates an overall ratio of damages in

the region of interest to damages globally. If the user specifies that damages in the region of interest only are to be counted, the SCC multiplies the \$/kg-global-damage value by the overall ratio of damages in the region of interest to global damages. For example, in the case study of Sacramento, the user specifies the ratio of U. S. ("REGION1" in the SCC) to global damages, the ratio of California ("REGION2") to U. S. ("REGION1") damages, and the ratio of Sacramento (the region of interest) to California ("REGION2") damages.

(Note that in most cases if climate-change damages are limited to the region of interest then they turn out to be trivial.)

Data

Emissions parameters. Carbon contents, fuel densities, and ratios of fuelcycle CO₂-equivalent emissions to end-use CO₂ emissions are derived from the LEM (Delucchi, 2003). To derive the ratios, the LEM was run for the year 2025, with diesel-vehicle fuel economy set at 5/7 city/highway mpg (simulating heavy trucks) and gasoline-vehicle fuel economy at 18/26 city/highway mpg. The LEM estimates that the ratio of non-CO₂ to CO₂ emissions (on a CO₂-equivalent basis) from end use is 0.31 for diesel vehicles and 0.15 for gasoline vehicles, the ratio being higher for diesel vehicles because of relatively high emissions of black carbon, a strong GHG. The ratio of upstream CO₂-equivalent emissions to end-use CO₂ emissions (on a gram-CO₂-equivalent/10⁶-BTU-fuel basis) is 0.19 for diesel fuel and 0.27 for gasoline. ("Upstream" refers to all sources in the lifecycle of fuels up to and not including actual end use.) These figures imply overall ratios (lifecycle CO₂-equivalent/end-use-CO₂) of 1.46 for gasoline and 1.56 for diesel fuel. I bracket these with ranges, 1.40 to 1.50 for gasoline, and 1.50 to 1.60 for diesel fuel. Although these ratios are based on U. S. conditions, ratios for Sacramento specifically are not likely to be appreciably different. Therefore, I assume that these ratios apply to all fuel use in all Sacramento MTP alternatives.

Unit damages. The \$/Mg-CO₂ global damage figures are based on the literature analysis and summary presented in revised report #9 in the UCD social-cost series. That analysis indicates that global damages per unit of CO₂-equivalent emission are anywhere in the range of \$1.0 to \$10 per 10⁶ grams of CO₂ equivalent emitted, in 2002

U. S. dollars. If the analyst chooses to estimate damages in the region of interest only, the global damages are scaled in up to three steps: <REGION1>:<global>, <REGION2>:<REGION1>, and <region of interest>:<REGION2>. In the case study of Sacramento, these ratios are: US:global = 0.0 (low) or 0.14 (high) (based on estimates in revised report #9 in UCD social-cost series, which indicate that the U. S. bears a relatively small fraction of global damages, partially on account of its ability to adapt to climate change); CA:US = 0.10 (low) or 0.25 (high) (based partly on California's share of national GNP {which is about 0.12}, but also on assumption that California is more sensitive to climate change [on \$-damage/\$-GDP basis] than is the U. S. on average), and Sacramento:CA = 0.05 (low) or 0.07 (high) (my estimate). The result is that unit damages in Sacramento are only 0.03% to 0.17% of global unit damages. (This scaling ignores price differences between Sacramento and the U. S., because such differences are utterly trivial compared with the scaling factors just derived.)

Fuel use. The model user provides data on gasoline and diesel fuel use by individual area within the region and transportation scenario (in the "Model inputs" sheet).

OIL-USE EXTERNAL COSTS

Definition

Oil-use external costs include the following:

- The capital, operating, and oil-holding costs of the SPR. The oil-holding cost (which may be a negative cost) can be viewed as the cost of investing funds in oil (by holding it in the reserve) versus in another opportunity.
- Military expenditures related to protecting vulnerable crude oil supplies.
- The pecuniary externality of higher prices in non-transportation oil-using sectors caused by the demand for transportation petroleum.
- The potential loss in GNP due to using oil, which arises from the inability of the economy to adjust instantly to rapid changes in the price of oil.

- Water pollution costs arising from oil spills, oil runoff, and groundwater contamination by leaking petroleum storage tanks.

The pecuniary externality and the GNP cost bear further elaboration.

Pecuniary externality. The use of oil in transportation raises the price of and hence consumer payments for oil in non-transportation sectors such as heating or power generation. These higher payments are a cost to oil consumers, but in the global market are balanced by a corresponding benefit (a gain in revenue) to oil producers. In economic parlance, so long as we are considering the welfare of producers and consumers together, there is no net external cost within the system, just a transfer. However, if the analysis focuses on a particular region which has oil consumers but not oil producers, then by this focus the cost to consumers is *not* balanced by the benefit to producers (because the oil producers are outside of the boundaries of the analysis). This sort of net cost, which is dependent upon changes in prices without attendant changes in production functions, is referred to as a pecuniary externality. (A similar issue arises in regards to the non-cost “producer surplus” portion of the price of transportation fuel, and is addressed here in the section on “Fuel costs.”)

Price-shock GNP cost. This cost refers to the loss of economic output that results from sudden changes in the price of oil, apart from the cost directly embodied in the higher price-times-quantity payment for oil. Put another way, it is 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 (because the price-times-quantity payment for fuel already is counted as part of the “fuel cost” estimated in the SCC).

Are all of these oil-use costs external costs? For some of the oil-use impacts, the relationship between the use of petroleum and the existence and magnitude of any external cost is tenuous. This is particularly true of expenditures for defense and the SPR, which do not vary directly and explicitly with the use of motor-fuel by transportation. For this reason, some users may wish to not count these as external costs, or even to not count them as costs of motor vehicle use at all. (Users may designate which costs are external in the “Summary of results” sheet). Nevertheless,

these concerns notwithstanding, I prefer to count all of the oil-use costs listed here as external costs.

Methods

General. In general, oil-use costs are estimated by multiplying the damage cost per gallon of gasoline or diesel fuel, in each cost category (SPR, defense expenditures, etc.), by the quantity of gasoline or diesel fuel consumed. The damage cost per gallon (\$/gal) is the product of three factors:

- the damage cost per gallon (\$/gal) for the whole U. S. in 1991;
- the ratio of unit costs in the U. S. in 2002 to unit costs in 1991;
- and the ratio of unit costs in the region of interest (e.g., Sacramento) to unit costs in the whole U. S.

(Note that these unit cost scalars may include relevant quantity changes as well as price changes.) Details on the methods used to calculate the damage cost per gallon for the U. S. in 1991 are provided in report #7 (SPR), report #8 (price-shock costs, pecuniary externality), report #9 (water pollution), and report # 15 (defense expenditures) in the UCD social-cost series.

Focus on the pecuniary cost of oil use. Although the calculation of the \$/gal pecuniary external cost of oil in the region of interest follows the general method outlined above, there are additional details that warrant elaboration here.

The pecuniary external costs of oil use for any region are a function of the price of petroleum and of quantities that involve consumption of non-transportation oil relative to consumption of transportation oil and the amount of imported oil. The price of petroleum is relevant because it determines the magnitude of payments from consumers to producers. Non-transportation oil consumption relative to transportation oil consumption is relevant because the pecuniary external cost is based on the affect in the non-transport oil sector of using oil in the transport sector. The quantity of oil imported to the region of interest is relevant because if we take a regional (local) perspective we must distinguish between revenues that accrue to local producers and revenues that accrue to non-local producers. (This is discussed more in the next subsection.) Report #8 in the UCD social-cost series provides additional details.

In the SCC calculation of the pecuniary externality, the quantities that involve consumption of non-transportation oil relative to consumption of transportation oil and the amount of imported oil are defined formally as follows. First we have the ratio of:

<consumption of *imported* non-transportation petroleum in region X>

to: <consumption of transportation petroleum in region X>.

Let us call this ratio PER. Next is a closely related parameter, the ratio of:

<consumption of *all* non-transportation petroleum in region X>

to <consumption of transportation petroleum in region X>.

Call this ratio PER[^]. Note that the difference between PER[^] and PER is that PER[^] is based on *all* non-transportation petroleum, whereas PER is based on *imported* non-transportation petroleum.

With these parameters defined, we may now delineate the complete calculation of the pecuniary externality. In the SCC, the \$/gal pecuniary external cost in the region of interest in 2002 is calculated by multiplying the following factors:

- the \$/gal external cost for the U. S. in 1991;
- the ratio of non-transport petroleum prices in the U. S. in 2002 to non-transport petroleum prices in the U. S. in 1991;
- the ratio of non-transport petroleum prices in the region of interest in 2002 to non-transport petroleum prices in the U. S. in 2002;
- the ratio of PER in the region of interest in 2002 to PER in the U. S. in 1991.

The quantity PER for the region of interest in 2002 is itself the product of two factors:

- PER[^] for the region of interest in 2002;
- and the imported fraction of non-transport petroleum for the region of interest in 2002.

Now, in the estimation of "Fuel use costs," there is a parameter for the fraction of producer surplus in the oil industry that accrues within the region of interest. This can be understood to be the same as the fraction of petroleum that is produced within the region of interest – i.e., the fraction that is *not* imported. Hence, the fraction that is imported – which is what we are interested in here – is just one minus the producer surplus fraction specified in the "Fuel use costs" sheet.

The pecuniary cost of oil use: regional vs. global perspective. Whether the pecuniary impact of oil use is counted as an actual external cost depends on whether a regional or global perspective is taken. (As noted elsewhere in this report, the SCC has a toggle that allows the user to select which perspective is taken.) If a regional perspective is taken, then only regional costs and benefits are counted. In this case, the portion of the higher payment for non-transportation oil that accrues to oil producers outside of the region of interest is a pecuniary external cost, because it represents a net loss to oil consumers within the region of interest. (Any portion of the higher payment that accrues to oil producers within the region of interest is *not* counted as a pecuniary external cost because it is a transfer from oil consumers to oil producers within the region of interest.)

If a global perspective is taken, then oil producers everywhere gain in higher revenues whatever local oil consumers pay in higher prices, and there is no net economic cost, only a transfer. In this case, the pecuniary externality is zeroed out.

Data

Reference damage costs, US 1991. The estimates of the U. S. average 1991 cost per gallon for all oil-use external cost categories are taken directly from report #8 in the UCD social cost series, which summarizes estimates developed in reports 7, 8, 9, and 15.

US year 2002/US year 1991 unit costs. The cost of the SPR is a function of the current versus the expected future price of oil, construction costs, and operating and maintenance (O&M) costs. Construction and O&M costs have increased since 1991, but the expected cost of future versus current oil may not have. I assume that for the SPR \$-per-gallon cost the US 2002/1991 price ratio is 1.20 (low) to 1.40 (high).

The \$/gallon cost of military expenditures related to protection of foreign oil undoubtedly has increased, definitely because of increases in prices and possibly because of increases in the amount of defense per gallon of fuel. I assume a 2002/1991 unit cost ratio of 1.20 (low) or 1.40 (high).

