SPECIAL REPORT 246

PAYING OUR WAY

ESTIMATING MARGINAL SOCIAL COSTS OF FREIGHT TRANSPORTATION

TRANSPORTATION RESEARCH BOARD
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COMMITTEE FOR STUDY OF PUBLIC POLICY FOR SURFACE FREIGHT TRANSPORTATION

TRANSPORTATION RESEARCH BOARD
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PREFACE

A long-standing debate in transportation policy addresses the extent to which the various users of transportation systems pay the full costs of the services that they use. If some users pay their costs while others do not, the subsidized users will be unfairly advantaged and shippers and carriers will lack incentive to operate and use freight transportation efficiently. Traditionally, the focus of this debate has been whether users pay for the services and facilities that government provides. For historical reasons, the railroads generally have been responsible for providing and maintaining their own rights-of-way, whereas truck and barge operators use roads and waterways that are built and maintained by government agencies. The government also collects fees and taxes from freight carriers and shippers, and the often-asked question is whether these fees and taxes are sufficient to defray the costs of the government-provided services and facilities.

In recent decades the subsidy debate has broadened to include the external costs of transportation services. External costs are those that freight carriers or shippers impose on others by, for example, adding to air pollution, increasing accident risks, or contributing to traffic congestion and delays. Government has tried to reduce external costs by regulating pollutant emissions and mandating safety procedures for freight carriers, among other measures. Some external costs remain, nevertheless, in part because it is seldom practical or efficient to eliminate such costs completely.

The debate over whether some shippers or carriers are subsidized has bearing on nearly all areas of government policy affecting freight transportation, including highway and waterway user taxes, truck size and weight limits, railroad labor laws, emission controls, urban truck use restrictions, and public infrastructure investment. Ideally, decisions about government policies in these areas should be made using knowledge about

the extent to which current policies foster efficient use of the freight system and the extent to which the performance of the freight industries differs from that which would be expected if no subsidies were provided. Such knowledge does not exist, and providing it would be a formidable undertaking given the conceptual and practical difficulties involved.

As a first step, the Transportation Research Board (TRB) convened a committee to explore the potential usefulness and feasibility of a comprehensive study to measure subsidies in freight transportation and to assess their consequences for economic efficiency. The study committee included engineers with expertise in highway design and pollution control, economists, experts in distribution management, manufacturing executives responsible for distribution, and state transportation officials. The committee's work was sponsored by the National Cooperative Highway Research Program, the Federal Highway Administration, the Federal Railroad Administration, the Maritime Administration, and TRB.

Joseph R. Morris managed the study and drafted major portions of the report under the guidance of the committee and the supervision of Stephen Godwin, Director, Studies and Information Services. Harry Cohen and Dan Haling of Cambridge Systematics, Inc., contributed to the cost analyses under the guidance of the committee. The report was edited under the supervision of Nancy A. Ackerman, Director, Reports and Editorial Services. Norman Solomon edited the report. Administrative support was provided by Frances E. Holland.

José A. Gómez-Ibáñez, *Chairman*
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Policy for Surface Freight Transportation

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EXECUTIVE SUMMARY

This study is a preliminary examination of whether shippers of domestic surface freight pay the full social costs of the services that they use. Freight carriers and shippers do not pay directly for all of the costs of providing freight service. Some costs are borne initially by government, such as the cost of roads and ports that are built and operated by public agencies. Other costs, called external costs, are borne by nonshippers or the general public; these include the health and other damages caused by air pollution and noise generated by trucks, towboats, and locomotives and the traffic delays and congestion that an additional truck or barge imposes on other users of roadways and waterways. Social costs are all costs of the shipment, whether borne initially by the shipper, carrier, government, or public. However, carriers and shippers also pay special taxes and fees—such as fuel taxes or vehicle registration fees—that at least partially compensate for the costs that they impose on others.

It is desirable that shippers and carriers pay the full social costs of their freight operations—that is, that the special taxes and fees paid by the shipper or carrier for each shipment of freight be enough to offset the cost to the government of the shipment and the external costs that the shipment imposes on others. If the shipper and carrier do pay the full cost of each freight shipment, then they will be more likely to use transportation services responsibly and efficiently. Information on the extent to which they pay their way would help government to design policies on taxation, investment, and regulation that promote economic efficiency and to establish financing practices that are accepted as equitable.

This study is intended not to provide definitive answers as to whether shippers pay their full social costs but rather to determine the feasibility of making such estimates. Moreover, it is not this study's purpose to build a case for any new form of extensive government involvement or inter-

ference in the industry. Freight transportation is an essential activity in the U.S. economy, and more efficient freight service means lower prices and higher living standards for the entire public. Private-sector firms are best positioned to find the least-cost ways of moving freight, as long as markets provide them with information about costs. In making freight decisions, firms consider numerous factors that are not considered in this study, including differing service characteristics and prices of the freight choices open to them and the specific requirements of each shipment. The concern is only that certain costs, including that of providing public infrastructure and environmental costs, may not now be fully taken into account in private-sector decisions about freight.

MARGINAL SOCIAL COST APPROACH

This study uses the concept of marginal social costs in measuring whether freight users are subsidized or not. The marginal social cost of a good or service is defined as the increase in total social costs that results from producing one additional unit of output of the product above the level being produced. For freight, this unit of output could be an additional shipment between a particular pair of cities at a particular time of day or season of the year. Some of the components of the marginal social cost of that shipment are not borne directly by the shipper or carrier, but the shipper or carrier does pay additional special taxes and fees on the shipment. If the marginal taxes or fees that the shipper or carrier pays for each shipment equal the marginal costs that the shipment imposes on others, then the shipment is paying its way. If the taxes are less than these costs, the shipment is being subsidized by the amount of the shortfall.

The marginal social cost perspective differs significantly from the approach used in traditional studies of ways to allocate the costs of government services among transportation users. These traditional studies—federal and state highway cost allocation studies or federal waterway cost allocation studies—are undertaken to develop a schedule of user fees that will be sufficient to recover or finance the costs of current government programs. The highway cost allocation studies are concerned with ways to apportion highway agency costs between automobiles and trucks of different classes, for example, and waterway allocation studies are concerned with apportioning the U.S. Army Corps of Engineers waterway expenditures among barges, pleasure boats, and various nontransportation purposes such as flood control.

One obvious difference is that the traditional government cost allocation studies include only costs that appear on government budgets and not other external costs. The marginal social cost approach, by contrast, includes all social costs, to the extent they can be practically measured.

A second important difference is that traditional studies generally do not use the concept of marginal costs to estimate the government costs attributable to different types of users. They often compare fees paid and costs incurred by broad classes of transportation users (e.g., automobiles versus trucks) over an extended period rather than comparing fees and costs for the marginal shipment of a particular type. Moreover, they generally try to ensure that all of the government's costs are assigned to one user or another, so as to establish a schedule of fees for the various classes of users that will exactly recover the targeted level of revenue (which may equal the government's budgetary cost for providing service to fee payers or may include revenue raised for other purposes as well). With marginal costing, however, there is no guarantee that fee receipts will cover total costs exactly—they could be higher or lower.

Focusing on whether users of a particular mode or any other aggregation of users pay their way as a group is likely to be misleading, since such aggregate results often disguise considerable variation. The extent to which a freight user pays its way varies from shipment to shipment. The costs imposed on nonusers and the user fees paid often vary according to a shipment's origin and destination; the time of day, day of week, or season of the movement; and many other factors. The test of economic efficiency is whether individual purchases of freight services are at prices that coincide with costs, and not whether the sum of all payments equals the sum of all costs within broad groups. Also, focusing on cost comparisons among the modes tends to reinforce the unjustified preconception that the most important efficiency gains from eliminating subsidies would come about through shifts of freight among modes. In practice, carriers and shippers would develop numerous strategies for modifying their operations to reduce costs in response to the elimination of subsidies, from changing equipment specifications to altering shipping schedules.

Historically, the trucking industry has been reasonably satisfied with the government cost recovery approach, whereas railroads and environmentalists have advocated the use of marginal social cost. Many federal and state highway cost allocation studies using the traditional cost recovery approach conclude that truckers pay, or nearly pay, their share of government highway construction and maintenance costs. Many observers believe that including pollution, congestion, and other external costs

along with government expenditures might lend support to policies disadvantageous to trucks and barges relative to railroads.

The marginal social cost perspective is used here, not to promote the point of view of any particular interest group in debates over user fees, but because it provides more complete information to guide public policy. It is unreasonable to focus exclusively on the costs of government services since pollution, congestion, and other social costs represent real burdens on society. Moreover, marginal costs measure the real increase in costs due to an additional shipment, and thus they are the costs that the shipper should consider to encourage responsible and efficient transport use.

There is no guarantee that special taxes and fees set at marginal social costs will exactly finance the costs of government-provided services. Cost recovery often is an important objective of policy makers in setting fees for government transportation facilities. If cost recovery is the goal (and if cost recovery is possible under any fee schedule), it is possible to design fee schemes that provide the required revenue without sacrificing all the efficiency incentives inherent in the marginal cost approach.

The traditional government cost allocation studies have evolved over time to incorporate some concepts similar to marginal costing. Nongovernmental costs are still ignored, but the concept of marginal costs has the advantage that alternative cost allocation principles are harder to defend or apply consistently.

Improved freight transportation provides benefits throughout the economy. For example, reductions in freight costs can increase industrial productivity, reduce consumer costs, and attract new economic activity to an area. Such benefits occur because competition forces carriers and shippers to pass on some of their benefits to their customers. Because the primary beneficiaries of freight services are carriers and shippers (and through them, their customers), nonuser benefits do not justify subsidizing services that users are unwilling to pay for.

CASE STUDIES

The marginal social costs of a shipment vary considerably depending on the route, time of day, season, and other factors. Pollution costs usually will be greater for shipments passing through densely populated urban areas, for example, whereas external costs of congestion will be greater for shipments moving in the peak hour or season. National or aggregate estimates therefore obscure the extent to which costs and subsidies vary from one shipment to the next.

The committee has developed case study estimates of whether freight shippers are paying their marginal social costs for specific freight movements, both to explore the variation in marginal social costs and user payments among shipments and to test the feasibility of a more definitive analysis. The case studies are fictional but are intended to approximate plausible, real-world circumstances. The use of specific cases exposes the practical difficulties of defining marginal social cost and subsidies, the limitations of available models and data, and the categories of social costs that are most important.

The four case studies reflect a wide range of situations, but they are not intended to represent a majority of shipments in the United States. As a result, one should be extremely cautious about drawing policy implications from them. The cases are as follows:

1. A short-haul grain movement from an elevator in Minnesota to a Mississippi River port; this shipment moves by local roads (Case 1A), by Interstate highway (Case 1B), or by rail (Case 1C);
2. A long-haul grain movement from Minnesota to New Orleans by different combinations of rail and barge (Cases 2A and 2B);
3. A container moving from Los Angeles to Chicago by either truck (Case 3A) or rail (Case 3B); and
4. A truck delivering groceries to stores in Hartford, Connecticut (Case 4).

The marginal costs, fees, and subsidies were estimated for an additional trip of a loaded freight vehicle over each route. The costs estimated are as follows:

- Congestion: the delay cost to others caused by the added trip on a congested road or waterway (rail delay costs were assumed internal).
- Accidents: deaths, injuries, and property loss that occur because of the added shipment and whose costs are not borne by the operator.
- Air pollution: health and other damages caused by emissions produced during the shipment.
- Energy consumption: the difference between the social and private costs of petroleum consumed in the trip (excluding air pollution costs).
- Noise: the irritation and other costs of the noise caused by the trip.
- Public facility costs: the increase in costs of the public operating agency caused by the added shipment.

Marginal taxes and fees are then calculated and deducted from these costs to determine the subsidy.

Other possible sources of external costs or subsidies exist, for example, disamenities other than air pollution and noise, some government costs of rail-highway crossings, road user delays and pollutant emissions at rail crossings, and some direct government subsidies to railroads. The costs estimated in this study are those believed to be major ones from the marginal cost perspective.

FINDINGS FROM CASE STUDIES

The case studies demonstrate that it would be possible to make reasonably reliable estimates of the marginal social cost and subsidy for specific freight movements, provided full use were made of the best available information relevant to costs. Important uncertainties in the estimates, as will be discussed in more detail, must be kept in mind when drawing policy conclusions. However, the uncertainties are generally not so severe as to prevent conclusions about whether, for example, the degree of subsidy is large or small compared with overall carrier costs.

A focus on particular shipments is important because the estimates of marginal social costs and special taxes or fees per truckload mile vary widely (Table ES-1). The estimates of marginal taxes and fees fall short of the marginal costs imposed on the government and others in all of the case studies. The amount of subsidy varies widely, however, from $0.02/truckload-km (Case 2B) to $0.22/truckload-km (Case 4). The estimates are highly sensitive to specific circumstances. It can make a big difference whether trucks take local roads or Interstate highways (compare Cases 1A and 1B), for example, or whether grain is loaded on barges on the Upper Mississippi, where the locks are often congested, or on the Lower Mississippi, which has no locks (Cases 2A and 2B). Similarly, the subsidy per truckload kilometer is high for the grocery delivery truck (Case 4), the only case in which the shipment moves entirely within a metropolitan area, where many people are exposed to its effects.

In the cases selected, it is also striking that the subsidy is not very large when expressed as a percentage of total carrier costs. In seven of the eight situations studied, the subsidy is only between 7 and 14 percent of the costs that the carrier pays directly. If the subsidy were eliminated, the costs to carriers (and eventually to shippers) would go up by at most 7 to 14 percent in these cases, and probably less as carriers and shippers found ways to reduce costs.

One should be careful not to infer from this result that making shippers pay the marginal social costs is not important or would not matter since shippers already pay almost enough of the costs. The cases are not necessarily representative, and in one of the cases the subsidy is 31 percent of direct carrier costs (Case 2A). Moreover, even modest changes in shipping costs may induce beneficial changes in shipper or carrier behavior. This study did not project carrier and shipper responses to the elimination of subsidies, but carriers and shippers surely would have many ways of responding if subsidies were eliminated, some of which might be relatively inexpensive. Carriers and shippers might reroute shipments, use equipment that pollutes less, alter the location of terminals, change the hours of departures, or move some shipments to a different mode. If it is cheaper for the carrier or shipper to make such changes than to pay the full costs of old practices, then the transport system will become that much more efficient.

The presence of a subsidy is an indication that the freight service under consideration probably could be made more efficient. However, the findings of the case studies do not, by themselves, provide support for any particular policy aimed at improving efficiency.

Although it is not apparent from the summary figures in Table ES-1, the major causes of subsidy in the cases studied are some combination of external congestion, accident, and air pollution costs. Congestion is by far the largest component of marginal social costs in the cases involving a barge movement on the Upper Mississippi (Case 2A) and the container trucked from Los Angeles to Chicago (Case 3A), for example, because the Upper Mississippi locks are congested and the truck's departure time is such that it encounters congestion in several urban areas along its route. Similarly, accidents are the single most important component of marginal social costs in the short-haul movement of grain by truck (Cases 1A and 1B) because there is little congestion on the rural roads used. Air pollution is never the most important cause of subsidy in the cases, but it is often a significant contributor.

The case studies reveal important sources of uncertainty of the components of external costs.

Congestion

The major uncertainty in the highway delay estimates probably is the contribution of nonrecurring delay, that is, delay that occurs because of vehicle breakdowns or accidents. So-called recurring delay results from

TABLE ES-1 SUMMARY OF CASE STUDY ESTIMATES

CASE	MARGINAL SUBSIDY ($)	CARRIER AVERAGE COST ($)	SUBSIDY AS PERCENTAGE OF CARRIER COST	SUBSIDY PER TRUCKLOAD KILOMETER ($)
1 Grain shipment from Minnesota to Mississippi River port				
1A Truck	54	450	12	0.16
1B Truck via Interstate	44	530	8	0.11
1C Rail	11	120	9	0.03
2 Grain shipment from Minnesota to New Orleans via rail and barge				
2A Rail to Winona; barge to New Orleans	137	440	31	0.06
2B Rail to St. Louis; barge to New Orleans	40	590	7	0.02
3 Container shipment, Los Angeles to Chicago				
3A Truck	343	2,470	14	0.09
3B Rail linehaul	123	1,050	12	0.04
4 Grocery distribution in Hartford, Connecticut	20	280	7	0.22

NOTE: The estimates apply only to the cases specified and only under the assumptions regarding cost relationships described in Chapters 3 and 4. The estimates are subject to large uncertainties and cannot be generalized to freight traffic as a whole.

Terms are defined as follows:

- Case: the movement of one truckload of freight over the specified route.
- Marginal subsidy: the sum of marginal external accident, air pollution, noise, petroleum consumption, and congestion costs, plus the marginal cost of government-provided roads and waterways, less user fees paid to government for the shipment.
- Carrier average cost: the average freight charge that would be paid by shippers for similar freight movements.
- Subsidy as percentage of carrier cost: 100 × (marginal subsidy)/(carrier average cost).
- Subsidy per truckload kilometer: The marginal subsidy divided by the number of truckload kilometers constituting the shipment. A truckload kilometer is the movement of one truckload of freight 1 km. One truckload is 21 945 kg (48,380 lb) of grain in Cases 1 and 2 and one loaded container in Case 3. In Case 4, each fully or partially loaded kilometer of the truck is counted as a truckload kilometer. Costs of empty backhaul travel are included as a cost of the fronthaul. Costs for rail and barge movements are computed as the cost of one additional train or tow and then prorated on a tonnage basis to cost per truckload.

the effect of traffic volume on average speed. The case study estimates assume, on the basis of very limited information, that nonrecurring delay costs are larger than recurring delay costs on all roads. Very little is known about the extent of nonrecurring delay or about how traffic volume, road capacity, or other factors (such as incident management programs) affect it. If, in fact, nonrecurring delay costs are insignificant on many roads, then marginal external delay costs may be less than half the values estimated in the cases.

Accidents

Although uncertainties exist in the data on accident frequencies and costs, the major source of uncertainty is the relationship between the truck-car fatal accident rate and truck traffic volume on a road. The marginal cost of accidents depends on how each vehicle's risk of an accident changes as traffic increases. Relationships between accident rates and traffic volume have never been adequately measured.

Diesel Particulates

In the cases, the health effects of diesel particulates account for most of the air pollution costs. A growing body of data suggests that particulates in general are a serious health risk. Diesel particulates are believed to be among the more hazardous because of their size distribution and composition. The average diameter of diesel particulates is less than the average diameter of all PM10 (particles smaller than 10 microns in diameter), and diesel particulates have constituents that are more likely to be toxic than the constituents of PM10 from some other sources.

An important source of uncertainty arises from the assumptions in the case studies about the relative health effects of particulates generated by diesel engines and other combustion compared with so-called fugitive emissions such as dust from roadsides and construction sites. The case study computations assume that all emissions of PM10, regardless of source, have equivalent health and property damage effects. The case studies may underestimate pollution costs if diesel-generated PM10 is more toxic than fugitive dust. The assumption that all PM10 has the same effects is made in the baseline case studies because epidemiological data do not provide a quantitative estimate of the relative health effects of diesel particulates compared with the fugitive component of PM10 and because

national data are not available on the contributions of fugitive and nonfugitive sources to ambient PM10.

An alternative assumption, which has been tested in a sensitivity analysis, is that all health effects are attributable to diesel particulates and other nonfugitive sources. This assumption increases the estimates of marginal external air pollution cost by from $.03 to $.08/truckload-km. This sensitivity analysis is an upper bound on the health effects, because PM10 from fugitive sources probably does have some health effects and because the sensitivity analysis, for lack of data on relative contributions of fugitive and nonfugitive sources to ambient PM10, assumes that the ambient shares equal the shares in emissions, most likely overstating the fraction of nonfugitive PM10 in the atmosphere. The actual health cost may lie somewhere between the original and sensitivity analysis estimates.

Federal regulations limiting particulate emissions from diesel trucks in effect since 1988 are reducing the quantity of particulates produced in trucking. These reductions will continue as old trucks are retired. A new 1995 heavy diesel truck is allowed to emit particulates at one-sixth the allowable rate in 1988.

The pollution cost estimates have uncertainty from other sources as well, including emission rates of vehicles, the relationship of emissions to exposure, the health effects of pollutants other than particulates, and the dollar value that individuals assign to reducing their risk of premature death. Although the case studies took simplified approaches to some of these components of the cost estimates, the best available models have significant deficiencies. The cost estimates also would have been higher if dust generated from roadsides, in the volumes estimated by the Environmental Protection Agency (EPA), had been attributed to the passage of vehicles, but this uncertainty has not been quantified.

Petroleum Consumption

The case studies assign an external cost to the consumption of petroleum on the assumption that the vulnerability of petroleum supplies to disruption entails potential costs to the national economy that are not fully reflected by the market price of petroleum. However, over time, U.S. energy supply sources have diversified and the economy has become less vulnerable to the effect of petroleum supply disruptions, closing any gap between the market value of petroleum and its social cost. Consequently some analysts have estimated that the marginal external cost of petroleum consumption is approaching zero.

RECOMMENDATIONS

The committee's recommendations are in three areas: first, research needed to close several critical data gaps revealed in the case studies that are impeding a better understanding of freight costs; second, expansion of the case analysis to produce more complete and reliable external cost and subsidy estimates; and third, consideration of the policy implications of external costs and subsidies in future government studies of cost allocation, user fees, and public investment.

Critical Data Gaps

The U.S. Department of Transportation (DOT), together with EPA, should give high priority in its research programs to technical studies aimed at closing these information gaps:

- Measurement of the external safety cost of increased truck traffic. This will require measuring the relationship between traffic volume and accident rates and reliably measuring average truck accident rates.
- Measurement of the air quality effects of a change in freight volume on a road, waterway, or rail line, especially the effect on particulate concentration. Understanding air quality effects will require collection of in-use emissions data for a random sample of vehicles, statistically valid sample measurements of concentrations, refinements to models of the formation of secondary particulates, and information on the relative contributions of fugitive dust and other source categories to observed concentrations.
- Additional studies of the health effects of particulates, especially studies comparing the effects of particulates from different sources. Diesel particulates may be among the more hazardous particulates because of their size distribution and composition, but the relative risk has not been established. In the case studies, the estimated health effects of particulates account for most of the costs of air pollution from freight.
- Systematic measurement, for a variety of road environments, of the nonrecurring component of highway congestion delay and of truck passenger-car-equivalence ratings.
- Improved measurement of the marginal highway costs of truck traffic on a site-specific basis. Especially, the relationship of truck traffic to

bridge fatigue cost and the relationship of highway agency maintenance and reconstruction practices to road user and agency costs should be determined.