The pecuniary externality \$/gallon cost for the U. S. is a function of the price of petroleum, the ratio of imported to total petroleum, and other factors (Report #8 in the UCD social-cost series). Gasoline prices in 2002 were about 20% higher than in 1991

(EIA, 2004a). The ratio of imported to total petroleum may have changed from 1991 to 2002, but rather than update this to the U. S. in 2002 and then compare that with the region of interest in 2002, I will compare the region of interest (e.g., Sacramento) in 2002 with the original U. S. 1991 estimates directly, in the next subsection. Hence, I assume here US 2002/US 1991 price factors of 1.10 (low) to 1.20 (high).

Price-shock costs per gallon may be presumed to increase with the price of fuel and with the ratio of fuel consumption to GPD, although not necessarily linearly (Greene, 2000; Leiby et al., 1997). The GDP /fuel ratio was in 0.021 in 1991 and 0.016 in 2002 (BEA, 2004; FHWA, 2004a), and the price of gasoline was \$1.20 in 1991 and \$1.44 in 2002 (EIA, 2004a). Thus, the GDP /fuel ratio decreased by 0.74, and the fuel price increased by 1.20. Multiplying the two yields an overall US 2002/US 1991 factor of 0.89, which I use in the low case. For the high case I use a factor of 1.0.

Water pollution costs are a function of exposure and valuation (prices). I assume a general increase in the relevant prices of 1.20 (low) to 1.40 (high). Differences in exposure between that embodied in the original 1991 estimates and that in any particular region in the years 2000 and 2025 are ignored, as discussed below.

Regional unit costs vs. US unit costs. Since the SPR is a federal U. S. cost, it does not involve any regional price differences, which means that the regional/U. S. adjustment for the SPR is 1.0.

In the low case, I assume that defense expenditures are related to the value of crude oil. For the Sacramento case study, we note that since crude oil is not produced in the Sacramento region, the Sac/US factor is 1.0. In the high case I assume that defense expenditures are related to the value of the finished fuel, the idea being that higher fuel value puts more “pressure” on defense expenditures. (Note that in recognition of the tenuousness of this link between fuel use and defense expenditures, the user may choose to not count defense expenditures as an external cost in the “Summary of results” sheet.) According to EIA data on gasoline and diesel fuel prices in California and the U. S., diesel fuel is about 9% more expensive in California than in the U. S. (EIA, 2004b), and gasoline is about 13% more expensive (EIA, 2004d).

As detailed in the “methods” section, the \$/gal pecuniary external cost for any region in 2002 is a function of the \$/gal cost for the U. S. in 1991, petroleum prices in the

region relative to prices in the U. S. in 2002, and the parameter PER for the region in 2002 relative to the parameter PER for the U. S. in 1991 . The parameter PER for the region is a function of the parameter PER^{\wedge} and the fraction of non-transportation petroleum imported to the region.

- I estimate that for the U. S. in 1991, PER is 0.45 to 0.73 (report #8 in the UCD social-cost series).
- EIA (2004c) data on petroleum consumption for California indicates that PER^{\wedge} is 0.34 for the state. Given this, I assume a range of 0.30 to 0.40 for the Sacramento case study.
- Here, the imported-oil fraction is calculated as 1 minus the *non-imported oil* fraction specified in the “Fuel use costs” section. In the Sacramento case study, non-imported oil is 0%, so the imported-oil fraction is 100%.
- On the basis of data cited in the “Fuel use costs” section that indicate that motor-fuel prices are higher in California than in the U. S., I assume that prices of non-transport petroleum are a 0% to 10% higher in Sacramento than in the U. S.

Price shock costs are related to characteristics of the economy. In the Sacramento case study, I have no basis for assuming that Sacramento in particular would be affected any differently than would the nation on average, so to bracket this I assume a Sacramento/US factor of 0.90 in the low case and 1.10 in the high case.

Water pollution costs are a function of the frequency of leaks and spills, exposure, and valuation parameters. I assume that because of its long coastline and significant receipt of crude oil by ship, California (and hence Sacramento) generates more water pollution per unit of oil consumed than does the nation on average. I also assume in the high-cost case that valuation parameters (prices) are slightly higher in Sacramento than in the nation on average. Combining these two, I assume Sacramento/US factors of 1.30 (low) and 1.40 (high), for all MTP plan alternatives.

In the case of water pollution I ignore differences in exposure between the region of interest in 2002 and the U. S. in 1991, because the original unit costs (for the U. S. in 1991) were not based on formal models with explicit exposure terms, and in any case were very uncertain (see report #9 in the UCD social-cost series).

Fuel use. The model user provides data on gasoline and diesel fuel use by individual area within the region and transportation scenario (in the “Model inputs” sheet).

FUEL-USE COSTS

Definition

For the purpose of estimating social and external costs of transportation, the retail price of motor fuel has several relevant components:

Fuel taxes are federal, state, and local excise and sales taxes on gasoline and diesel fuel. Taxes are distinguished because they may be either a non-cost transfer from consumers to government, in the case in which both consumers and government are included within the boundaries of the analysis, or else a net cost to consumers, in the case in which some tax receipts by government are excluded from the analysis¹.

Producer surplus is the revenue that oil producers receive above and beyond that which covers normal economic cost, where “normal economic cost” includes a normal return on investment, or profit. Producer surplus is distinguished because it may be either a non-cost transfer from oil consumers to oil producers, in the case in which both consumers and producers are included within the boundaries of the analysis, or else a net cost to consumers, in the case in which some revenues to producers are excluded from the analysis.

¹ While fuel taxes do not in themselves represent social costs (because they are transfers), changes in tax revenues can have implications for government revenue collection that in turn can result in real welfare gains or losses. Suppose that there is a loss of fuel-tax revenue, and that government wants to maintain a constant level of total revenue. Government then will have to raise revenue elsewhere. These alternative sources of revenue may have a different distortionary effect on the economy than the fuel tax did. For example, if a more price-elastic activity or commodity is taxed to make up for the lost fuel tax, then there will be a greater social deadweight loss (i.e., greater foregone consumer and producer surplus due to the reduction in output caused by the tax) than there was with the fuel tax. The difference between the deadweight loss with the new revenue source and the loss with the fuel tax is a real welfare cost to society.

The *cost of fuel net of taxes and producer surplus* is equal to the full retail price less taxes and producer surplus. This portion of the fuel price is a social cost regardless of the boundaries of the analysis.

The *total cost of excess fuel consumed due to delay* is the value of the additional fuel consumed due to fuel economy being lower in congested conditions than in uncongested conditions. This category is distinguished because it is an external cost of travel. I estimate it here, as a fuel cost, rather than as a cost of travel, because the methods used to estimate it are different from the methods used to estimate travel-time costs.

The *total cost of fuel consumed excluding that due to delay* is the value of all fuel consumed excluding any “excess” fuel consumed due to fuel economy being lower in congested conditions than in uncongested conditions (see above). This is not an external cost.

Methods

The cost (price) of fuel: regional vs. global perspective. The relevant cost of fuel depends on whether a regional or global perspective is taken. (As noted elsewhere in this report, the SCC has a toggle that allows the user to select which perspective is taken.) If a regional perspective is taken, then only regional impacts are counted. In this case, the regional cost of fuel is equal to the price net of taxes and producer surplus, plus the amount of tax that does *not* accrue (directly or indirectly) within the overall region of interest and the amount of producer surplus that does *not* accrue to producers within the overall region of interest. (The amounts that *do* accrue within the overall region of interest are transfers and hence not costs.)

The producer-surplus fraction of the fuel price, the fraction of producer surplus that accrues to regional (local) oil producers, and the fraction of taxes that accrue to regional governments, are input parameters. One set of parameter values is used for all areas and all transportation scenarios.

If a global perspective is taken, then taxes and producer surplus are, to a first approximation, a transfer from consumers to government or producers and hence not

a real economic cost. In this case, the relevant cost of fuel is the price net of all taxes and of producer surplus.

The total cost of excess fuel consumption resulting from delay. The total cost of excess fuel consumption resulting from travel delay is estimated as the gallons of excess fuel consumed due to delay multiplied by the relevant cost (price) of fuel in the analysis. The relevant cost of fuel in the analysis is discussed above. The amount of excess fuel consumed due to delay is estimated as a function of:

- the fuel economy during delay vs. the fuel economy during free flow (one value is used for all areas and all transportation scenarios);
- the fraction of travel time subject to delay (discussed below),
- the ratio of the average speed during delay to the average speed during free flow, over miles subject to delay;
- and the total amount of fuel consumed under all conditions.

The formulae, which are included in the SCC, are developed in report #5 in the UCD social-cost series.

The fraction of travel time subject to delay is calculated for each scenario analysis as a function of:

- the average speed for the scenario;
- the ratio of the average speed during delay to the average speed during free flow, over miles subject to delay;
- and the average speed over all miles if with no delay anywhere.

The average speed with no delay anywhere is calculated on the basis of year-2000 conditions and is assumed to be the same for all transportation scenarios. (See report #5 in the UCD social-cost series for details.)

The total cost of fuel *not* resulting from delay. The total cost of fuel *not* resulting from travel delay is estimated as the total amount of fuel used less excess fuel consumed due to delay, multiplied by the relevant cost of fuel in the analysis.

Data

Fuel price components. In the following, fuel price components are documented for the Sacramento case study.

The EIA (2004b, 2004d) provides data on gasoline and diesel fuel prices in California and the U. S., and the FHWA (2004c) provides data on federal and state excise taxes and state sales taxes on motor fuels. Data for 2002 are:

Diesel fuel				
	<i>U. S.</i>	<i>CA</i>	<i>CA:US</i>	<i>Notes</i>
Pre-tax price (\$/gal, except ratio)	\$1.05	\$1.19	1.13	Price of highway diesel fuel, before taxes, all sellers, average of all months in 2002 (EIA, 2004b)
Federal and state excise taxes (\$/gal)	\$0.44	\$0.42		Federal plus state excise taxes on diesel fuel, March 2002 (FHWA, 2004c) (weighted state average in case of U.S.).
State sales tax on motor fuel (%)	2%	6%		U. S. is my estimate of national average state sales tax on motor fuel, based on Census data (report #17 in UCD social-cost series). California is state sales tax on motor fuel (applied to price including excise taxes) (FHWA, 2004c). There may be additional local taxes.
Retail price including federal and state taxes (\$/gal, except ratio)	\$1.51	\$1.67	1.11	Doesn't include any local taxes.
Gasoline				
	<i>U. S.</i>	<i>CA</i>	<i>CA:US</i>	<i>Notes</i>
Pre-tax price (\$/gal, except ratio)	\$1.08	\$1.17	1.09	Price of regular reformulated gasoline, before taxes, all sellers, average of all weeks in 2002 (EIA, 2004d)
Federal and state excise taxes (\$/gal)	\$0.38	\$0.36		Federal plus state excise taxes on motor gasoline, March 2002 (FHWA, 2004c) (weighted state average in case of U.S.).
State sales tax on motor fuel (%)	2%	6%		U. S. is my estimate of national average state sales tax on motor fuel, based on Census data (report #17 in UCD social-cost series). California is state sales tax on motor fuel (applied to price including excise taxes) (FHWA, 2004c). There may be additional local taxes.
Retail price including federal and state taxes (\$/gal, except ratio)	\$1.47	\$1.60	1.08	Doesn't include any local taxes.