Expanded Case Analysis

DOT should conduct an expanded analysis to estimate subsidies in U.S. surface freight transportation. Such an analysis could be conceived as an extension of the case estimates performed for this study, including a larger sample of freight shipment cases and more detailed estimation methods. The definitions of costs should be those used in the case studies. The expanded analysis should include projections of freight market response to possible policies for eliminating subsidies so that the economic loss caused by subsidies in freight transportation can be estimated. The analysis would constitute a benchmark for assessing whether existing policies affecting freight, taken together, hinder or help the efficiency of the freight industries and whether the freight market as a whole is seriously out of balance. The expanded case analysis will need to consider whether categories of possible external costs and subsidies not considered in this study should be included.

The expanded analysis would have three applications. First, it would be a basis for screening potential problems to identify the sources of inefficiency (i.e., categories of costs and geographical and other circumstances) that are most worthy of public attention. Second, by emphasizing the effects of transportation policies on economic efficiency, the expanded analysis would highlight policy options that tend to be overlooked, including pricing policies. Third, the expanded analysis would provide an essential underpinning for studies of truck size and weight regulation, highway cost allocation, and waterways policies that governments will be conducting in the future. Most government actions affecting freight are necessarily incremental—adjusting a fee or a standard, or upgrading a road or a waterway, to solve an immediate problem. If the expanded analysis did not reveal fundamental distortions in the freight markets, it would allow government to proceed with more confidence that incremental actions intended to improve efficiency would have their desired effect. Without a baseline, it is difficult to determine whether incremental changes are in fact moving the transportation system toward greater efficiency.

Consideration of Economic Efficiency in Planning Studies

When DOT, the state transportation departments, and the U.S. Army Corps of Engineers conduct cost allocation studies, studies of alternative user fee systems, and evaluations of investment proposals, they should routinely consider the effects of the structure of road and waterway user fees on freight transportation efficiency and consumer welfare and search for user fee schedules that improve economic efficiency. The Corps of Engineers should consider congestion pricing as an alternative or complement to capacity expansion in its planning for the inland waterway system. In considering changes in fee schedules, the government must recognize that penalizing beneficial uses of roads and waterways can cause as much economic harm as subsidizing nonbeneficial ones.

The committee does not endorse any particular policy to impose new charges on freight operators in an effort to capture external costs. This study did not evaluate the costs and benefits of possible alternative user fees and taxes. Simplistic approaches to attempting to recover external costs by increasing freight carriers' fuel taxes or registration fees so as to generate revenue equal to an estimate of external costs almost certainly would harm efficiency. For example, charging congestion tolls reflecting immediate traffic conditions to vehicles at the actual time that they enter a congested highway might, in the future, as toll collection technology evolves, be an efficient way of managing congestion in the best interests of the public. However, estimating what an appropriate congestion fee would be on average, and then collecting equivalent revenues through a broad-based tax such as the fuel tax, would have virtually no effect on congestion but would harm efficiency by discouraging many worthwhile trips on uncongested roads for which the travelers were willing to pay the full cost.

Other barriers stand in the way of using taxes or user fees to reduce the inefficiency caused by external costs. First, the magnitudes of many costs are poorly known. Second, any new fee system, especially a complex one, could entail substantial administrative costs, and these costs would have to be shown not to outweigh the economic benefits of the more efficient use of transportation that would be the goal of the fees. Finally, it may often be ineffective or even counterproductive to impose a fee on one source of an external cost while ignoring other sources. Charging trucks but not cars for road congestion, for example, would be unjustifiable. Charging only transportation sources for air pollution probably would yield substantially lower net benefit than a policy that produced the same quantity of pollution reduction through charges to all sources.

However, the acknowledgment that pricing solutions would be difficult does not constitute an argument for not knowing the costs of freight. The economic losses caused by external costs and subsidies are real. Knowledge of the magnitudes of external costs and subsidies is essential for determining whether these losses are likely to be relatively great or small and whether practical government policies aimed at reducing such losses would have payoffs justifying their costs.

The important practical constraints on user fee policies—revenue requirements and considerations of administrative and political feasibility—do not preclude promoting efficiency through user fees. Considering the effect of user fees on economic efficiency does not demand an all-or-nothing policy choice: developing sophisticated, complex schemes versus ignoring efficiency altogether. For any two fee options under comparison, one will always be more efficient than the other—one will encourage economically beneficial use of the facility more than the other. These differences ought to be weighed carefully in decisions on tax policy.

1

INTRODUCTION

One of the oldest debates in transportation policy addresses the extent to which the various users of transportation systems pay for the services that they use. The implicit assumption is that making users pay their costs is generally equitable and encourages the efficient use of transport services. If some users pay their costs while others do not, the subsidized users will be unfairly advantaged and shipper and carrier choices distorted.

Traditionally, the focus of this debate has been whether users pay for the services and facilities that government provides. For historical reasons, the railroads usually have been responsible for constructing and maintaining their own tracks, for example, whereas trucking companies and barge operators use roads and waterways that are built and maintained by government agencies. The government also collects fees and taxes from freight carriers and shippers. The often-asked question is whether these fees and taxes are sufficient to defray the costs of the government-provided services and facilities.

In recent decades the subsidy debate has broadened to include the external costs of transportation services. External costs are those that freight carriers or shippers impose on others in society by, for example, adding to air pollution, increasing accident risks, or contributing to traffic congestion and delays. Government has helped to reduce these external costs by regulating the allowable air pollution emissions of trucks and locomotives, mandating safety procedures for freight carriers, and enforcing a variety of other measures. Some external costs remain, nevertheless, in part because it is seldom practical or efficient to eliminate such costs completely. Transportation policy analysts now debate whether the remaining external costs are substantial and whether government taxes and fees offset the combination of these remaining external costs and the costs of government-provided facilities and services.

The debate over whether some shippers or carriers are subsidized or otherwise treated equally has spawned numerous proposals for government policies affecting freight transportation, including proposals on user fees, weight limits, rail labor laws, emission controls, urban truck restrictions, and public infrastructure investment.

Decisions about such proposals should be made using knowledge about the extent to which current policies foster efficient use of the freight system. The U.S. Department of Transportation's (DOT's) 1990 statement of national transportation policy recognized this need in declaring that

> It is essential to review periodically Federal policies and subsidies to domestic transportation, . . . to identify and correct the unintended and undesirable effects on the competitive status of carriers and modes. . . .
>
> Attempting to estimate [costs of safety and environmental impacts] and incorporate them into user charges may offer public benefits. If users had to face the costs of these additional burdens they are imposing, they would have greater incentives to adjust their activity to minimize the costs they were being assessed and thus reduce the adverse environmental, safety, and other costs on other users, the system, and the Nation in general. (DOT 1990, 75–76)

Developing a quantitative understanding of the ways in which subsidies affect freight industry performance and are influenced by government policies would be a complex undertaking; indeed, some parts of such an analysis would require data and behavioral models that are not available. This study is a preliminary step toward developing such an understanding. It describes the economic framework for analyzing subsidies, roughly assesses the scale of subsidies, and examines the relevance of such estimates for public policy questions about taxation, public investment, and regulation. The study committee's recommendations identify areas for further analysis that would have practical value in decision making and propose approaches for these analyses.

This study's scope excludes two potentially important aspects of government activities that may influence freight industry efficiency and bias competition among the modes. The study does not consider how income taxes and other general taxes affect efficiency, nor does it address the overall impact of regulations.[1] The efficiency consequences of general taxation and regulation may be as important as the effects of the factors that are considered in the study: external costs and government provision and financing of infrastructure.

The following sections in this chapter describe the origin of the study, the study scope and objectives, and some of the public policy questions

for which its findings may be relevant. A framework for analyzing subsidies in freight transportation is presented in Chapter 2, and methods and problems of estimating each major component of subsidies are described in Chapter 3. Subsidy estimates for case study freight movements, designed to highlight conceptual issues and data requirements, are given in Chapter 4. Chapter 5 contains a description of ways in which more refined estimates of subsidies could aid decision making on taxation, public investment, and regulation, and the committee's recommendations are presented in Chapter 6.

STUDY ORIGIN

The policy questions underlying this study—how to set highway user fees for trucks, how best to control the pollution and accidents generated by freight, how to justify waterways subsidies, how to plan highway capacity to accommodate trucks, and others—are among the oldest, most consequential, and most controversial transportation issues that legislatures, Congress, and public transportation agencies must deal with. Aspects of these issues have been addressed in many past analyses. The Transportation Research Board (TRB) activities that led to the present study were three reports: *Twin Trailer Trucks* (TRB 1986) and *Truck Weight Limits: Issues and Options* (TRB 1990a), both conducted in response to congressional requests, and *New Trucks for Greater Productivity and Less Road Wear* (TRB 1990b), which was conducted for the state transportation departments. These three studies all reached similar conclusions—that certain liberalizations of truck size and weight limits would produce freight productivity benefits greater than any resulting increases in highway maintenance costs, and without significant effects on highway safety, congestion, or pollution. The two most recent TRB studies also recommended changes in truck taxes to make taxes correspond more closely to highway maintenance costs generated by the use of particular truck types.

Few of the recommendations of these TRB studies were acted on, and the studies were criticized on grounds that they had underestimated certain costs of truck travel and that their recommendations were impractical politically. More fundamentally, the studies are subject to the criticism that their recommendations were for incremental changes in a system that is severely distorted because of subsidies, and that these incremental changes might move the freight system in the opposite direction (toward a greater market share for trucks) from the way in which it would move if the necessary fundamental changes to remove the large market distortions

were made. The implication is that baseline knowledge about the overall efficiency of the freight transportation system is necessary to set the context for policy decisions about particular incremental changes in regulations, taxes, or other policies that affect freight costs and competition.

In response to the reactions to its truck size and weight studies, TRB convened an expert panel in 1991 to explore the need for a more comprehensive or strategic perspective on freight transportation policy issues. The panel recommended a program of research aimed at developing a better understanding of the freight industry and improving estimates of relationships between freight activity and pollution, safety, and highway agency costs (TRB 1991). One of the panel's recommendations was for the conduct of the present study of subsidies and external costs in surface freight transportation.

This study was initiated by TRB, and support has been received from the National Cooperative Highway Research Program (NCHRP, a joint research program of the state departments of transportation) and from the Federal Highway Administration (FHWA), Federal Railroad Administration, and Maritime Administration of DOT. Two other of the 1991 panel's recommended studies are being conducted by NCHRP: one on characteristics of and trends in freight transportation demand (NCHRP forthcoming a) and another on multimodal freight capacity in particular corridors (NCHRP forthcoming b).

STUDY SCOPE AND OBJECTIVES

In this study, the potential usefulness and feasibility of a comprehensive analysis that would measure subsidies received by freight carriers and shippers are examined. The objectives of such an analysis would be to determine the efficiency gain to the national economy, the changes in market shares of the surface freight modes, and the distribution of economic gains and losses among shippers, carriers, and the public that would occur if subsidies were eliminated.

Conducting such an analysis would require that several substantial difficulties be overcome, including the conceptual problems of establishing the appropriate framework for the analysis and defining concepts of subsidy and external costs and the technical problems of estimating external costs and government subsidies—many of the important costs are poorly understood and can be estimated only roughly with current data and models. Even if reliable estimates could be produced, further difficulties would be encountered in applying them to practical policy and reconciling

conflicting objectives of economic efficiency, revenue adequacy, administrative simplicity, fairness to affected industries, and environmental and social goals beyond efficiency.

This study is a preliminary survey to answer critical questions about the conceptual framework, methods, and data that would need to be resolved before a comprehensive study could be undertaken. Specific study objectives are as follows:

- Determine the appropriate economic framework for the comprehensive analysis;
- Roughly assess the scale of subsidies to help determine the feasibility and approach of a comprehensive analysis;
- Inventory data and methods and determine the activities needed to fill gaps in knowledge of the costs of freight transportation;
- Recommend whether the comprehensive analysis or some of its components ought to be carried out, considering the practical information needs of government decision making and the technical difficulties of conducting the analysis; and
- Specify the technical approach, data requirements, and resource requirements for any recommended further analyses.

A premise of this preliminary study is that a well-established baseline of information about the extent to which current policies foster efficient use of the freight system would be worthwhile even if fundamental reforms to transportation finance and regulation were not contemplated. Such a baseline could also guide decisions on incremental changes to truck size and weight limits, highway and waterway taxes, infrastructure investment, environmental and safety regulations, and other transportation policies.

Several studies over the past 20 years have estimated the social costs of highway transportation and, in some studies, competing modes. Examples include an appendix to DOT's 1982 highway cost allocation study report, which estimates efficient user fees related to the costs of pavement damage, congestion, air pollution, and noise (FHWA 1982, Appendix E). *Road Work*, a Brookings Institution study, estimates, in an economically rigorous framework, congestion costs and road wear costs for trucks and cars and proposes a major change in highway finance and investment that would introduce road wear pricing, congestion pricing, and a policy of optimal investment in highway durability (Small et al. 1989). *The Going Rate*, published by the World Resources Institute, estimates aggregate sub-

sidies and external costs for U.S. highway transportation (MacKenzie et al. 1992). Costs considered are highway construction, maintenance, and operation; parking; air pollution; the national security cost of energy consumption; accidents; congestion; and noise. A study sponsored by the Conservation Law Foundation estimated the infrastructure and external costs for a variety of automobile and mass transit trips in Portland, Oregon, and Boston, Massachusetts (Apogee 1994); the study showed how costs and subsidies varied not only by mode but also by the time of day traveled and location of the trip (suburb or central city).

Outside the United States, *Getting the Prices Right*, a study funded by the European Commission, three European governments, and Swedish State Railways, estimates costs per freight ton and per passenger kilometer of air pollution, noise, and accidents and proposes a scheme of European user charges to internalize these external costs (Kågeson 1993). *Directions*, the report of a Canadian government commission charged with recommending a national passenger transportation policy, deals solely with intercity passenger transport, but its approach is noteworthy: it uses consistent definitions of costs, attempts to include all private and social costs, considers all transportation modes, and examines who bears the cost burden (RCNPT 1992). *Transport and the Environment*, the report of a British government commission, exhaustively reviews environmental impacts of transport, both freight and passenger, and recommends actions by which the "development of transport can be made environmentally sustainable" (RCEP 1994).

Most past studies differ in approach from the present study, even defining basic concepts such as external costs differently. Some definitions in previous studies are incorrect, and some studies draw policy conclusions that are not supported by the cost estimates that they present. This study may also be distinguished from past studies by its focus on freight, its U.S. perspective, its inclusion of all surface modes (except pipeline), and its consideration of all costs, external as well as infrastructure costs. The study committee has attempted to resolve some of the outstanding conceptual problems encountered in analyzing some costs, address skepticism among public administrators about the relevance of marginal cost and efficiency concepts to practical problems, and consider the implications of uncertainty.

POLICY CONTEXT

One of the main tasks of this study has been to identify the policy relevance of analyses of subsidies in freight transportation to ensure that es-

timates have more than academic interest. The main areas of public policy that affect freight directly are the following:

- Public investment decisions, historically in waterways and roads but recently to a limited extent in rail and intermodal facilities as well, including decisions about design specifications and capacity;
- Assessment of user fees or other taxes (specifically, taxes on trucks and barges) to fund capital and operating costs of public facilities;
- Truck size and weight regulations;
- Air, water, and noise pollution control measures, including emissions regulations and traffic restrictions;
- Congestion reduction through traffic operations measures;
- Safety regulations; and
- Economic regulation—of freight rates, entry into the industry, and service abandonment; regulation in these areas has greatly diminished in the past 20 years.

All of these areas of government activity affect costs, efficiency, and the distribution of costs and benefits of freight activity. Public policy in these areas has had multiple objectives: building public facilities to yield economic payoffs; financing these facilities in a way that is perceived as fair; controlling the costs of building and maintaining public facilities; avoiding extreme changes in the competitive status quo among the rail, barge, and truck modes; protecting shippers from monopoly pricing or loss of service; and shielding the public from health and safety hazards.

The long-standing protagonists in debates over these policy areas, since early in the century when trucks first emerged as competitors to railroads, have been railroad and trucking companies and their customers. The railroads, who provide and maintain their own tracks while roads are publicly provided, see government actions on highway use taxes and truck size and weight as vital to their interests. State highway agencies, recognizing that trucks are a principal constraint in the design of roads and bridges, often have joined the debate in support of restrictions to preserve roadway infrastructure. Automobile drivers, responding to increased urban traffic congestion and the widening difference between the typical sizes of cars and trucks, express antipathy for driving around truck traffic (Wagenaar et al. 1988). Transportation energy consumption and pollution are considerations carrying great weight today, and environmental advocacy groups play an important part in policy debates affecting freight.

Historically, most policy disputes have centered on alleged subsidies to trucking. The conventional wisdom is that trucks are subsidized because

the highway taxes that they pay do not pay their full road costs, and that they have high external costs from pollution, accidents, road congestion, and petroleum consumption. Rail, in contrast, is often characterized as environmentally friendly, energy efficient, safe, and relatively free of subsidies.

On the basis of this characterization of the modes, some observers have argued for public policies to promote more reliance on rail and less on trucks. However, caution is warranted, given the lack of quantitative knowledge about the impacts of such policies. The magnitudes of subsidies are poorly known; nor is it known to what extent the diversion of freight from one mode to another, in market segments where the modes are close competitors, would reduce external costs. Some shippers place a premium on the service characteristics of trucks, so losing these qualities in a switch to rail would mean an economic loss to them. A public agency would have difficulty incorporating this loss in a cost-benefit analysis of a policy to promote one mode over another. If shippers and carriers were made responsible for external costs, however, they would themselves calculate the economic trade-offs among competing modes. It is likely also that they would discover ways to reduce significantly the external costs by a variety of innovations in addition to changing the mix of modes that they use.

No legislative proposals for comprehensive reform to public policy affecting freight markets are being considered today; rather, the pattern has been that many particular proposals for incremental changes are continually being debated or enacted. Although this pattern of incremental evolution of policy is likely to continue, the results could be improved if decisions were made with a baseline understanding of the ways in which changes affect freight efficiency; an overall framework for evaluating freight policy options would also help. Some current policy issues related to the efficiency of freight transportation and intermodal competition are identified here. These are not topics on which the study committee has made recommendations; instead, they indicate some of the needs for baseline information about freight costs. The seven issues described are

1. Truck size and weight regulation,
2. Highway cost allocation and user fees,
3. Freight intermodal issues,
4. Public rail subsidies and investment,
5. Clean air requirements and local truck route restrictions,

6. Regulatory costs, and
7. Congestion pricing.

Truck Size and Weight Regulation

The rail industry has warned for years that the decades-long upward creep in truck size and weight limits is at a point where the next logical step—widespread introduction of so-called longer combination vehicles (an LCV is a tractor pulling two full-sized trailers instead of one trailer or two small ones)—could have a major, nonincremental impact on rail market share and profitability and on the volume of freight carried on highways (AAR 1991). The rail industry argues that acceptance of LCVs would eliminate prospects for intermodal growth and kill incentives for rail industry investments that otherwise would result in billions of dollars of productivity savings over the next decade (AAR 1993). In 1991 Congress enacted a freeze on any extension of the use of LCVs beyond states and routes where they are now legal. The Association of American Railroads supports continuing the freeze, as do many state departments of transportation.

Some analyses have disputed the magnitude of the threat to rail posed by larger trucks and the potential of intermodal transport to divert major quantities of freight from highways. If the freight industry is at a critical juncture, however, then government policy decisions today on truck size and weight and intermodal infrastructure investments could have long-term repercussions for the shape of the freight industry. Regardless of the fate of LCVs, moreover, the states and the federal government undoubtedly will face proposals for revisions of truck size and weight limits in the coming years.

Highway Cost Allocation and User Fees

The 1956 act that created the federal-aid highway program mandated a study with the objective of assigning responsibility for federal highway costs to specific classes of users. The assignment would be for the guidance of Congress in setting user taxes, in keeping with the policy declared in the 1956 act that "if it hereafter appears . . . that the distribution of the tax burden among the various classes of persons using the Federal-aid highways, or otherwise deriving benefits from such highways, is not equitable, the Congress shall enact legislation in order to bring about . . . such equitable distribution." The 1978 highway act required DOT to con-

duct an updated highway cost allocation study, which was completed in 1981 (FHWA 1982). Many states have imitated the federal studies to provide a basis for state highway user fees.

These analyses have always encountered conceptual and practical difficulties, including definition of the congressionally mandated criterion of equitable distribution of costs, allocation of joint costs among automobiles and different types of trucks, and poor data on cost relationships such as the relationship of truck traffic to pavement wear. The studies take historical levels of highway investment and existing design practices as given and so do not attempt to determine the correct or optimum amount of revenues to raise.

An option that was discussed in the 1982 federal highway cost allocation study (but that played no part in the study's conclusions) is marginal cost-based pricing for road wear, as one part of a highway user tax system (FHWA 1982, III-1–III-15 and V-10–V-14). Such a scheme could be consistent with the congressional mandate for equity, as long as an administratively practical way to collect the tax could be found and a funding mechanism provided for any revenue shortfall. Road wear pricing would require a truck tax scheme based on axle weights, distance traveled, and other truck and road features, replacing or augmenting the current system of fuel taxes, registration fees, and excise taxes dedicated to highway use.

A few states now have some form of weight-distance tax. Truckers oppose such taxes, arguing that any theoretical efficiency benefit is canceled by higher administrative costs and that the taxes are unfair because it is easier to cheat on a complicated tax. The industry has succeeded in having weight-distance taxes repealed in several states. In another congressionally mandated study, FHWA considered the possibility of a federal weight-distance tax and concluded that the idea has merit but is impractical at present (FHWA 1984).

The 1990 TRB study of truck weight limits proposed a permit fee system for heavier trucks as a mechanism for relating taxes more closely to actual costs (TRB 1990a). Operators of trucks with weights above normal limits would apply for permits that specified the routes and amount of use of the trucks. Permit fees would be calculated to cover all incremental costs to the highway agency caused by the operation of the heavier trucks, taking into account the condition of roads and bridges on the proposed route. This proposal would, in effect, enable truck operators to buy a permit for any operation for which they were willing to pay the highway costs, within limits dictated by safety considerations.

Freight Intermodal Issues

Developments in intermodal freight have given rise to predictions that sizable shifts of freight from highways to rail via intermodal are possible. Rail revenue from intermodal grew rapidly in the late 1980s (AAR 1992). Several recent cooperative agreements between major trucking companies and railroads indicate that many longhaul truckers contemplate relying on intermodal service for a large share of linehaul carriage (Machalaba 1992).