	<u>U. S.</u>	<u>CA</u>
Ratio of gasoline to diesel fuel, pre-tax price	1.03	0.99
Ratio of gasoline to diesel fuel, price incl. taxes	0.98	0.96

On the basis of these data and further details not presented here, I assume the following for all transportation scenarios and all individual areas within the Sacramento region:

	<u>gasoline</u>	<u>diesel</u>
Cost of fuel, excluding all taxes (\$/gal)	1.200	1.200
Federal excise tax (\$/gal)	0.184	0.244
State excise tax (\$/gal)	0.180	0.180
State and local sales tax (% of cost+excise tax)	7.25%	7.25%

I assume that 100% of the total tax accrues directly or indirectly within the Sacramento region. (That is, I assume that fuel taxes paid in Sacramento do not, on balance, subsidize transportation or other government projects outside of the region. Put another way, I assume that Sacramento gets back in transportation-related and other benefits an amount equal to the local, state and federal taxes it pays into the pot.) This applies to all areas and transportation scenarios.

On the basis of estimates presented in report #5 in the UCD social-cost series, I assume that the producer surplus is 20% to 30% of the pre-tax cost of fuel. This applies to all areas and transportation scenarios. I assume that none of this producer surplus accrues within the Sacramento area.

Change in fuel economy when delay is eliminated. Fuel economy can improve drastically when delay is eliminated, because when delay is severe and vehicles spend a lot of time idling -- consuming fuel but not going anywhere -- they drive very few miles per gallon of fuel consumed. I assume that eliminating delay completely increases fuel

economy by about 50% over that in delayed conditions. I bracket this with a low of 40% and a high of 60%. These apply to all areas and transportation scenarios.

Delay/free-flow speed. The ratio of the average speed during delay to the average speed during free flow, over miles subject to delay, is taken from report #8 in the UCD social-cost series.

Scenario average speed. The average speed for each transportation scenario is specified in the “Model inputs” sheet.

Fuel use. The model user provides data on gasoline and diesel fuel use by individual area within the region and transportation scenario (in the “Model inputs” sheet).

Comparison with TTI estimates of excess fuel use

The Texas Transportation Institute (TTI; Schrank and Lomax, 2004) performs detailed analyses of the annual costs of congestion in major metropolitan areas in the U. S. They estimate that congestion caused the consumption of an extra 46 million gallons of fuel in the Sacramento metropolitan region, or 1.6 gal/VMT/day given their estimate of 28.5 million VMT/day. Our model estimates 39 to 77 million gallons of excess fuel consumption due to delay, or 0.9 to 1.8 gal/VMT/day given 43 million VMT in the five-county SACOG region. The TTI estimate falls within this range.

NOISE COSTS

Definition

Noise costs are the value of damages inflicted by noise from the use of motor vehicles. They include the value of “defensive” expenditures as well as unmitigated damages, and include damages to people in business and commercial as well as residential settings. All estimated noise costs are externalities of motor-vehicle use.

Methods

Noise costs are the product of three factors:

- VMT (by vehicle class: LDAs, MDTs, HDTs, buses, and motorcycles);
- noise CPM by vehicle class; and
- exposure scalars.

These products are summed over all vehicle classes. The exposure factors scale the results from the exposure basis in the original U. S. 1991 estimates to that pertinent to each of the transportation scenarios. The noise CPM is itself the product of three factors:

- CPM for U. S. urbanized areas in 1991 by type of vehicle and type of road (interstate highways, other freeways, principal arterial, minor arterial, collector, local road);
- distribution of VMT by type of road; and
- the ratio of relevant prices in the region in 2002 to prices in the U. S. in 1991.

Data

CPM in the U. S. in 1991. The 1991 U. S. CPM and travel fractions by type of vehicle and type of roadway are taken from report #14 in the UCD social-cost series. Complete details are available in that report.

Regional 2002 prices/US 1991 prices. The main time-and-place specific determinants of the CPM are the median value of housing and the density of housing (report #14 in the UCD social-cost analysis). The CPM is proportional to these two factors. The exposure factor (housing density) is discussed in the next subsection. For the Sacramento case study, we scale from a U. S. 1991 price basis to a Sacramento 2002 price basis by multiplying the original CPM by the ratio of the median housing price in Sacramento in 2002 to the median housing price used in the U. S. 1991 analysis. (Housing price is the correct parameter because as just mentioned it is the actual parameter in the detailed noise cost model in report #14 in the UCD social-cost analysis. Although it is possible that the percentage noise damage per dollar of housing value – another key parameter in the original noise analysis -- decreases with large

jumps in housing value, I ignore this possibility.) This housing-value scaling is done county by county in the SACOG region. U. S. Census data (SACOG, 2004) gives the median housing price by county in 2000. I multiply these by 1.15 (my estimates) to get prices in 2002. In the original noise analysis the median housing price in the urbanized areas of the analysis in 1991 was \$115,226 (unpublished value extracted from noise model used in report #14 in the UCD social cost series).

Exposure scalars. As a proxy for housing density (the actual parameter in the noise-cost model that generated the original U. S. 1991 unit costs) I use population density in Sacramento counties in the years of the SACOG MTP plan alternatives (2025 and 2000) relative to the population density in the original 1991 U. S. analysis.

Population density in the Sacramento counties in the year 2000 is based on the year 2000 Census, and is provided by SACOG. Population density in the year 2025 is estimated by multiplying the year-2000 density by a 2025/2000 scaling factor, which I assume to be 1.15 for all counties. (Schrank and Lomax [2004] estimate the density in the urban area of Sacramento increased by 15% from 1982 to 2001.) The average urbanized-area population density in the original 1991 U. S. analysis is 2594 persons/mi² (unpublished value extracted from the noise model used in report #14).

VMT. The model user provides data on VMT by vehicle class and individual area for each transportation scenario (in the “Model inputs” sheet).

ACCIDENT COSTS

Definition

Accident costs include all the costs to society associated with motor-vehicle accidents. Nonmonetary costs, such as pain and suffering and lost quality of life, are included as well as monetary costs such as property damage. Personal costs, which are borne by people responsible for accidents, are included as well as external costs. Costs to nonmotorists, such as bicyclists and pedestrians, are included as well as costs to motorists. Public sector costs are included as well as private sector costs. The complete list of accounted-for costs is:

- medical costs, including funeral-related expenses,
- emergency services,
- workplace costs, including worker retraining,
- lost market productivity,
- lost nonmarket productivity, including household productivity,
- changes in general consumption,
- insurance administration and legal costs,
- property damage,
- lost quality of life associated with fatalities and injuries.

For the purpose of classifying cost estimates in the “summary of results” sheet, the externality fractions of the above costs are distinguished from the non-externality fractions and counted as external costs in the summary. The definition and treatment of the externality fraction in this context is somewhat complex, and is presented in detail in report #19 in the UCD social-cost series and not reviewed here.

Methods

At the most general level, the accident cost is estimated as the total social cost per accident of a given severity class multiplied by the number of incidents in the severity class, with this product being summed over all accident severity classes. The accident severity classes are: property damage only, six classes of injury (from uninjured to severely injured), and fatalities. The total social-cost per accident severity class is the sum of the costs in each of the cost categories listed above (medical costs, insurance administration, etc.) for that severity class. Thus, the basis unit cost is the cost in each cost category and severity-class (for example, the medical costs of injury severity class 5). These basic unit costs are equal to U. S. average unit costs in 2002 dollars multiplied by regional/US cost ratios.

The number of incidents in each accident severity class are a nonlinear function of the number of accidents in a base year, changes in VMT, and changes in average

speed. Thus, accident costs for each transportation scenario are calculated on the basis of projected VMT and vehicle speeds in the scenario relative to base-line values.

Further calculations distinguish external costs from non-external costs. Payments for liability insurance premiums are a part of the calculation of external costs. Liability insurance premium payments in the region are calculated by multiplying the payment rate per mile nationally by regional VMT and by a regional/US insurance CPM price ratio.

The “accident costs” sheet in the social-cost model includes a complete version of the accident cost model developed for this project and documented in report #19 in the UCD social-cost series, with some parameter values condensed. Because the accident cost depends on changes in VMT and speed, the model first estimates the cost for a 100% reduction in VMT from year-2000 levels. This is the cost of the year-2000 plan alternative. To estimate the cost for year-2025 alternatives, the model calculates change in VMT and speed relative to the year 2000 for each year-2025 alternative, and then uses the complete accident-cost model to calculate the cost of these changes. This gives the external and social cost relative to the year 2000. The total cost is then equal to the cost relative to the year 2000 plus the year-2000 cost.

Data

Parameters in the model that are assumed to be constant for all analyses. The model as developed and documented in report #19 in the UCD social cost series is specified for the U. S. in 2002. (SACOG and NESCAUM supported the development of the accident cost model for this project.) As mentioned above, this model is included in near-entirety in the “accident costs” sheet of the social-cost model. I assume that all of the parameter values developed for the U. S. 2002 analysis *except* those discussed in the subsections below are valid for any particular regions. (Examples of these parameter values include the exponents and coefficients in the functions that relate speed and VMT to social and external costs). Report #19 provides complete documentation of these parameter values that are the same in a regional analysis as in the U. S. analysis.

Regional/US unit damage costs. Many of the U. S. 2002 \$/incident unit costs are a function of income levels. Therefore, to scale the unit costs to regional (e.g.,

Sacramento) economics, the U. S. unit costs in 2002 are multiplied by the ratio of median household (HH) income in the region to median HH income in the U. S. The Bureau of the Census reports median HH income in each of the five counties of the SACOG region in 1999 (SACOG, 2004); these are weighted by the number of HHs in each county to produce a region-wide average. The Census (2004) also reports the median HH income nationally in 1999. I assume that Sacramento/US HH income ratio for 2002 would be the same as the estimated ratio for 1999.

The ratio of insurance payments per mile in Sacramento to payments per mile nationally is estimated on the basis of California data. I divide total premiums for liability insurance from 1994 through 1997 in California (National Association of Insurance Commissioners, 2004) by total VMT in California (FHWA, 2004b), to produce an estimate of 2.59 cents/mile. The same calculation done for the same period for the U. S. using the same data sources results in 2.24 cents/mile. On this basis, I assume that insurance payments per mile in Sacramento are 1.10 (low) to 1.15 (high) times national payments per mile.

Incidents by accident severity in the region. The accident cost model included in the SCC requires as an input a reference number of incidents in each accident severity category for a reference year and activity level. I take year-2000 VMT and hence year-2000 incidents as the baseline. For the Sacramento case study, SACOG has provided data on injuries and fatalities in each county in 1999 and as an average over the period 1990-1999. I assume that the 10-year averages represent year-2000 baseline conditions. The SACOG-reported fatality total summed for all six counties is input directly into the cost model. However, the SACOG-reported total injuries must be distributed to the various non-fatality accident severity classes; this is done using distribution factors calculated from the U. S. data.

Changes in speed and VMT. Recall that the model calculates accident rates (and then costs) as a function of changes in VMT and speed relative to a base case. For the Sacramento case study, base case VMT and speed are for the year 2000 as estimated by SACOG. Changes in VMT and speed from 2000 to 2025 are estimated and input by SACOG (see "Model inputs"). Note that the vehicle speed parameter ideally should be

the average speed on all roads except local roads, local roads being excluded because speeds on them generally don't change.