Prospects for intermodal are viewed hopefully not only by railroads, but also by state highway agencies seeking relief from growing truck traffic and by trucking firms that believe they can capitalize quickly on the trend. Some trucking industry spokesmen have stated that they hope the growth of intermodal service will move the politics of freight policy away from confrontation and toward a more cooperative approach among industry and government (Murphy 1993).

Intermodal development sets the context for many current public policy debates affecting freight. The 1991 federal-aid highway act was entitled the Intermodal Surface Transportation Efficiency Act (ISTEA), and DOT's 1994 Strategic Plan specifies a goal to "'Tie America Together' through an effective intermodal transportation system" and an objective to "achieve a new National Transportation System that integrates all modes and emphasizes connections, choices, and coordination of transportation services" (DOT 1994). Presumably, government actions to promote intermodal freight could include improving highway links to port and rail facilities and giving direct public assistance to ports and railroads.

The emergence of new organizational arrangements in the freight industry does not mean that questions about the effects of government policy on modal competition have become any less significant. The modes will always compete as technologies on the basis of cost and performance, whether the choices are made internally by a multimodal freight services company or by shippers choosing between traditional trucking and railroad companies. Regardless of the organizational setting, subsidies can still lead to choices among the modes that are economically wasteful.

Public Rail Subsidies and Investment

Several states offer aid to short-line freight railroads in the form of loans or other assistance for capital improvements (Maze et al. 1992). Some federal aid has been available for these activities in the past (FRA 1993).

Traditionally, these activities are justified on economic development grounds, but recently some states have considered supporting rail development or investing in facilities to promote intermodal freight as cost-effective alternatives to making highway improvements in corridors with heavy truck traffic. An NCHRP project recently considered under what circumstances it would be cheaper for a state to provide rail capacity to carry a portion of freight traffic than to provide highway capacity for the traffic (NCHRP forthcoming c).

As an example of state projects, Ohio in 1994 sought congressional approval of a plan to use federal transportation aid funds to finance the development of an intermodal terminal. The state argued that the project would improve air quality in a region currently not in compliance with federal clean air requirements by removing trucks from the roads and that it would retain employment in the state by lowering transportation costs (*Governing* 1994). In California, the Alameda Corridor project is one of the most ambitious local government rail projects. A special authority has been formed to acquire right-of-way and build a rail connection between the ports of Los Angeles and Long Beach and rail yards (*Governing* 1994). Economic development, pollution reduction, fewer grade crossing accidents, and congestion reduction are the intended benefits. In Texas, the port of Houston is seeking approval to use funds provided by the Congestion Mitigation Air Quality program of ISTEA to improve rail facilities serving the port, justifying the proposal on the basis of predicted transportation cost savings and pollutant emissions reductions from eliminating some truck drayage of containers at the port (Brennan 1994).

Clean Air Requirements and Local Truck Route Restrictions

The 1990 Clean Air Act Amendments and ISTEA together have increased pressure on urban areas to take action to meet air quality standards and have created the possibility of more stringent transportation restrictions for accomplishing this. Some proposals have been made for route or time-of-day restrictions on trucks in urban areas as air quality measures or for other environmental ends.

Industry has argued that local agencies considering such proposals do not understand the economic consequences of truck restrictions. A related, more general industry concern is that the local metropolitan planning organizations, or MPOs, which have been given major new authority for highway capital budgeting under ISTEA, lack the understanding or

perspective necessary to provide properly for freight transportation needs in planning urban transportation improvements.

Regulatory Costs

The cost of health, safety, labor, and other regulations affects modal competition, and if these regulations have low benefits or do not achieve their benefits in the cheapest way, they are sources of inefficiency in freight transportation. Publicizing the growth of these costs has been a major recent theme in trucking industry political activities. The American Trucking Associations has estimated that existing mandates will increase industry costs for highway use taxes, workers compensation, and environmental and safety regulations from $30 billion today to $73 billion by 2000 (Schultz 1992).

A category of rail industry regulations that has been a long-standing cost concern is the special federal labor law provisions applying to railroads. A recent TRB policy study compared the cost to the rail industry of Federal Employers' Liability Act provisions governing workers compensation with costs if rails were subject to workers compensation requirements that apply to most other industries (TRB 1994a).

This study does not address the total impact of regulation on freight industry efficiency; however, the kind of information about external costs that this study has begun to develop could be applied to improve the cost-effectiveness of regulation.

Congestion Pricing

The external costs of freight transport include the costs of delay that trucks impose on other road users in congested traffic and that barge tows impose on other traffic at locks. Charging for trucks' congestion costs would be unreasonable unless congestion pricing was adopted for all vehicles, cars as well as trucks. Road congestion pricing still faces great technical and political obstacles, but recently the idea has received more serious attention than in the past, in part because of technological developments such as automatic toll collection systems and also because of support for the concept from environmentalist groups. A TRB policy study commissioned by DOT recently reviewed the prospects of congestion pricing (TRB 1994b), and ISTEA provided for federal funding of five demonstration projects of road congestion pricing. Imposition of waterways

congestion pricing is also a potentially beneficial policy and might face fewer practical obstacles than road pricing.

Summary

These policy questions are examples of areas in which public decisions might be improved if better information were available about whether freight transportation users are paying the cost of the services that they receive. In general, the applications of information about freight subsidies involve user fees for roads and waterways, cost-effectiveness of regulations, and public infrastructure investment. Potential applications will be addressed in more detail in Chapter 5.

NOTE

1. If the regulations are controlling external costs, then the differences in regulatory burdens among kinds of freight movements typically will be considered in the subsidy calculations as they are carried out in this study. In such cases, the more strictly regulated category of freight service provider or user may have higher internal costs as a result of the regulation, but such a provider or user will be more than compensated by being charged for fewer remaining external costs. Only if the regulations imposed are excessively stringent will the increase in internal costs be greater than the savings in external costs and the strictly regulated mode be disadvantaged in ways not compensated for in the subsidy calculations.

   A related but separate issue is the extent to which government regulations that are not designed to control external costs are stricter for some modes than others. The most important examples are regulations governing railroad employee compensation and labor relations. Railroads argue that they are unfairly disadvantaged by these requirements. These issues are discussed later in this chapter (see p. 28).

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ABBREVIATIONS

AAR	Association of American Railroads
DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
NCHRP	National Cooperative Highway Research Program

RCEP Royal Commission on Environmental Pollution
RCNPT Royal Commission on National Passenger Transportation
TRB Transportation Research Board

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2

FRAMEWORK FOR ANALYSIS

This study's fundamental concern is that the freight transportation system may be operating inefficiently and that public roads and waterways may be financed inequitably because some freight carriers or shippers do not pay the full social costs of the transportation modes that they use. The framework employed in this study for determining whether freight users pay their way is outlined in this chapter. The reasons that such calculations are useful, several alternative methods that are commonly used in such calculations, and the basic advantages and limitations of the marginal social cost approach recommended in this study are then described in more detail. Key terms used in this chapter are defined in a glossary on page 48.

BASIC FRAMEWORK

Freight carriers and shippers do not pay directly for all of the costs of providing freight services—some costs are initially paid or borne by governments and the public at large. But shippers and carriers also pay special taxes and fees (for example, fuel taxes and vehicle registration fees) that at least partly compensate for the costs that they impose on others. This study identifies these costs and then examines whether the special taxes and fees paid by carriers for use of public facilities suffice to offset them. The scope of costs considered includes, to the extent practical, all such social costs of transportation as pollution and congestion as well as costs of public provision of roads and waterways.

Table 2-1 presents, in simplified form, who initially pays the principal costs of a truck, barge, and rail shipment in the United States. Initial costs are borne by the carrier responsible for the shipment in question, the government, other carriers and users of the same infrastructure (e.g., other truckers and automobiles using the same highways), or the general public.

TABLE 2-1 TYPICAL INITIAL BURDEN OF U.S. FREIGHT TRANSPORTATION COSTS

Mode and Type of Cost	Initial Bearer of Cost[a]				
	Carrier	Government	Other User of Common Infrastructure	Public	Shipper
Truck or barge					
Vehicle	All				
Infrastructure[b]	Part	Part	Part		
Air pollution				All	
Noise pollution			Part	Part	
Congestion	Part		Part		Part
Accidents	Part	Part	Part	Part	Part
Railroad					
Vehicle	All				
Infrastructure	All				
Air pollution				All	
Noise pollution				All	
Congestion	Part			Part	Part
Accidents	Part	Part	Part	Part	Part

[a] The initial burden is the incidence of the cost before the freight tariff is paid by the shipper to the carrier and before user fees are paid by truck and barge operators to government.

[b] The costs of infrastructure wear caused by traffic are borne initially in part by government in the form of higher road maintenance costs and in part by users in the form of higher vehicle operating costs.

In this analysis it is assumed that market forces will cause any cost, fee, or tax paid by freight carriers to be passed on to shippers in the form of higher freight tariffs. Given competition or efficient regulation, shippers and carriers can be thought of almost interchangeably; if a carrier is paying its way, its customers ultimately will be as well.

The carrier normally pays the cost of owning and operating its vehicles.[1] Infrastructure capital, maintenance, and operating costs are usually paid by the carrier or by the government. The government pays the cost of infrastructure for barges and trucks, but carriers pay most infrastructure costs in the case of railroads.

For the most part, the public bears the costs of the air and noise pollution generated by freight transportation. Those who live and work near the right-of-way suffer most from noise pollution and certain types of air pollution, for example. Persons far from the right-of-way suffer as well, since some pollutants travel great distances or may affect climate. Costs such as air and noise pollution that are imposed on others through nonmarket or nonprice mechanisms are called external costs.

Congestion costs for trucks and barges are borne partly by the carrier of the shipment in question and partly by others using the same facilities or infrastructure. When a truck or barge uses a highway or a waterway, its presence slows average traffic speeds and imposes delays on others. Congestion costs that are imposed on others are external costs.

Costs of train delays caused by congestion on railroads, by contrast, are borne entirely by the carrier and its customers, not by others. The railroad usually has exclusive access to its right-of-way (or is compensated for its use by other railroads). Thus any train delays caused by scheduling an additional train on the right-of-way usually will hurt the railroad itself, not other carriers. (The cost of delay to automobiles at grade crossings caused by an additional train would be external.)

The burden of accident costs is complex and is discussed in more detail in Chapter 3. In general terms, accident costs typically are borne partly by the carrier itself, partly by other users of the common infrastructure (in the form of increased accident rates), partly by the government, and partly by the general public.

The costs that the carrier imposes on others are offset by such special taxes and fees as the carrier pays. The problem of defining what constitutes a "special" tax or user fee is discussed in more detail later, but generally carriers or shippers are credited with any tax or fee that is applied only to freight carriers or shippers and not to nontransportation companies or services.

The extent to which a freight user pays its way varies from shipment to shipment. The costs imposed on nonusers and the user fees paid often vary according to the shipment's origin and destination, the time of day, day of week, season of the movement, and many other factors. Thus, it is usually misleading to focus on whether users of a particular mode or any other aggregation of users pay their way as a group, since such aggregate results often disguise considerable variation. The test of economic efficiency is whether individual purchases of freight services are at prices that coincide with costs, and not whether the sum of all payments equals the sum of all costs within broad groups.[2] Also, focusing on cost comparisons among the modes tends to reinforce the preconception that the most important potential efficiency gains from eliminating subsidies would come about through changes in mode shares. In fact, carriers and shippers would have numerous possible technological and operational strategies for responding to elimination of subsidies, from changing equipment specifications to changing shipping schedules, if subsidies were eliminated through fees or other means that communicated the costs of these choices to carriers.

REASONS FOR CALCULATING WHETHER FREIGHT USERS PAY THEIR WAY

Rationale for User Cost Responsibility

Three justifications are often given for trying to ensure that transportation users pay the full costs of the modes that they use. These justifications are not mutually exclusive, but neither are they necessarily consistent with one another. Advocates of requiring that users pay their way may differ in the justification that they believe to be most compelling, and the different justifications can imply somewhat different measures of what users should pay.

Efficiency

The first rationale is to make sure that society's resources are allocated efficiently among the various transportation modes and between transportation in general and all other goods and services. The basic idea is that if a user must pay the cost of a service, then that user has an incentive to use the service only when its value is at least as great as its cost.

This argument assumes that the user of the service is the primary beneficiary, which is not always the case. A classic example is vaccination: those vaccinated reduce the risk of spreading disease, protecting not only themselves but also others who are not vaccinated. Society therefore might want to subsidize vaccinations. Otherwise, too few individuals would choose to become vaccinated, because they would not consider the benefits that their vaccinations provide for others.

Freight transportation offers benefits to nonusers and thus, at first glance, might appear to be as deserving of subsidy as vaccinations. For example, reductions in freight costs can increase industrial productivity, reduce consumer costs, and attract new economic activity to an area. Such benefits usually occur, however, because market forces eventually compel freight users (carriers and shippers) to transfer some of their benefit to others, not because any new or additional benefits are created. To the extent that industrial productivity increases, consumer costs decline, or activity is attracted to an area, it is usually because competition has forced carriers and shippers to pass some or all of their freight cost savings to their customers. In the case of vaccinations, by contrast, the nonuser benefits are distinct from and additional to the user benefits in that the protection afforded nonusers (the unvaccinated) does not come at the expense of any reduction in the protection afforded to users (the vaccinated). Because the principal beneficiaries of freight services are carriers and shippers (and through them, their customers), society's resources are likely to be wasted in providing freight services unless the users are willing to pay the costs.

Most economists have strongly advocated efficiency as a goal of public policy in all economic areas, not just freight. Efficiency concerns increasingly are advanced by others as well in debates over freight transportation policy. For example, some environmentalists contend that as a society we consume too many transportation services because transportation users do not pay directly for the environmental damage that their modes cause. Similarly, the railroads traditionally have argued that trucks and barges are overutilized and railroads underutilized because truckers and barge operators do not pay the full costs of the publicly provided highways, locks, dams, and other facilities that they use.

Equity

A second rationale is that it is equitable for users to pay their way. Why should society as a whole implicitly subsidize those who use transporta-

tion heavily, for example, by not requiring transportation users to pay their costs? Why should the users of one mode subsidize users of another because users of the first mode pay their way while users of the second do not?

There are other definitions of equity that conflict with the requirement that consumers pay their way. In particular, as a society we provide certain goods and services regardless of willingness or ability to pay because access to them is thought to be important to ensuring equality of opportunity or providing a safety net for the less fortunate. Primary and secondary education are offered without tuition, for example, to guarantee equality of opportunity and the well-educated citizenry necessary for a democracy. Just how far this principle should be extended is a topic of continuing public discussion, as illustrated by the debate over health insurance. But even though freight transportation services are important to the poor, the arguments for free or subsidized provision are far less compelling for freight than for other services, such as education or health, that appear more central to equal opportunity.

Finance

Financial considerations are the third rationale for requiring users to pay their way. Public and private transportation agencies must find sources of income sufficient to finance the infrastructure and other costs of transportation services. User charges are often far more reliable and politically acceptable than other sources of finance, such as broad-based taxes. Thus getting users to pay their way often has important fiscal advantages.

One complication arises because the user charges needed to encourage efficiency are not necessarily the same as those needed to fund agency budgets. As is discussed in Appendix A, discrepancies can occur if social costs that do not appear on agency budgets, such as pollution, are included, if the agency's costs do not vary in direct proportion to output, or if the agency temporarily has excess or insufficient capacity. It is possible to design user fee schedules that collect enough revenue to meet the agency's financial requirements while still largely maintaining efficiency incentives.

Practical Objections and Answers

There are several practical objections to making users pay, or even to trying to calculate whether they do. One is that it is extremely difficult

to accurately measure all the costs of freight transportation. For example, the human health effects of the pollutants emitted by freight vehicles are not fully understood, and placing dollar values on the morbidity and mortality effects is controversial. Some might claim that it is more responsible and less misleading to not estimate transportation costs at all than to present results that are bound to be full of errors and uncertainties.

A primary purpose of this study is to assess the practical possibilities for measuring whether transportation users pay their way. Substantial areas of uncertainty exist, particularly in measuring pollution and accident costs imposed on others. Not all components of transportation costs are subject to such large uncertainties, however, and plausible estimates of the degree to which transportation users are paying their way are often possible. It is important to recognize, moreover, that most transportation policies are based on implicit assumptions about the degree to which various categories of users are paying their way. The relevant choice is thus not whether to estimate if users are paying their way but whether the estimates that guide policy will be implicit, based largely on intuition and hunches, or explicit and thus subject to review, refinement, and debate.

A second objection bears on the degree to which the goals of efficiency and financing conflict. Historically, government policy has been concerned with whether users pay for the budgetary costs that they impose on public agencies, not whether they pay their social costs. Governments have long felt the need to balance their budgets, but many of the social costs of transportation have been widely recognized only in the past few decades. As a result, governments have depended on fuel taxes and other user fees to finance their transportation services. A shift to a social efficiency perspective could be disruptive, particularly because the efficient fees can be lower than the charges currently collected in some cases.

This study examines the degree to which financing and efficiency objectives might conflict by comparing charges designed to promote efficiency with those designed for governmental cost recovery. Significant conflicts do exist that may be difficult to resolve. In many cases, however, the discrepancy between the two perspectives is not large, and it is possible to imagine strategies for reconciliation.

A third objection to calculating whether freight users pay their way is the claim that significant reforms to freight user charges are politically unlikely. Current user fees and taxes reflect decades of political compromise among the various transportation modes and interests. Reform proposals are often seen as partisan exercises, with the railroads and envi-

ronmentalists often the strongest lobbyists for change and the truckers and waterway operators often the opposition. In any event, skeptics argue that the political inertia is immense and that there are no obvious and dramatic crises in the freight system that might generate the political energy required to effect major reform.

Calculating whether users pay their way can be helpful for policy makers, however, even if user charge reform proves undesirable, impractical, or politically unacceptable. This study is not concerned with recommending specific changes in freight user charges or other transportation policies, only with assessing the practicality and utility of estimating whether users pay their way. Nevertheless, one could easily imagine using such estimates to assess other policy changes or intervention short of user charge reform. An estimate that competing services were not paying their full social costs might be helpful, for example, in deciding whether the government should subsidize a freight service or facility that would not otherwise be commercially viable. Similarly, knowledge that a freight service is not paying its full social costs because of large pollution or accident costs would be useful in deciding whether to require reductions in emissions rates or additional safety equipment.

THREE METHODS OF COST ALLOCATION

To allay some of these practical concerns about the utility of the marginal cost accounting framework used in this study, it is helpful to compare three methods of calculating the costs that a freight user imposes on others. One method—marginal social cost in the short run—is the approach most often recommended by economists concerned with efficiency. The second method—governmental cost recovery—is the approach traditionally used to allocate responsibility for the costs of government-provided services. The final method—marginal social cost with facility expansion—is a variant of the first that is sometimes recommended to advance efficiency.

Illustration of Three Methods

The basic differences among the methods are presented in Table 2-2, which shows the user cost responsibility for a truckload of grain moving 350 km (217 mi) from an elevator at Walnut Grove, Minnesota, to a port on the Mississippi River at Winona, Minnesota (Case 1A). The sources of

TABLE 2-2 THREE METHODS OF CALCULATING COST RESPONSIBILITY

	Marginal Social Cost in Short Run[a]	Traditional Government Cost Recovery	Marginal Social Cost with Facility Expansion
Costs not initially borne by carrier ($/truckload)			
Vehicle	0	0	0
Infrastructure	39	75	~75[b]
Air pollution	7	0	7[c]
Noise pollution	2	0	2[c]
Energy security	3	0	3[c]
Congestion	9	0	0
Accidents	46	0	46[c]
Total	106	75	133
Less fees and taxes paid by carrier ($/truckload)	51	51	51
Equals net subsidy ($/truckload)	54	24	82
Carrier's cost ($/truckload)	454	454	454
Subsidy as percentage of carrier's cost	12	5	18

[a] The estimated costs are the same as those in Table 4-2 for Case 1A, the movement of a truckload of grain from Walnut Grove, Minnesota, to Winona, Minnesota. The truck is assumed to return empty to Walnut Grove. Costs of this empty return mileage are included as a cost of the cargo-carrying leg of the trip. The number of decimal places to which estimates are displayed in this illustration is not indicative of the number of significant digits in the estimates.

[b] It is assumed here for purposes of illustration that the cost of accommodating one added vehicle with no degradation of service is on the same order as the average cost of the facility per vehicle.

[c] In general, capacity expansion could cause marginal external pollution, energy security, and accident costs to differ from their values in the short-run marginal cost method. However, if the scale of the capacity expansion is chosen to provide capacity for one additional truck trip with no change in total congestion delay, then these costs probably would differ only slightly from the short-run marginal cost case.

the specific cost estimates in the table are described in more detail in Chapters 3 and 4. Present purposes require focusing only on the differences in the cost categories included in the three methods.

Certain key terms must be defined at the outset:

- *Marginal cost* is the change in total costs caused by increasing output in a time period by one unit; in this example, it would be the increase in costs from moving one additional truckload of grain from Walnut Grove to Winona. The adjective "social" is usually added as a reminder that the costs included are not just costs that the freight carrier incurs directly but costs that are imposed on others as well.
- *Short-run marginal social cost* is the marginal cost when the added traffic must be accommodated with the existing physical plant; in this example, it is assumed that the traffic will be accommodated without widening or strengthening the roads connecting Walnut Grove and Winona.
- *Marginal social cost with facility expansion* differs in assuming that there is enough lead time to adjust the investment in infrastructure and other facilities to the new traffic levels.

Short-Run Marginal Cost

The first column of Table 2-2 presents the short-run marginal cost method. Using this approach, the truckload movement of grain costs others $106. Infrastructure costs increase, for example, because the passage of the truck damages the pavement, thereby hastening the date at which the road will be resurfaced. Similarly, congestion increases because in the short run road capacity cannot be increased, so the passage of the additional truck delays other vehicles. The carrier pays $51 in additional fuel taxes, vehicle registration fees, and other user charges for the trip, leaving a net subsidy of $54. To put this subsidy in perspective, the costs paid directly by the carrier (and presumably charged to the shipper) are shown at the bottom of the column. In this example, the carrier marginal costs are $454/truckload, so the subsidy is 12 percent of carrier and shipper costs.

Government Cost Recovery

The traditional government cost recovery approach, given in the middle column of Table 2-2, differs in two important respects. First, this approach

generally excludes any cost that does not appear on government budgets, such as the congestion and pollution generated by transportation users.[3] With the marginal social cost approach, by contrast, all costs are considered, to the extent practical.