UNPRICED OFF-STREET NON-RESIDENTIAL PRIVATE PARKING

Definition

Parking costs include the capital, land, and O&M costs of private off-street non-residential parking places. Private parking that is explicitly priced to users (as opposed to being bundled into the price of other goods and services) is not included here because in general any directly, explicitly, and efficiently priced items are not counted in this social-cost analysis (see the "Background" section of this report). The cost of *on*-street parking is not included here because it is included in the cost of roads, which is estimated separately in this analysis as a public-sector cost. The cost of off-street *public* parking is not included here because it is estimated separately as a public-sector cost. The cost of residential parking is not included because one can argue that people pay directly and efficiently for garages and parking places either in a monthly rate or up front when they purchase a house.

The parking costs estimated here are bundled costs, which means that their cost is bundled into the price of other goods and services. For example, the cost of parking spaces at a shopping mall is included in the price of goods and services sold at the mall. Bundled costs are not necessarily external costs, because generally bundling is not the result of the sort of market failure in property rights that gives rise to externalities. Hence, in the "Summary of results" sheet, I do not count parking costs and other bundled costs as external costs. (Users who have a different opinion may change the designation in the "Summary of results" sheet.)

Methods

The total cost of parking is calculated simply as the product of VMT and the parking CPM. The parking CPM is the product of the CPM for the U. S. in 1991, a U. S. 2002/US 1991 price ratio, and a regional/US price ratio.

Data

The parking CPM for the U. S. in 1991 is taken directly from report #6 in the UCD social-cost series. The U. S. 2002/US 1991 price ratio is based on the PPI for non-residential construction (low case) or street and highway construction (high case) (BLS,, 2004a). The regional/US price ratio is the generic regional/US price ratio in the “Model inputs” sheet.

TRAVEL-TIME AND CONGESTION COSTS

Definition

Travel time and congestion costs include the opportunity cost of traveling in motor vehicles and the hedonic or “comfort” cost of being in motor-vehicles. I estimate travel-time and congestion costs in four categories, distinguishing external from private (personal) costs and monetary from nonmonetary costs. External travel-time costs are those that are attributable to congestion delay, whereas private or personal costs are those that are *not* attributable to delay. Nonmonetary costs displace activities, such as unpaid housework, that are not monetarily compensated, whereas monetary costs displace monetarily compensated activities, such as salaried work. Our four travel-time cost categories are thus personal nonmonetary, private monetary, external monetary, and external nonmonetary. The external costs also can be referred to as “congestion” costs.

Note that I distinguish a special external monetary cost of congestion -- the cost of excess fuel consumed due to the lower average fuel economy in congested conditions -- because the methods used to estimate it are different from the methods

used to estimate travel time costs. This cost is estimated in the “Fuel use costs” section of the model and this documentation.

General methods

The cost of travel time is estimated simply as person-hours of travel time multiplied by the cost per hour of time. The external cost is equal to person-hours of delay multiplied by the cost per hour, and the private cost is equal to cost per hour multiplied by the difference between total travel hours and delay hours.

The “Congestion costs” sheet in the model includes the complete travel-time cost model documented in report #8 in the UCD social-cost series. This model calculates the costs for one set of VMT and speed inputs at a time. The macros “low_cost” and “high_cost” run the model once for each transportation scenario, using the VMT and speed data for each scenario.

Cost per hour. The cost per hour consists of an opportunity cost component, which represents the value of activities foregone while driving or being in a car, and a “hedonic” cost component, which represents the pure utility or disutility of the conditions during traveling. In this analysis, the hedonic cost component is updated from that estimated in report #8 in the UCD social-cost series.

The opportunity cost per hour depends on the purpose of the trip (e.g., personal or business-related), whether the driver is paid, and other factors. In the first instance, I distinguish the following general categories of travel, by type of vehicle:

- Private vehicles, for personal purposes
 - daily travel (LDAs, LDTs)
 - long trips (LDAs, LDTs)
- Private vehicles, for business purposes
 - LDAs, without paid drivers
 - LDTs, without paid drivers
 - LDTs, with paid drivers
 - HDTs, with paid drivers
- Buses

- intercity and transit buses
- school buses
- Public (government) vehicles
 - federal civilian vehicles (LDAs, LDTs, HDTs)
 - federal military vehicles (LDAs, LDTs, HDTs)
 - state and local civilian vehicles (LDAs, LDTs, HDTs)
 - state and local police vehicles

Report #8 in the UCD social-cost series derives the *nonmonetary* cost per hour in each of these categories in the U. S. in 1991. In that report, the nonmonetary cost per hour is estimated as a nonlinear function of the hourly wage rate and the trip purpose, weighted by travel time by trip purpose. In the SCC, those formulae and coefficients are applied to individual-area average HH income and hours of travel by trip purpose, where the trip purposes here are home-based work (HBW), home-based other (HBO), and non-home based (NHB). These estimates of nonmonetary cost per hour by area and trip purpose are then aggregated (within the SCC) over all areas and trip purposes (weighted by travel time) to obtain a single region-wide nonmonetary cost per hour.

Report #5 in the UCD social-cost series derives the *monetary* cost per hour in each of these categories in the U. S. in 1991. This analysis starts with those 1991 U. S. results, and then updates them to U. S. year 2002, and then to the individual-area costs in the year 2002.

Travel time and delay. Total travel time in each travel category is estimated as person-miles of travel (PMT) divided by the actual region-wide average speed over all conditions (congested and uncongested). PMT is equal to VMT multiplied by vehicle occupancy.

Person-hours of delay is estimated as the difference between total actual person-hours of travel time (as estimated above) and the total amount of person-hours of travel time there would have been had there been no congestion anywhere. This latter term is estimated by dividing PMT by what the region-wide average speed (all conditions) would have been had there been no congestion anywhere. The no-congestion region-wide average speed is calculated as a function of the actual average

speed over all conditions (congested and uncongested), the fraction of travel time spent in congested conditions, and the ratio of the average speed during delay to the average speed during free flow, over miles subject to delay.

Travel and delay time are apportioned to the monetary and nonmonetary cost categories by assumptions.

All of the formulae used in the SCC are given in report #8 in the UCD social-cost series.

A key part of the calculation of travel delay is the difference between the region-wide average speed without delay and the actual region-wide average speed. The actual region-wide average speed differs for each transportation scenario. However, the hypothetical region-wide average speed without delay anywhere is calculated on the basis of year-2000 conditions (that is, with the fraction of time spent in congested conditions specified for year 2000), and is assumed to be the same for all transportation scenarios. This assumption that the region-wide average speed absent congestion is the same for all scenarios is reasonable if the scenarios do not significantly change the distribution of travel on each major road-type class (interstate, arterial, collector), because the average speed absent congestion is a characteristic of the type of road. The result of this assumption is that any changes in actual average speed translate directly into changes in delay.

Aggregation. Because income, average speed, occupancy, and VMT vary from area to area, one must either do the cost calculation for individual area and then sum the results for each individual area, or else do the calculation based on the appropriate region-wide all-area averages and totals. Because it is too cumbersome to run the model for each area and transportation scenario (6 individual areas x 5 transportation scenarios = 30 different cases, as opposed to just 5 if we use region-wided averages), I use the appropriate region-wide averages for each transportation scenario. The appropriate region-wide averages are determined by the form of the cost calculation. The cost calculation ultimately is of the form: $\$/\text{hr} \cdot \text{VMT}/\text{mph} \cdot \text{Occ}$ (where "Occ" is occupancy). If the areas are designated 1, 2, 3..., and the correct all-area region-wide average is designated "A", then the correct region-wide average income, speed, and occupancy are given by:

$$\begin{aligned}
 & \$/\text{hr}_1 \cdot \text{VMT}_1/\text{mph}_1 \cdot \text{Occ}_1 + \$/\text{hr}_2 \cdot \text{VMT}_2/\text{mph}_2 \cdot \text{Occ}_2 + \$/\text{hr}_3 \cdot \text{VMT}_3/\text{mph}_3 \cdot \text{Occ}_3 + \\
 & \dots \\
 & = (\$/\text{hr}_A/\text{mph}_A \cdot \text{Occ}_A) \cdot (\text{VMT}_1 + \text{VMT}_2 + \text{VMT}_3 + \dots)
 \end{aligned}$$

The region-wide average income ($\$/\text{hr}_A$), the region-wide average speed (mph_A), and the region-wide average occupancy (Occ_A) are averages based on travel time (hours), rather than miles of travel, because of the form of the calculation. Using a travel-time weighted regional average in combination with other travel-time weighted regional averages gives the same results as doing the calculations first for individual areas and then summing the individual area results to the region-wide levels.

Specific methods and data

Person hours of personal travel. For the Sacramento case study, SACOG has provided estimates of travel time (in vehicle-minutes/day) and vehicle occupancy (person/vehicle) by trip purpose (home-based work, home-based other, non-home based) and county in the year 2000. The data are input in the “Model inputs” sheet. Person-hours of travel is calculated as the product of vehicle-hours and persons/vehicle.

Note that the SCC requires person-hours of “personal” travel in private vehicles, which excludes commercial travel in light-or heavy-duty vehicles, travel on the clock for business purposes, government travel, and travel in buses, but does include the commute to work.

Person-hours of travel in buses are calculated as a fraction of person-hours of travel in private vehicles. This fraction is assumed to be the same as person-miles of travel in buses divided by person miles of travel in private vehicles. SACOG provides data on person miles of travel in the categories “ride alone,” “shared ride,” and “transit.” I assume that the categories “drive alone” and “shared ride” comprise all person-miles of travel in private motor vehicles for personal purposes, and thereby are consistent with our basis for estimating person-hours of travel. I assume that in Sacramento, 63% of the SACOG-reported transit PMT is by bus (based on dataa from

the Federal Transit Administration [FTA], 2004), and that in all the other counties bus transit is 100% of the SACOG-reported transit PMT. I further assume that 65% of bus PMT is for home-based work travel, and that 25% is for other home-based travel.

Vehicle occupancy. Vehicle occupancy for personal travel in private vehicles, by trip purpose and county, is input in the “Model inputs” sheet. From these figures I calculate a travel-time weighted region-wide average occupancy, for all county and personal trip purposes. This is used as the occupancy in the travel category “daily travel, private vehicles for personal purposes,” which is the main travel category. For all other travel categories, I use the occupancy estimates and assumptions from the 1991 U. S. national analysis are used (Report #8 in the UCD social cost series).

Average speed. The actual average speed in each travel category is calculated by multiplying the actual region-wide, fleet-wide average speed (excluding local roads) by the ratio of the speed in each category to the region-wide fleet-wide average (excluding local roads). For the Sacramento case study, the actual region-wide, fleet-wide average is calculated for each MTP plan alternative on the basis of SACOG-input average speed and VMT by county and MTP plan alternative. The ratios of average speed in each category to the region-wide fleet-wide (excluding local roads) average are assumed to be the same as the ratios estimated for the U. S. in 1991 (report #8 in the UCD social-cost series). (Note that the 1991 national average ratios were calculated with respect average speed on all roads, including local roads, whereas the SACOG average-speed estimates exclude travel on local roads. I assume that the differences arising from this are minor.)

The hypothetical region-wide, fleet-wide average speed were there no delay anywhere is calculated on the basis of the ratio of speed without delay to speed with delay over miles subject to delay (this is assumed to be constant for all Sacramento MTP plan alternatives) and the fraction of travel time subject to delay in Sacramento in the year 2000. In report #8, I assumed that anywhere from 10% to 30% of travel time was subject to delay in the U. S. in 1991, depending on travel category. I assume that these figures apply to region of interest (e.g., Sacramento) in the year 2000.

Annual income and hourly wages. HH annual income figures are used to derive an hourly wage rate upon which the cost of travel time can be based. To derive the

hourly wage, total HH income is divided by total paid working hours. In Report #8 in the UCD social-cost series I assumed that there is one full-time worker equivalent per household, and so used a figure of 2024 work hours per year. I believe that this is low, and so for this project use data from the U. S. Census to calculate a more accurate figure for each county.

For the Sacramento case study, the Census reports the median annual HH income in 1999, the median annual income of full-time male workers in 1999, and the median annual income of full-time female workers in 1999, in each county of the SACOG region. Assuming that the average HH is 70% full-time males and 30% full-time females, I calculate the ratio of the median annual HH income to the median 70/30 weighted male+female income, for each county. This ratio tells us the number of full-time weighted (or composite) male+female jobs in each HH. In most cases the ratio is around 1.2, which seems reasonable. I multiply this ratio by 2024 hours in a full time work year, for each county.

Hedonic cost of travel. The hedonic cost has been updated from the original estimates of \$1.00/hr (low) or \$1.50/hr (high) (report #8 in the UCD social-cost series) to \$1.50/hr or \$2.00/hr.

Monetary cost per hour 2002/1991. The original U. S. 1991 estimates of the monetary cost per hour are updated using data similar to that used to develop the original estimates. The BLS (2004b) reports total employer costs for employee compensation in different job categories. I apply the BLS-reported ratio of 2002/1991 total compensation to the travel categories used in this analysis as follows (using one set of ratios, for both the low and the high case):

<u>Travel category in this analysis</u>	<u>BLS (2004b) compensation category for 2002/1991 updating</u>
Personal travel, daily	Not applicable
Personal travel, long trips	Not applicable
Business travel, LDAs	Average of ratio for “finance, insurance, and real estate” and ratio for all private industry
Business travel, LDTs without paid	Average of ratio for “finance, insurance, and real estate” and

drivers	ratio for “all private industry”
Business travel, LDTs with paid drivers	“Transportation and material moving occupations”
Business travel, HDTs (assume all with paid drivers)	“Transportation and material moving occupations”
Buses, intercity and transit	Average of ratio for “finance, insurance, and real estate” and ratio for “all private industry”
Buses, school	Not applicable.
Federal civilian	“State and local government”
Federal military	“State and local government”
State and local civilian	“State and local government”
State and local police	“State and local government”

The BLS (2004c) also reports annual average wages in metropolitan areas. The ratio of the annual average in Sacramento to the national average in 2002 was 1.02. I apply this factor to all monetary cost categories.

VMT in each travel category. These data are input by vehicle type and scenario, in the “Model inputs” sheet. For the Sacramento case study, SACOG reports VMT by LDAs, MDTs, HDTs, buses, and motorcycles for each MTP plan alternative. However, the travel-time cost calculation requires the estimation of VMT in each of the travel categories shown above. Thus, the VMT in the SACOG-reported vehicle categories must be mapped into the travel categories of the analysis here. I do this as follows:

- I distribute SACOG-reported LDA VMT to all travel categories except buses, HDTs, and LDTs with paid drivers according to the national-average distribution estimated in Report #8 for 1991, except that I assume in the SACOG region there is a higher percentage of travel by state and local government vehicles.
- I distribute SACOG-reported MDT VMT 10% to LDTs without paid drivers, 80% to LDTs with paid drivers, and 10% to HDTs.
- I distribute SACOG-reported HDT VMT 100% to the HDT travel category.

- I distribute SACOG-reported bus VMT 30% to intercity transit and 70% to school buses, roughly following national average distribution in 1991 (report #8 in the UCD social-cost series).
- I distribute SACOG-reported motor-cycle VMT 95% to daily travel, 4% to long trips, and 1% to business travel in LDAs.

Comparison with TTI estimates of person-hours of delay

The Texas Transportation Institute (TTI; Schrank and Lomax, 2004) performs detailed analyses of the annual costs of congestion in major metropolitan areas in the U. S. They estimate that in the year 2000 there were 27.1 million person-hours of delay resulting from 28.5 million VMT/day in the Sacramento metropolitan region, or roughly 1.0 person-hour of delay per VMT/day. Our model estimates 28 to 69 million person-hours of delay from the 43 million VMT/day in the five-county SACOG region in the year 2000, or about 0.6 to 1.6 person-hours of delay per VMT/day. Our range thus brackets the TTI estimate.

AIR POLLUTION COSTS FROM MOTOR-VEHICLE EXHAUST

Definition

Motor-vehicle exhaust air pollution costs are the estimated monetary value of the physical impacts of urban air pollution attributable to motor vehicle exhaust. (Note that in this report “exhaust” includes evaporative emissions of VOCs.) The physical impacts include damages to human health, visibility, materials, agriculture, and forests. The motor-vehicle exhaust emissions that cause air pollution include CO, VOCs, NO_x, SO_x, and PM₁₀. Essentially all motor-vehicle exhaust air pollution impacts are completely unpriced and hence are external costs.

In this section of the analysis only exhaust (and evaporative) emissions from motor vehicles are counted; “upstream” emissions, say from petroleum refineries that make motor-fuels, and emissions of particulate matter from road dust, brakewear, and tirewear, are treated in separate sections.

Methods

In the SCC motor-vehicle air pollution costs are estimated as the product of three factors:

- mass emission rate from motor vehicles, by vehicle class, pollutant, and transportation scenario; (g/mi)
- VMT, by vehicle class, area, and transportation scenario (mi);
- dollars of damage per kg of pollutant emitted by motor vehicles, by pollutant, area and impact category (health, visibility, materials, agriculture, and forests).

These products are summed over all vehicle classes, pollutants, impact categories, and areas, to produce an estimate of the total air pollution cost for each transportation scenario.

In general, estimates of \$/kg damages are a function of several relationships: between emissions and air quality, between air quality and exposure, between exposure and physical impacts, and between physical impacts and valuation. Ideally, one would estimate these relationships specifically for each area and transportation scenario. However, this is beyond the scope of this social-cost analysis. A next-best alternative is to start with generic urban-area estimates and then adjust them to account for the most important easily specifiable factors in an air-pollution-damage analysis that differ in time and place: exposure and valuation. Hence, in this analysis, the \$/kg damage figures by pollutant, area and impact category are the product of four factors:

- original or “reference” \$/kg damage factors, by motor-vehicle exhaust pollutant and impact category for urban areas of the U. S. in 1990 or 1991;
- adjustments to the original damage factors, accounting for new information about pollution and its effects since the original \$/kg damage factors were estimated;

- exposure scalars to get from the average exposure basis in urban areas of the U. S. in 1991 to the average exposure in each individual area within a region in the scenario analysis years 2025 or 2000;
- valuation scalars to get from U. S. urban average values (prices) in 1991 to regional values (prices) in 2002. This valuation scalar is itself the product of two components: a U. S. 2002/US 1991 scalar and individual-area/US scalars.

The original estimates of \$/kg damage by pollutant impact category for urban areas of the U. S. in 1991 are the result of detailed modeling, documented in several reports in the UCD social-cost series: report #9 (nonmonetary externalities), #10 (apportioning costs), #11 (health costs), #12 (agricultural costs), #13 (visibility costs), and #16 (air quality). The reader is referred to those reports for details.

Data

Original estimates of \$/kg damages in U. S. urban areas, 1991. Report #9 in the UCD social-cost series summarizes the original estimates (developed in reports 10 through 14 and 16) of \$/kg damages in urban areas of the U. S. in 1991, by motor-vehicle exhaust pollutant, for the health, visibility, and agricultural impact categories. I start with those original estimates here. On the basis of total 1991 U. S. damage estimates (as opposed to \$/kg damage estimates) for the materials and forests categories, summarized in report #9, I have estimated \$/kg damages for the forest and materials categories for this analysis.

Adjustments to the original \$/kg damage estimates. Since the time of the UCD social-cost studies that generated the original \$/kg damage estimates (see previous paragraph), new information about pollution and its effects has become available. Had this information been available at the time the original UC social-cost studies were done, the estimated \$/kg damage factors would have been different. Therefore, in this section we multiply the original \$/kg damage factors by adjustment factors that account for the impact of new information about pollution and its effects. (These adjustment factors, of course, are different from the exposure and valuation scalars discussed in the next sections.)

Much has been learned about pollution and its effects since the original UCD social-cost estimates of \$/kg damages were made. In at least two areas, this new knowledge has a significant impact on the estimation of \$/kg damages: i) the formation of secondary particulate matter (PM) air pollution from NO_x and SO_x precursors, and ii) the impact of ozone air pollution on human mortality. We consider each of these next.

i) The formation of secondary particulate air pollution from NO_x and SO_x precursors.

Through a series of chemical reactions in the atmosphere, emissions of NO_x and SO_x from motor vehicles and other sources eventually contribute to the formation of “secondary” PM-nitrate and PM-sulfate compounds. These secondary particulates damage human health and reduce visibility.

In Report #16 in the UCD social-cost series, we estimated the extent to which NO_x and SO_x emissions converted to PM nitrate and PM sulfate by making an assumption about the conversion of NO_x and SO_x emissions to intermediate nitrate (NO_3) and sulfate (SO_4) compounds, and then estimating the conversion of the intermediate nitrates and sulfates to PM ammonium nitrate and PM ammonium sulfate on the basis of local emissions of ammonia and a simplified chemistry scheme. Specifically:

- We assumed that in the Western U. S., 25% to 15% (low-cost to high-cost) of the sulfur in SO_2 was converted to sulfur in sulfate, and that in the Eastern U. S., 35% to 25% (low-cost to high-cost) was converted.

- We assumed that 5% (low-cost) to 7% (high-cost) of the N in NO_x was converted to N in nitrate.

- Our simplified model appears to have estimated that virtually all of the intermediate sulfate was converted to PM ammonium sulfate, and that most (but not all) of the intermediate nitrate was converted to PM ammonium nitrate. (We do not know definitively because we did not report the actual overall conversion rates.)

Thus, we estimated that overall, approximately 25% of the S in SO_x was converted to S in PM ammonium sulfate, and that approximately 4% of the N in NO_x was converted to N in PM ammonium nitrate. However, the information upon which these assumptions and calculations were based was poor (especially in the case of N- NO_x to N-PM-nitrate), and new model studies now suggest that we significantly

underestimated the formation of secondary PM nitrate and PM sulfate. Model results summarized in the IPCC (2001), and the work of Martin et al. (2004), Park et al. (2004), Liao et al. (2004), and Ansari and Pandis (1998) indicate that the conversion of S-SO_x to S-PM-sulfate is on the order of 45%, and that the conversion of N-NO_x to N-PM-nitrate is about 10%. This suggests that we underestimated conversion to PM sulfate by almost a factor of 2, and underestimated conversion to PM nitrate by at least a factor of 2.