Second, under the government cost recovery approach all transportation agency costs are assigned to a user class; the procedures used to assign these costs vary from one study to the next, but the goal is to allocate all costs. In essence, the cost recovery approach is designed to generate a schedule of charges for different types of users that will recover the government's budgetary costs exactly. With the marginal social cost approach, costs are assigned according to the concept of marginal cost. Marginal costing does not necessarily result in a schedule of charges that would just recover costs, governmental or social.

The government cost recovery approach does not necessarily imply greater or lesser subsidies than the short-run marginal cost approach. Although some categories of costs are excluded, the infrastructure costs allocated are often greater. In the specific example in Table 2-2, the government cost recovery approach suggests a subsidy of only $24/truckload, or 5 percent of carrier and shipper costs.

Marginal Cost with Facility Expansion

Marginal cost with facility expansion, in the third column of Table 2-2, differs from short-run marginal costs in that the added traffic is assumed to be accommodated by increasing the investment in the infrastructure rather than by tolerating accelerated pavement damage or increased congestion. Lanes are widened or capacity is otherwise improved so that the extra truckload can pass without delaying other vehicles; therefore, there is no marginal congestion cost. Pavement is built to higher standards so that passage of the extra truckload does not accelerate the date for resurfacing. Therefore, the infrastructure costs differ from those included in the short-run marginal cost approach: in this approach the infrastructure cost is the investment in capacity improvement and pavement strengthening, whereas in the short-run approach the infrastructure cost is the cost of accelerating the date at which the road must be resurfaced.

Estimates of the marginal cost with facility expansion are of particular interest in that they signal whether infrastructure investment is needed or not. As explained in Appendix A, the level of investment in the infrastructure is optimal if the short-run marginal cost is just equal to the marginal cost with infrastructure expansion. If short-run marginal cost is higher,

then there has been an underinvestment in infrastructure; if it is lower, an overinvestment has occurred.

As a result, the two marginal cost methods will provide conflicting estimates of whether a freight carrier is paying its way only when the investment in infrastructure is too small or too large. If the investment is just right, both methods will yield the same result. In the long run and with reasonably sensible infrastructure investment policies, one would expect the two marginal cost estimates to converge.

In the example in Table 2-2, the marginal cost with facility expansion exceeds the short-run marginal cost. If this result is correct, and if it holds for other vehicles as well, it suggests that either the state may have overinvested in roads connecting Winona and Walnut Grove or that the least expensive practical road design provides more capacity than is needed on the route. Because the marginal cost with facility expansion is higher, it implies a higher subsidy of $82/truckload, or 18 percent of shipper costs.

In this illustration, the assumption that capital expenditures are undertaken so as to ensure that total congestion and pavement wear costs remain unchanged is somewhat arbitrary. Highway capital expenditures could be made such that other categories of costs were unchanged as well, for example, noise barriers to leave noise costs unchanged or safety improvements to leave accident costs unchanged.

Marginal Social Cost Versus Government Cost Recovery

Historically, the trucking industry has been reasonably satisfied with the government cost recovery approach, whereas the railroads and environmentalists have advocated the use of marginal social cost.[4] Many federal and state highway cost allocation studies using the traditional cost recovery approach conclude that truckers pay, or nearly pay, their share of government highway construction and maintenance costs.[5] Most observers also believe that including congestion, pollution, and other external costs along with government expenditures would probably disadvantage trucks relative to railroads and perhaps barges.

This study recommends the marginal social cost approach as a generally superior guide for public policy. The approach has a flaw in that its recommended user charges will not necessarily generate the revenue needed to fund government transportation agency budgets. As explained in more detail in Appendix B, however, revenues from charges based on marginal social costs will be sufficient to approximately cover government infrastructure and maintenance expenditures under assumptions that are

plausible for many kinds of freight shipments. If charges based on marginal costs were to generate too much or too little revenue to meet budgetary needs, moreover, user fee schemes that provide the required revenue without entirely sacrificing the efficiency incentives inherent in the marginal cost approach could be designed.

Setting user charges is only one of the potential policy applications of calculating whether users pay their way; for these other purposes as well, marginal cost dominates the government cost recovery approach. The marginal social cost approach advances the goal of efficient resource allocation that is at the heart of many current surface freight transportation policy debates. The case for including nongovernmental costs appears obvious, since pollution and congestion represent real burdens on society. Quantifying these nongovernmental costs is often difficult, but ignoring them would be a great mistake. Marginal social cost is the change in total social costs caused by one more unit of output—it is the cost that we want to be sure that a carrier or shipper is willing to pay.

In addition, marginal cost is arguably at least as equitable as the traditional cost recovery approach. If the basic equity concern is to make sure that users pay the costs that they impose on society, then marginal social cost provides a logical and consistent definition of user cost responsibilities. By comparison, the traditional cost recovery approach is arbitrary and imprecise, even ignoring that cost recovery considers only governmental expenditures. Indeed, it is interesting that the specific cost allocation procedures used in cost recovery studies have evolved to incorporate concepts similar to marginal costing. Nongovernmental costs are still ignored, but the marginal costing concept increasingly is applied to government expenditures in part because the alternative procedures are harder to defend or apply consistently.

This evolution is illustrated by the three procedures used in federal highway cost allocation studies over the past 30 years. The 1961–1965 federal study considered two basic procedures. The first, which the study ultimately did not recommend, is to allocate highway costs on the basis of the relative benefits that different user classes receive. These benefits were estimated on the basis of the vehicle operating cost savings, travel time savings, and accident cost reductions enjoyed as a result of specific government highway investments or programs.[6] The truckers liked this procedure because it tended to allocate relatively more costs to automobiles, and they argued that it was sensible because benefits are the underlying reason for government highway programs (TRI 1990, 33–37). The Federal Highway Administration decided not to base its recommen-

dation on this procedure, however, because of the difficulty of accurately estimating user benefits from certain highway programs, particularly repaving, and because allocating costs on the basis of cost responsibility appears more appropriate.

The second procedure used, the so-called incremental method, was the basis for the final recommendations of the 1961–1965 study and of updates produced in 1969, 1970, and 1975 (CBO 1978, 59–73). Under this procedure, a "basic" highway system is designed as if all traffic were a "basic" vehicle, usually an automobile or light truck. The costs of the basic system are allocated to all vehicle classes on the basis of vehicle miles traveled. The costs of increments to pavement strength needed to accommodate heavier vehicles are assigned to the heavier vehicle classes.[7]

The incremental procedure was criticized sharply by the Congressional Budget Office in the late 1970s on the grounds that it arbitrarily assigns all of the economies of pavement thickness to trucks. The strength or durability of pavement increases exponentially with its thickness, so strengthening pavement for heavy trucks is far cheaper than building the basic system.

> The trouble with this argument is its asymmetry: If trucks were considered to be the basic vehicles instead of cars—that is if roads were assumed to be built primarily for trucks—then trucks would be assigned almost all the costs of the pavement since the incremental cost of improving an all-truck road to carry cars as well would be virtually nil. And it is not unreasonable to consider trucks as the basic vehicles (CBO 1979, 59).[8]

The most recent federal highway cost allocation study, completed in 1982, responded to these criticisms by adopting a method to allocate a substantial portion of pavement costs that yields a result consistent with marginal costing principles. These costs were allocated on the basis of equivalent single-axle loads (ESALs), a measure of the pavement damage caused by the passage of an axle relative to that caused by an axle of a standard weight. Pavement damage increases as the third or fourth power of the weight of an axle, so the passage of a normal car or light truck axle causes little damage relative to the reference axle. Marginalist principles were not applied to all costs, however, including the costs of building the basic roadway.[9]

In short, given the broad policy concerns that motivate this study, all social costs, not just governmental expenditures, should be included in calculating whether shippers pay their way. Moreover, marginal costing is the procedure that advances efficient resource allocation, is arguably more

intellectually consistent and equitable, and can be made approximately consistent with budgetary or financial targets if necessary.

Short-Run Marginal Cost Versus Marginal Cost with Facility Expansion

In practice, short-run marginal cost is often likely to differ from marginal cost with facility expansion because investments in a particular highway, waterway, or railroad are seldom optimal. Differences occur, for example, if there are economies to adding to durability or capacity in large increments. In such cases, short-run marginal costs would only occasionally equal marginal costs with facility expansion (in the years when the investment was optimal for current traffic), although they would fluctuate about the marginal costs with facility expansion (being lower in years soon after major investments and higher in years immediately before).

Investments also may not be economically optimal because of political considerations. Some rural Interstate highways may be wider and stronger than would be economically efficient, for example, because of the desire to build an extensive national Interstate network to uniform minimum standards. Similarly, some urban expressways may be smaller than economically efficient because of popular opposition to the land takings and environmental damage caused by highway expansion.

Where the two concepts of marginal cost differ, choosing which one to use can have important implications for cost allocation. The short-run approach should favor the railways, for example; they argue that they have significant excess capacity in infrastructure, so their short-run marginal costs should be less than their marginal costs with facility expansion (Wilner 1990, 21–22). The waterway operators also argue that there is excess capacity in large parts of the inland system, although not on the most heavily traveled rivers (Boyd 1990).

Whether trucks are favored by the short-run approach is more difficult to tell. On the one hand, there is probably no excess investment in pavement durability or capacity on urban highways, so marginal costs with facility expansion might be lower than short-run marginal costs for shipments moving on heavily loaded axles or in urban areas. On the other hand, where there is excess investment in the capacity for rural highways, short-run marginal costs are lower, at least for rural movements on lightly loaded axles.

The case of trucks is also complicated because recent research suggests that existing pavements are too lightly built to minimize life-cycle costs

(Small et al. 1989, 18–21; TRI 1990, Appendix A). The truckers favor basing cost allocations on optimized rather than actual designs, arguing that it is unfair that they be penalized for the high maintenance costs caused by design mistakes. The railroads maintain that allocations should reflect actual costs and that any savings from improved designs should be counted only when these improvements are implemented. This controversy may apply to waterways, too, particularly if some of the existing facilities are under- or overdesigned for the traffic volumes that they carry.

REVENUE ALLOCATION

In deciding which taxes and fees to credit to freight transportation carriers and shippers, this study adopts the convention used in most government cost recovery studies of crediting those taxes or fees applied to carriers but not to other types of businesses. Moreover, a tax is credited to highway users regardless of whether the tax receipts are diverted to nontransportation purposes. All state gasoline taxes are counted as user charges, however, even in states that levy a general sales tax on other goods and services.

This convention can be criticized on the grounds that it credits carriers with fees that do not vary directly with use. The basic idea of marginal cost pricing is that prices should vary with cost and use so that carriers use a facility only when they benefit by at least as much as it costs to serve them. The diverse highway user fees vary in different ways with use. For example, the gasoline excise depends closely on distance traveled and varies with load carried. The annual registration fee varies according to how many trucks a carrier chooses to have in service in a given year, but it does not vary with distance traveled once the vehicle is registered (assuming that the carrier retains it for the year). Fortunately, the bulk of highway and waterway user revenues are from fuel taxes, which can be regarded as a marginal cost of vehicle use in a wide range of circumstances.