How does this underestimation of conversion affect the original estimates of the \$/kg damage factors for NO_x and SO_x? Because in our work all health and visibility damages from SO_x emissions were due to ambient secondary PM sulfate (as opposed to being due to ambient SO₂ itself, which in our work did not cause damage), and all visibility damages from NO_x were due to secondary PM nitrate, an X-fold underestimation of the conversion to PM sulfate or PM nitrate results in an X-fold underestimation of the \$/kg-SO_x health damage factor, the \$/kg-SO_x visibility damage factor, and the \$/kg-NO_x visibility damage factor. If we assume that we underestimated conversion to PM sulfate by a factor of 1.2 to 1.8, and underestimated conversion to PM nitrate by a factor of 1.6 to 2.2, then we must now multiply the original \$/kg-SO_x health and visibility damage factors by 1.2 (low-cost case) to 1.8 (high-cost case), and the original \$/kg-NO_x visibility damage factors by 1.6 (low-cost case) to 2.2 (high-cost case).

In the case of health damages from NO_x emissions, 88% (low-cost case) to 96% (high-cost case) (rather than 100% as in the case of SO₂) of the original \$/kg-NO_x damage was due to secondary particulate nitrate (the remaining 4-12% was due to ambient NO₂ itself) (see Report #11 in the UCD social-cost series). If we underestimated conversion to PM nitrate by a factor of 1.6 to 2.2 (as assumed above), then to account for the effect of this underestimation on the \$/kg-NO_x health damage factor we multiply the original \$/kg-NO_x health damage factors by $1.6 \times 0.88 = 1.4$ (low-cost case) to $2.2 \times 0.96 = 2.1$ (high-cost case).

i) The impact of ozone air pollution on human mortality. At the time of the UCD social-cost analysis, there was little evidence that ozone had an independent effect on human mortality (see Report #11 in the UCD social-cost series). Recently, however, Bell et al. (2004) have demonstrated an independent, statistically significant effect of ozone on

short-term mortality in the U. S., even after accounting for the effects of weather, season, and PM air pollution.

Bell et al. (2004) estimate that in 95 large urban communities in the U. S., a 10 ppb increase in daily average ozone would cause an 0.52% increase in daily mortality (in the week following the ozone increase), which would amount to 3767 premature deaths annually in the 95 large areas. They note that, for two reasons, this likely would underestimate total U. S. deaths due to ozone: i) they found that ozone was associated with mortality at ambient levels below the National Ambient Air Quality Standards, which suggests that ozone would cause premature deaths in small communities and rural areas; and ii) they estimated only short-term mortality, and note that any long-term effects would be additional.

With the estimates from Bell et al. (2004) and data from the original UCD social-cost analysis (in Report #11 and Report #16), we can estimate approximately what the additional ozone damages would have been had the original UCD social-cost analysis included the effect of ozone on mortality as estimated by Bell et al. (2004). The major steps to calculate this adjustment are: i) to estimate the the ozone-related mortality rate per unit of ozone for the urban areas in the UCD social-cost analysis; and ii) to estimate how much a 10% change in motor-vehicle-related emissions (the basis of the \$/kg damage factors that we are adjusting here) would have changed daily average ozone levels, averaged across all urban areas of the U. S. All of the data and assumptions used to calculate this ozone-mortality adjustment factor are shown in the following table:

INPUTS	Low	Best	High	Notes
Change in annual mortality rate (excluding non-resident deaths and deaths due to injuries) due to ozone change of P in area A	0.31%	0.52%	0.68%	Best is from Bell et al. (2004); I assume low is 40% less and high is 30% more.
Multiplier to account for long-term deaths	1.2	1.5	2.0	My assumption.
Change in average daily ozone P associated with short-term deaths above (ppbv)	10	10	10	From Bell et al. (2004).
Baseline annual mortality rate, as a percent of the population, excluding deaths of non-residents	0.66%	0.66%	0.66%	Based on mortality data from Bell et al. (2004) and population data from supplementary online material for

and deaths from injuries				Bell et al. (2004) study (www.ihapss.jhsph.edu/data/NMMAPS/documentation/frame.htm).
Population of urban areas in UCD social-cost analysis (millions)	198	198	198	Report #11 in UCD social-cost series (Table 11.7-1).
Annual daily average ozone in urban areas in UCD social-cost analysis (ppbv)	25	30	35	Based on urban-area statistics in Report #11 in UCD social-cost series (Table 11.7-1).
Exponent on VOC emissions in ozone formation equation	0.50	0.55	0.60	In UCD social-cost analysis, ozone formation is a nonlinear function of VOC and NO _x levels (Report #16).
Exponent on NO _x emissions in ozone formation equation	0.35	0.40	0.50	In UCD social-cost analysis, ozone formation is a nonlinear function of VOC and NO _x levels (Report #16).
Contribution of MV emissions to total ambient VOC in urban areas in UCD social-cost analysis	0.55	0.65	0.75	We calculated the MV share of dispersion-weighted emissions by multiplying EPA-reported emissions in 1990 (http://www.epa.gov/ttn/chief/trends/index.html) by the dispersion weights for “within county” emissions from Report #16. The result was that MVs contributed 53% to 68% of dispersion-weighted VOC emissions.
Contribution of MV emissions to total ambient NO _x in urban areas in UCD-social cost analysis	0.65	0.74	0.80	See note for VOC emissions, above. MVs contributed 68% to 86% of total dispersion-weighted NO _x emissions. ² We assume a slightly lower range because the “in-county” weights may slightly overstate the overall MV contribution.
Change in motor vehicle emissions	10%	10%	10%	This is the change for which the original \$/kg damage factors were estimated.
Statistical value of life, harvest death (million 1991 \$)	0.015	0.050	0.100	Based on Report #11 in the UCD social-cost series (Table 11.7-2). I have increased the original assumed values. A “harvest” death is one that would have occurred only a few days or weeks later had there been no pollution.
Statistical value of life, non-harvest death (million 1991 \$)	1.00	2.50	4.00	Report #11 in the UCD social-cost series (Table 11.7-2).

² Our unpublished analysis of the MV contribution to ambient NO_x in 21 cities in the U. S. (mainly the western U. S.), using the emission inventories and dispersion models from the original UCD social-cost analysis, indicates a range of 0.62 to 0.86. We suspect that the MV contribution is higher in western cities than in eastern.

Harvest-death fraction of short-term deaths	0.50	0.30	0.25	Report #11 in the UCD social-cost series (Table 11.7-2).
Total ozone damages, 10% reduction in MV use, UCD social-cost series (million 1991 \$)	20	59	173	Low and high from Report #11 in the UCD social-cost series (Table 11-A.7 and 11-A.8; values are for MV end use emissions only). Best is geometric mean.
Total VOC damages, 10% reduction in MV use, UCD social-cost series (million 1991 \$)	66	239	862	Low and high from Report #11 in the UCD social-cost series (Table 11-A.7 and 11-A.8; values are for MV end use emissions only). Best is geometric mean.
Total NO _x damages, 10% reduction in MV use, UCD social-cost series (million 1991 \$)	854	3,462	14,034	Low and high from Report #11 in the UCD social-cost series (Table 11-A.7 and 11-A.8; values are for MV end use emissions only). Best is geometric mean.
CACLULATED VALUES	Low	Best	High	Notes
Total annual deaths (short-term plus long-term) in urban areas of the UCD social -cost analysis, per ppbv increase in ozone	493	1,026	1,779	By expressing the death rate per ppbv ozone, I assume that the death rate is proportional to the change in ozone.
Change in ozone levels due to the specified percentage change in motor vehicle emissions in urban areas of the U. S., in the UCD social-cost analysis	5.0%	6.5%	8.5%	Caclulated using eq. 13 in Report #16 in the UCD social-cost series.
Annual deaths associated with change in motor-vehicle emissions, UCD-social-cost basis	616	2,009	5,313	Equal to the ozone change multiplied by the ozone level <i>P</i> (ppbv) and the death rate per ppbv-ozone.
Value of ozone-related annual deaths, UCD-social-cost basis (million 1991 \$)	363	4,037	18,661	Deaths are separated into harvest and non-harvest and multiplied by corresponding statistical life values.
Ratio of original damages+new deaths to original damages, for VOCs	5.2	14.6	19.0	Original \$/kg-VOC damage factors in UCD social-cost analysis included damages from ozone, so ozone damages are included here.

Note that for the purpose of adjusting \$/kg damage factors we assign all ozone damages to VOC emissions. On the basis of the analysis tabulated above, we assume an adjustment factor of 5 (low-cost case) to 20 (high-cost case).

Exposure scalars. Population density is the best simple measure of exposure to air pollution. For health, visibility, and materials, the individual-area/US exposure scalar is the ratio of population density in each individual area in the future years (e.g., the four SACOG year-2025 MTP alternatives) or the baseline year of 2000 (e.g., the SACOG year-2000 MTP alternative) to the average urban-area population density in the original analysis of \$/kg damages in urban areas of the U. S. in 1991. For the Sacramento case study, the population density in each county in the year 2000 is provided by SACOG, and the population density in the year 2025 I assume to be 15% higher than in 2000. (This percentage increase is an input variable that can be changed by SACOG.) I estimate the population density in the original 1991 urban-area analysis to be 2150 persons/mi², on the basis of data in the Bureau of the Census (1992).

For agriculture and forests, a useful simple exposure scalar would be the fraction of total land in agriculture or forest in each county relative to average fraction in the original 1991 U. S. analysis. Although data may be available to estimate these fractions, I have for estimated them on the basis of my judgment, assuming for the Sacramento case study that counties in the Sacramento Valley have a higher fraction of agricultural land a lower fraction of forested land than did the average U. S. county in 1991, and that the foothill counties have a higher fraction of forested land than did the average U. S. county in 1991.

Individual-area 2002/US-1991 valuation scalars. To scale from U. S. 1991 values to U. S. 2002 values I assume an increase in values (shadow prices) of 1.8%/year (low) or 2.5%/year. To scale from the U. S. in 2002 to the region of interest in 2002, I use the ratio of median HH income in each individual area in 1999 to the median HH income in the U. S. nationally in 1999, or the square root of that ratio, whichever is lower, in the low case, and whichever is higher in the high case. This method assumes that relative income is a good proxy for the pertinent relative values, and that the 2002 income ratio is the same as the estimated 1999 ratio. Median HH income is provided by the U. S. Census (SACOG, 2004; Bureau of the Census, 2004).

Emission rates. The model user provides data on the g/mi emission rate by vehicle class, pollutant, and scenario analysis (in the "Model inputs" sheet).

VMT. The model user provides data on VMT by vehicle class and individual area within the region, for each transportation scenario (in the “Model inputs” sheet).

AIR POLLUTION COSTS FROM THE UPSTREAM FUELCYCLE

Definition

Air pollution costs from the upstream fuelcycle are the estimated monetary value of the physical impacts of urban air pollution attributable to activities related to the production and transportation of motor fuels. These upstream fuelcycle activities include: the recovery, storage, and transport of crude oil; the refining of crude oil to produce motor fuel; and the storage, distribution, and dispensing of motor fuels. The physical impacts include damages to human health, visibility, materials, agriculture, and forests. The upstream fuelcycle emissions that cause air pollution include CO, VOCs, NO_x, SO_x, and PM₁₀. Essentially all upstream air-pollution impacts are unpriced and hence are external costs.

Methods

In the SCC, upstream fuelcycle air-pollution costs are estimated as the product of several factors:

- grams of each pollutant from the upstream fuelcycle per gallon of gasoline or diesel fuel delivered to end users, in the region;
- factors that adjust for differences in damages per gram of upstream fuelcycle emissions relative to damages per gram of motor-vehicle emissions, by pollutant and upstream fuelcycle activity (feedstock recovery and transport; fuel production; fuel distribution, storage, and dispensing);
- dollars of damage per kg of pollutant emitted by sources whose emissions have been adjusted (by the factors mentioned above) to have the same \$/kg damage values as do motor-vehicle exhaust emissions, by pollutant,

individual area within the region, and impact category (health, visibility, materials, agriculture, and forests);

- gallons of gasoline or diesel fuel consumed by end users, by individual area and transportation scenario.

These products are summed over all pollutants, impact categories, and individual areas within the region, to produce an estimate of the total upstream fuelcycle air pollution cost for each transportation scenario.

The \$/kg damage values are the same as those used in the analysis of damages from motor-vehicle exhaust air pollution, because as mentioned immediately above the upstream emissions are adjusted so as to have the same \$/kg damage effect as do motor-vehicle exhaust emissions. Hence, the reader is referred to the preceding section for details on the method of estimating the \$/kg damage values.

Regional vs. global values. The g/gal upstream emission factors pertinent to a particular region may be different from U. S. or global-average values. As mentioned above, the SCC allows the user to specify a regional or a global accounting (see “Model inputs” section). If the “global | regional” toggle is set to “regional,” then region-specific g/gal upstream emission factor are used. Region-specific g/gal upstream emission factors are equal to reference values for the U. S. in the year 2025 or 2000 multiplied by individual-area/US-average scalars, for each pollutant and individual area within the region. However, if the toggle is set to “global,” then U. S. -average (reference) values are used automatically, and the individual-area/US-average scalars are not used.

Data

Grams of upstream pollution per gallon of fuel: reference U. S. values. Delucchi’s (2003) Lifecycle Emissions Model (LEM) estimates emissions from the upstream lifecycle of gasoline and diesel fuel in the U. S., by pollutant, year, and stage of fuel lifecycle. For this analysis we start with LEM-estimated U. S.-average g/gal emissions in the year 2025 and 2000, by pollutant (CO, NMOCs, SO_x, NO_x, and PM₁₀) and three stages of the upstream fuelcycle:

- i) fuel storage, distribution, and dispensing;
- ii) fuel production; and
- iii) all feedstock activities.

These LEM-generated U. S. average reference rates are reported in the “Upstream emissions” sheet.

Grams of upstream pollution per gallon of fuel: individual-area/US scalars. For the Sacramento case study, the ratio of Sacramento-area g/gal emissions to U. S.-average (reference) g/gal emissions, by pollutant and county, are estimated on the basis of my judgment. There are two factors to consider in estimating these ratios: the amount of upstream activity (e.g., petroleum refining) in Sacramento relative to the U. S. average, and the amount of emissions per unit of activity in Sacramento relative to the U. S. average. I assume that in Sacramento there is much less fuel production (petroleum refining) and feedstock activity (crude oil recovery and transport) than in the U. S. on average, but approximately the same amount of fuel distribution, storage, and dispensing activity. I assume that emissions per unit of activity in Sacramento are the same as in the U. S., on average.

Damages per gram of upstream emission relative to damages per gram of motor-vehicle exhaust emissions. In report #16 in the UCD social-cost series, Delucchi and McCubbin use a Gaussian dispersion air quality model to estimate the ratio of:

<damages per gram of pollutant from upstream emission-source categories>
to: <damages per gram of exhaust pollutant from light-duty gasoline vehicles>.

They estimate “high-cost” and “low-cost” ratios for different emission-source categories (electric utilities, industrial boilers, chemical manufacturing, solvents, etc.), for sources inside or outside the same county as the motor-vehicles of interest, and for different-size air basins. Some of these tables of estimated ratios are reproduced in the “Upstream emissions” sheet of the SCC.

To apply these estimated ratios to this analysis, the emission-source categories in the UCD social-cost series must be matched with the upstream fuelcycle stages from the LEM. (The UCD social-cost series generates the \$/kg damage ratios by emission-source category; the LEM generates g/gal emission rates by stage of fuelcycle). I assume *generally* the following correspondence:

<u>Stage of upstream fuelcycle (LEM)</u>	<u>Emission-source category (UCD social-cost series)</u>
Feedstock activities	Agriculture and forestry, and managed burning
Fuel production	Chemicals and allied product manufacturing, metals processing, petroleum refining, and other industrial processes
Fuel storage, distribution, dispensing	Solvent utilization, storage and transport, and waste disposal and recycling

In principle, \$/kg damages from upstream emissions sources could differ from \$/kg damages from motor-vehicle exhaust on account of differences in the size and composition of PM from upstream sources compared with the size and composition of PM from motor-vehicle exhaust. For example, if, as is generally believed, smaller-diameter PM is more harmful than larger-diameter PM (McCubbin and Delucchi, 1999), and if there are systematic differences between the size of upstream PM and the size of motor-vehicle exhaust PM, then there might be corresponding differences in the \$/kg damages. The SCC does have adjustment factors to account for the impact on \$/kg damages of differences in the size and composition of upstream PM relative to that of motor-vehicle exhaust PM, but presently these factors are set equal to 1.0 on the assumption that in fact there are no significant differences in size or composition.

Fuel use. The model user provides data on gasoline and diesel fuel use by individual area within the region and transportation scenario (in the “Model inputs” sheet).

\$/kg damages in U. S. urban areas, 2002. These are the values calculated for motor vehicles. See the discussion under the section on motor-vehicle air pollution.

Note on results

With the methods and data assumptions discussed above, the SCC estimates that upstream air-pollution damages in Sacramento are approximately 5%-10% of vehicle exhaust air-pollution damages in the year 2000, and approximately 15% to 40% of vehicle exhaust air-pollution damages in the year 2025. In the UCD social-cost series,

upstream air-pollution damages for the entire U. S. were approximately 5% to 10% of vehicle exhaust air-pollution damages in the year 1990. Upstream damage costs relative to motor-vehicle damage costs increase over time because exhaust emissions from motor-vehicles have been declining and will continue to decline more rapidly than upstream emissions. Given this declining upstream/vehicle damage ratio over time, we can infer that the upstream/vehicle damage ratio estimated for Sacramento is lower than the ratio estimated for the U. S., which is consistent with our assumptions in this analysis.

AIR POLLUTION COSTS FROM PM FROM ROAD DUST, BRAKE WEAR, AND TIRE WEAR

Definition

The use of motor vehicles results directly in three kinds of PM emissions other than exhaust PM from fuel combustion: road dust kicked up into the air by moving vehicles, particles from brake wear, and particles from tire wear. Emissions of road dust actually are one of the largest sources of PM in the U. S. national emissions inventory, accounting for 10% of total national emissions of PM_{2.5} and PM₁₀. Road dust, brake wear and tire wear emissions are not regulated, although they can be controlled or at least mitigated by periodic street cleaning.

Air-pollution costs from PM for road dust, brake wear, and tire wear are the estimated monetary value of the physical impacts of urban air pollution attributable to these emissions sources. The physical impacts include damages to human health and visibility. Essentially all of these PM air-pollution impacts are completely unpriced and hence are external costs.

For convenience, I will refer to PM from road dust, brake wear, and tire wear from motor vehicles as “PM dust” emissions.

Methods

In the SCC, air-pollution costs from PM dust emissions are estimated as the product of several factors:

- grams of PM from road dust, brake wear, and tire wear, per mile of travel by vehicle class (LDAs, MDTs, HDTs, buses, and motorcycles), area, and transportation scenario;
- dollars of damage per kg of PM₁₀ from motor-vehicle exhaust, by emissions source (road dust, brake wear, or tire wear) and area;
- An overall adjustment factor that accounts for differences in \$/kg damages from PM dust emissions relative to \$/kg damages from motor-vehicle-exhaust PM₁₀ emissions, on account of differences in the size, composition, and transport of the PM (see additional discussion below);
- miles of travel by vehicle class, area and transportation scenario.

These products are summed over all emission sources, regions, and vehicle classes to produce an estimate of the total PM-dust damage for each transportation scenario

The \$/kg damage values for motor-vehicle exhaust PM₁₀ include health and visibility damages, and are the same as those used in the analysis of damages of air-pollution costs from motor-vehicle exhaust. Hence, the reader is referred to that section for details.

Overall adjustment factor for differences in PM size, composition, and exposure.
As noted above, \$/kg damages from dust PM are estimated relative to \$/kg damages from motor-vehicle exhaust PM₁₀. In order to estimate dust-PM damages relative to motor-vehicle exhaust-PM₁₀ damages, we must know the factors that determine PM damages and the differences between dust PM and motor-vehicle exhaust PM₁₀ with respect to these factors.

In general, damages due to PM emissions are a function of exposure to PM and of the size and composition of the PM. There is general agreement that smaller-diameter fractions of PM are the more harmful, and there is some indication that for

any given size class, PM from fossil-fuel combustion is more harmful than PM from earth-crustal sources (McCubbin and Delucchi, 1999; Report #11 in the UCD social-cost series). In addition, exposure to PM emissions is a function of the size of PM. Since most PM dust is relatively large (greater than 2.5 microns), and since road-dust PM comprises crustal matter, health damages from PM dust depend very much on what one assumes about the relationships between PM size and exposure, PM size and health effects, and PM composition and health effects.

Given this, I estimate the overall adjustment factor as the product of four input factors: i) a “size → damage effect” factor, which is the ratio of \$/kg damages in each particle size class to \$/kg damages from motor-vehicle exhaust PM₁₀, holding particle composition constant; ii) a “composition → damage effect” factor, which is the ratio of \$/kg damages from each type of PM dust relative to \$/kg damages from motor-vehicle exhaust PM₁₀, holding particle size constant; iii) an “exposure effect” factor, which is the ratio of exposure to particles in each size class relative to exposure to motor-vehicle exhaust PM₁₀, and iv) the distribution of dust particles across the various size classes. These four-fold products are summed over all PM size classes.

I estimate these four input factors with respect to health damages. Technically, because the overall adjustment factor is being applied to total health+visibility damages, the four input factors should be estimated with respect to visibility damages as well. However, given that health damages are more than 97% of total damages (Report #9), and that were adjustment factors to be calculated explicitly for visibility, they would be similar to those calculated for health effects (for example, in Report #13 of the UCD social-cost series, Delucchi et al. assume that PM > 10.0 microns causes no visibility damage, and that PM_{2.5} causes 5 times more damage than do “coarse” particles [2.5 to 10.0 microns]), an overall adjustment factor estimated with respect to health-plus-visibility damages would be almost the same as the factor we estimate with respect to health damages alone.

Data

Gram-per-mile emissions. Delucchi’s (2003) Lifecycle Emissions Model (LEM) estimates PM dust emissions as a function of vehicle weight. The methods and data

reviewed in the LEM documentation (Delucchi, 2003) suggest the following g/mi emission values for different vehicle classes in Sacramento:

	LDAs		MDTs		HDTs, buses		Motorcycles	
	<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>
Road dust	0.240	0.440	0.800	1.20	2.40	4.20	n.e.	n.e.
Brake wear	0.010	0.016	0.030	0.050	0.700	0.130	n.e.	n.e.
Tire wear	0.005	0.009	0.016	0.030	0.030	0.070	n.e.	n.e.

These values are assumed to apply to all areas and transportation scenarios. Values are not estimated for motorcycles because it is not clear that the weight-based methods used to estimate emissions are valid for modes as light as motorcycles.

Oveall adjustment for the size, composition, and transport of PM dust relative to that of motor-vehicle exhaust PM₁₀. As discussed in the “methods” section, in order to estimate the overall adjustment factor we need to specify the size distribution of PM, the “composition → damage effect,” the “size → damage effect,” and the exposure effect. The following table presents our assumptions:

	< PM _{1.0}		PM _{1.0} -PM _{2.5}		PM _{2.5} -PM ₁₀		> PM ₁₀		Basis of estimate
	<i>low</i>	<i>high</i>	<i>low</i>	<i>high</i>	<i>low</i>	<i>high</i>	<i>low</i>	<i>high</i>	
<u>Size distribution</u>									
Tailpipe	0.93	0.90	0.01	0.02	0.03	0.04	0.03	0.04	Size distribution data in Delucchi and McCubbin (2004)
Road dust	0.01	0.04	0.04	0.07	0.45	0.41	0.50	0.48	Size distribution data in Delucchi and McCubbin (2004) and Delucchi (2003)
Brake wear	0.00	0.05	0.10	0.15	0.60	0.55	0.30	0.25	Data in Delucchi (2003), and my judgment

Tire wear 0.00 0.10 0.10 0.15 0.55 0.45 0.35 0.30 Delucchi (2003) assumes PM_{2.5} is 25% of PM₁₀; I extrapolate from this.

Composition → damage effect

Road dust 0.10 0.40 0.10 0.40 0.10 0.40 0.10 0.40 McCubbin and Delucchi (1999) assume values of 0.10 to 0.50 for the composition→damage effect; I assume a slightly lower upper end.

Brake wear 0.20 0.60 0.20 0.60 0.20 0.60 0.20 0.60 my judgement

Tire wear 0.20 0.60 0.20 0.60 0.20 0.60 0.20 0.60 my judgment

Size → damage effect 1.068 1.074 0.40 0.80 0.10 0.40 0.00 0.03 McCubbin and Delucchi (1999) assume that the size →damage effect for PM_{2.5-10} vs. PM_{2.5} is 0.10 to 0.50 and that particles greater than PM₁₀ have no effect, and speculate that PM_{1.0} might cause more damage than PM_{2.5}. I use these assumptions as the basis of my estimates here.

Exposure effect 1.042 1.044 1.00 1.00 0.50 0.90 0.20 0.10 My assumptions based on particle residence time as a function of particle size shown in Delucchi and McCubbin (2004).

VMT. The model user provides data on VMT by vehicle class and individual area within the region for each transportation scenario (in the “Model inputs” sheet).

Note on results

Damage costs due to PM dust are very uncertain. For several of the key of the parameters in the calculation of damages, the range of uncertainty is about an order of magnitude, and as a result the total calculated damages from dust PM in Sacramento span nearly 3 orders of magnitude, from less than \$1 million to a several hundred million dollars. The lower end is negligible, but the upper end actually is the single largest source of air pollution damages in the year 2025, exceeding damages from motor-vehicle exhaust by a wide margin.

In the year 2000, PM dust damages in Sacramento are about 25% of total motor-vehicle-related pollution damages (including upstream and PM dust in the total), a result which is roughly consistent with that estimated in the UCD social cost series for the U. S. in 1990. However, by the year 2025 PM dust damages account for nearly 60% of total motor-vehicle-related air-pollution damages, a dramatic increase. This is because motor-vehicle emissions per mile are projected to decrease dramatically from 2000 to 2025, but PM dust emissions are not – unless the possibility of large damages such as are estimated here spurs regulatory activity.

COSTS PER GALLON AND COSTS PER MILE

The “Cost per gal and cost per mi” sheet gives intermediate summaries of costs per gallon of gasoline or diesel fuel and costs per mile of travel by LDVs and HDVs, by individual area and cost category. It also includes gallon- or mile-weighted regional (all-area) average costs. Note that the values in this sheet pertain to only *one* of the five transportation scenarios – the first or #1 labeled scenario in the “Model inputs” sheet.

This sheet also shows the social cost of fuel as calculated in the SCC, and the difference between the social cost and private cost of fuel (the latter being the full retail cost of fuel including all taxes).

These intermediate \$/gal and \$/mi costs by fuel and vehicle type can be used in simplified cost-benefit analyses.

SUMMARY OF RESULTS

In the “Summary of results” sheet, costs are aggregated over the six individual areas and reported in millions of year-2002 dollars by cost category and transportation scenario.

The summary sheet also sums all of the costs to two totals: grand-total social cost, and total designated external costs of motor-vehicles use. External costs are designated as such, by the model user, in this summary sheet. For default I have designated all costs to be external costs *except* bundled costs, highway capital costs, fuel resource costs excluding excess fuel consumed due to delay, and the private-cost portions of accidents and travel-time costs. (See the additional discussion in the sections on individual costs.)

Social costs and external costs are presented for each of the transportation scenarios. The SCC also calculates the difference between future scenarios and the baseline year-2000 cost (in 2002 dollars) for each of the four future scenarios.

Results for Sacramento analysis. In the low-cost case, the total social costs estimated here are on the order of \$17 billion for the year 2025 alternatives, with more than half of the total being travel time and congestion costs. Accident costs are the next largest, followed by bundled costs and public infrastructure and services. Total external costs are an order of magnitude smaller, about \$2.5 billion, and are due mainly to congestion, accidents, and some public services.

In the high-cost case total social costs are about \$32 billion, and total external costs are about \$9.5 billion. Again, congestion costs dominate, followed by accident costs, bundled costs, and public-sector costs.

The total external costs can be put in perspective by expressing them per gallon of fuel consumed. In the 2025 scenarios, total fuel consumption is about 1.4 billion gallons. Total external costs of \$2.5 to \$9.5 billion thus imply approximately \$2 to almost \$7 per gallon.

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(www.its.ucdavis.edu/people/faculty/delucchi.) Approximately 2100 pp. in 21 reports:

- Report 1: The Annualized Social Cost of Motor-Vehicle Use in the U.S., 1990-1991: Summary of Theory, Methods, Data, and Results (M. Delucchi).
- Report 2: Some Conceptual and Methodological Issues in the Analysis of the Social Cost of Motor-Vehicle Use (M. Delucchi).
- Report 3: Review of Some of the Literature on the Social Cost of Motor-Vehicle Use (J. Murphy and M. Delucchi).
- Report 4: Personal Nonmonetary Costs of Motor-Vehicle Use (M. Delucchi).
- Report 5: Motor-Vehicle Goods and Services Priced in the Private Sector (M. Delucchi).
- Report 6: Motor-Vehicle Goods and Services Bundled in the Private Sector (M. Delucchi, with J. Murphy).
- Report 7: Motor-Vehicle Infrastructure and Services Provided by the Public Sector (M. Delucchi And J. Murphy).
- Report 8: Monetary Externalities of Motor-Vehicle Use (M. Delucchi).
- Report 9: Summary of the Nonmonetary Externalities of Motor-Vehicle Use (M. Delucchi).
- Report 10: The Allocation of the Social Costs of Motor-Vehicle Use to Six Classes of Motor Vehicles (M. Delucchi).
- Report 11: The Cost of the Health Effects of Air Pollution from Motor Vehicles (D. McCubbin and M. Delucchi).
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- Report 14: The External Cost of Noise from Motor Vehicles (M. Delucchi and S. Hsu) (with separate 250-page data Appendix).

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- Report 16: The Contribution of Motor Vehicles to Ambient Air Pollution (M. Delucchi and D. McCubbin).
- Report 17: Tax and Fee Payments by Motor-Vehicle Users for the Use of Highways, Fuels, and Vehicles (M. Delucchi).
- Report 18: Tax Expenditures Related to the Production and Consumption of Motor Fuels and Motor Vehicles (M. Delucchi and J. Murphy).
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- Main Report: A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials (~ 415 pp.) (M. A. Delucchi).
- Appendix A: Energy use and emissions from the lifecycle of diesel-like fuels derived from biomass (20 pp.) (M.A. Delucchi).
- Appendix B: Data for other countries (88 pp.) (M. A. Delucchi).
- Appendix C: Emissions related to cultivation and fertilizer use (82 pp.) (M. A. Delucchi).
- Appendix D: CO₂-equivalency factors (124 pp.) (M. A. Delucchi).

- Appendix E: Data on methane emissions from natural gas production, oil production, and coal mining (24 pp.) (M. A. Delucchi).
- Appendix F: Emissions of nitrous oxide and methane from alternative fuels for motor vehicles and electricity-generating plants in the U. S. (76 pp.) (M. A. Delucchi and T. Lipman).
- Appendix G: Parameters calculated with the EV and ICEV energy-use and lifecycle-cost model (8 pp.) (M. A. Delucchi).
- Appendix H: The lifecycle of materials (137 pp.) (M. A. Delucchi, with D. Salon).
- Appendix J: Emission factors for heavy-duty diesel vehicles (~ 25 pp.) (in preparation) (M. A. Delucchi).
- Appendix K: Input-output data for hydrogen from coal and hydrogen from biomass conversion processes (48 pp.) (G. Wang and M. A. Delucchi).
- Appendix X: Pathways diagrams (26 pp.) (G. Wang and M. A. Delucchi).
- Appendix Y: Some results from the LEM (~ 50 pp.) (in preparation) (M. A. Delucchi).
- Appendix Z: References to the main report (53 pp.) (M. A. Delucchi).

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ACRONYMS

BEA = Bureau of Economic Analysis
BLS = Bureau of Labor Statistics
CBA = cost-benefit analysis
CO = carbon monoxide
CO₂ = carbon dioxide
CPM = cost per mile
EIA = Energy Information Administration
FHWA = Federal Highway Administration
FTA = Federal Transit Administration
GDP = Gross Domestic Product
GHG = greenhouse gases
HDT = heavy-duty truck
HH = household
LDA = light-duty automobile
LEM = Lifecycle Emissions Model
MDT = medium-duty truck
MTP = Metropolitan Transportation Plan
MV = motor vehicle
NO_x = nitrogen oxides
O&M = operating and maintenance
PM = particulate matter
PM₁₀ = particulate matter of 10 microns or less diameter
PMT = person-miles of travel
PPI = Producer Price Index
SACOG = Sacramento Area Council of Governments
SCC = Social Cost Calculator
SO_x = sulfur oxides
SPR = Strategic Petroleum Reserve
UCD = University of California, Davis

US = United States

VMT = vehicle miles of travel

VOCs = volatile organic compounds