VARIABILITY OF COSTS AMONG SHIPMENTS

Marginal social costs depend on the time, place, route, vehicle, and other characteristics of a particular shipment. Given that pollution and congestion are components of marginal cost, for example, costs are higher when

GLOSSARY

Efficiency: An efficient economic system is one in which goods and services are produced and distributed in such a way that it is impossible to reallocate resources to make someone better off without hurting someone else. In the case of pricing, efficiency is usually enhanced if each consumer of a good or service is charged the marginal social costs of producing it. This ensures that the consumer values the good or service by at least as much as it cost society to produce.

External cost: Costs, such as air pollution, that are imposed on others through mechanisms other than market prices.

Social cost: All the costs of the production of a good or service, whether borne initially (in the case of a transportation service) by the shipper, carrier, government, or public. Social costs include the costs of inputs to the production that are traded in markets as well as those that are not.

Marginal cost: The change in total cost caused by increasing output by one unit.

Short-run marginal cost: Marginal cost when the time horizon for expanding output is so short that it is not possible to adjust all inputs to accommodate the new output level. In this study, short-run marginal cost usually refers to marginal cost in the circumstance that the added output must be accommodated with the existing physical plant; for example, the cost of accommodating an additional truck freight shipment with existing roads.

Marginal cost with facility expansion: Marginal cost when there is enough lead time to adjust the investment in infrastructure and other facilities to the new output level.

User fee: A tax or fee collected by the government only from the users of a particular kind of facility or service and not from the general public. Thus a highway toll or highway motor fuels tax is generally regarded as a highway user fee because it is paid only by motorists, whereas a general sales tax that is collected on vehicles and many other products would not be regarded as a user fee because it applies to broad classes of consumers. This definition does not depend on the use of the revenues raised by the fee. The marginal user fee is the change in total user fees paid when use of the facility or service increases by one unit (for example, one added freight shipment on a highway).

Marginal subsidy: For a freight shipment, the marginal costs initially borne by government for the shipment plus the marginal external cost of the shipment, less marginal user fees paid by the shipper or carrier. In this report, the term "subsidy" always refers to the marginal subsidy, unless otherwise stated.

a vehicle is in an urban area. Similarly, movements in the peak direction or during the peak season may have higher costs.

The variability in marginal social costs means that it is usually misleading to say that users of a freight mode are or are not paying their way. Within any given mode, typically some shipments are paying their marginal social costs and others are not. As a result, this study examines several types of shipments instead of trying to identify a "typical" or "average" shipment. The shipments selected are not intended to be a representative sample of the shipments of any one mode, although they do reflect some common movement types. Instead, the intent is to explore the degree to which common shipment types might differ in paying their marginal social costs.

NOTES

1. Operating a vehicle can increase the operating costs of other vehicles on the facility, as, for example, when pavement wear caused by a vehicle leads to mechanical damage and reduced fuel efficiency for other vehicles. In the case study cost calculations presented in Chapters 3 and 4, it is assumed that the highway agency responds to added pavement wear by increasing pavement repairs so as to leave other vehicles' operating costs unchanged.
2. Comparing total costs to total revenue is a test that can help uncover sources of inefficiency: if total revenue is less than total cost, consumers are being subsidized, by definition. The subsidy is a source of inefficiency, except possibly for an industry with scale economies. However, equality of total revenue and total cost is no guarantee of efficiency, and forcing equality by arbitrary imposition of fees (i.e., imposition of fees not closely tied to the marginal cost of each individual purchase decision) will not, in general, improve efficiency.
3. Most government cost recovery studies consider only current operating and maintenance expenditures for a particular level of government. Federal highway cost allocation studies typically focus on federal highway costs and revenues only, whereas state studies consider state and local costs and revenues. Historical investments in existing highways are also not considered—in essence, the highway system is financed on a "pay as you go" basis.

   These parochial perspectives create important limitations. Federal highway programs account for only about one-fifth of total highway expenditures, and federal funds are spent disproportionately on new highway construction or major rehabilitation rather than routine maintenance and highway services (CBO 1992, 12).
4. The truckers' perspective is reflected in a report by the Urban Institute and Sydec, Inc. (TRI 1990). The railroads' perspective is reflected elsewhere (Wilner 1990, 21–22; Aaron et al. n.d.; Putnam Hayes and Bartlett 1991).
5. The railroads contend that most state cost allocation studies show that trucks do not pay their way (Wilner 1990, p. 28, fn. 84).

6. Benefits to nonusers were estimated as well and a small portion of costs (7 to 18 percent) was allocated to them. The nonusers were mainly adjacent property owners, who benefited from improved access (CBO 1978, 63–69, Tables A-3 and A-4). According to the Congressional Budget Office, the benefit-derived method has also been used by the U.S. Army Corps of Engineers to allocate costs of its projects among navigation, recreation, and flood control uses. See the Corps of Engineers, *Navigation Cost Allocation Study—A Feasibility Case Study* (October 5, 1980) as cited by the Congressional Budget Office (CBO 1992, 57).
7. Often pavement costs of the basic system are assigned on the basis of axle miles, whereas all other basic system costs are based on vehicle miles.
8. Truckers defend the incremental procedure, arguing that it reflects the historical reality of highway decision making. Early roads were designed primarily for automobiles (e.g., the parkways of the 1930s), and highway designs have been upgraded periodically since to accommodate heavier or larger vehicles on the basis of analyses of the incremental costs and benefits of doing so. Moreover, truckers contend that the basic vehicle might be considered a fire or garbage truck or transit bus, since most communities would not do without fire, garbage, or transit services. These vehicles have extremely heavy axle weights, and thus the costs of strengthening pavements for trucks would be small (TRI 1990, 18–25).
9. Under the new federal procedure, all repaving costs are allocated to vehicle classes on the basis of ESAL miles traveled. For new pavements, any increment in strength or durability beyond a road of minimal design is allocated on the basis of ESAL miles. The new federal procedure also applies the old incremental approach to a wider variety of nonpavement costs. In particular, heavier vehicles are charged for the incremental costs needed to build or repair structures strong enough to hold them, whereas wider vehicles are charged extra grading and right-of-way costs for the wider lanes they need (FHWA 1982).

REFERENCES

ABBREVIATIONS

CBO	Congressional Budget Office
FHWA	Federal Highway Administration
TRI	Trucking Research Institute of the American Trucking Association

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3

Cost and Subsidy Estimates: Methods and Data

In this chapter, methods are reviewed for estimating categories of cost that are possible sources of subsidies in freight transportation:

- Infrastructure (highway pavement and bridges and waterways),
- Operating and maintenance costs,
- Congestion on highways and waterways,
- Accidents,
- Air pollution,
- Noise, and
- Petroleum consumption (external costs other than air pollution).

User fees that should be counted as offsetting the costs of public highways and waterways are addressed in the final section of the chapter.

For each of these categories, the cost is defined, and the conceptual approach to estimating its magnitude that has been used in the case studies presented in Chapter 4 is described. Sources of uncertainty arising from conceptual problems in defining the costs and from shortcomings in the data are discussed. (Appendix C describes the computational details of the estimate of each cost in the case studies.)

The quantities to be defined are marginal external costs of congestion, accidents, air pollution, noise, and petroleum consumption; marginal cost of infrastructure use before payment of user fees; and marginal highway and waterway user fees. Other possible sources of external costs or subsidies exist, for example, disamenities other than air pollution and noise, some government costs of rail-highway crossings, and some direct government subsidies to railroads. The costs estimated in this study are those believed to be the major ones from the marginal cost perspective.

For purposes of the case studies in Chapter 4, the marginal cost to be estimated is the addition to total cost caused by one additional shipment of a specified quantity of freight over a specified route.

All costs, including increased risk of human injury and death from accidents or pollution, are valued in dollars. Such valuation is essential because the decisions that individuals and governments make that affect risk generally involve economic trade-offs. Governments, for example, cannot afford to spend unlimited amounts on highway safety improvements, but must decide not to make some improvements that would save lives because they have more beneficial uses for limited funds. Similarly, individuals trade off safety risks against rewards when they decide how fast to drive or whether to accept hazardous employment. The willingness-to-pay approach (i.e., estimating the value of a change in risk on the basis of observations of individuals' willingness to pay to avoid risks or compensation required for taking on risk in market settings, such as the effect of job hazards on wages) is the appropriate conceptual basis for valuing health and safety effects. It is important to keep in mind that the evaluations are of actions that cause small changes in risk to a number of people, and not of the life or health of any individual persons.

The appropriate method of estimating costs depends on the intended application of the estimates. The cost estimation methods described here and applied in Chapter 4 are in keeping with the objectives and resources of this study and would be useful in applications addressing broad policy issues. For other applications—a thorough analysis of a specific policy proposal or analysis of costs in a specific location or region, for instance—more refined methods would be needed.

INFRASTRUCTURE

The following subsections define and describe estimating methods for the marginal costs of highway pavement wear, highway bridge fatigue, and waterway operation and maintenance. The infrastructure costs for railroads are not estimated because railroads provide their own infrastructure and there is no reason to believe that they systematically charge their customers less than the marginal cost of their services. Governments incur some infrastructure costs to accommodate railroads, mainly by building rail-highway crossings. A complete analysis would include the marginal cost of maintaining these facilities, but this cost is minor compared with all rail infrastructure costs. Past government provision of right-of-way to railroads has no effect on marginal cost.

Highway Pavement

Truck traffic volume is correlated with highway agency expenditures for pavement repair and resurfacing. The total annual cost of pavement to a highway agency is annual resurfacing and maintenance expenses plus the annual opportunity cost and depreciation of the pavement capital stock. The marginal pavement cost to a highway agency of one additional highway shipment of a freight commodity is the change in this total cost that the agency would incur as a result of the shipment. Pavement wear also imposes costs directly on road users; the change in pavement-related user cost caused by an added shipment is also a marginal cost of the shipment.

Estimating Method

The estimating method is based on reasonable assumptions about ways in which highway agencies change their road repair schedules in response to an increase in the rate of road wear. The surface roughness of a road increases over time because of traffic and other factors, such as effects of weather. When a road surface deteriorates to a specified level of roughness (the terminal serviceability, determined by highway agency practice), it is resurfaced with a pavement overlay designed to last a specified lifetime before reaching terminal serviceability again. Adding a truck trip causes the highway agency to resurface the road earlier than it would have otherwise, and it forces the agency to construct heavier resurfacings in the future in anticipation of continued higher traffic volume. The cost of the added trip, thus, is the change in present value of the cost of future resurfacings resulting from changing the time until the next resurfacing and the cost of each future resurfacing. In this computation, the cost of each resurfacing should include the costs of road construction to highway users (primarily delay); however, this cost has been neglected in the case studies.

With this estimating method, the change in road user costs that depend on maintenance (the greater time, vehicle maintenance, and fuel costs that road users incur on a more worn road compared with a smooth one), as a result of adding one truck to the road, is approximately zero. The consequence of always resurfacing at the same terminal serviceability is that the average user cost over the life of the pavement is unaffected by a change in traffic volume and marginal user cost is negligible.[1]

In addition to pavement rehabilitation, truck traffic also influences costs of certain routine, frequently performed maintenance such as minor

pavement patching and guardrail and sign repair. These costs were not included in the case study estimates because of lack of data relating them to truck traffic. The marginal cost of these items with respect to a change in truck traffic probably is small, however, compared with resurfacing cost.

Sources of Uncertainty

The definition of marginal highway cost stated earlier—the change in present value of future highway agency maintenance expenditures, assuming the agency continues present maintenance practices—has often been used in similar studies in the past, including the Transportation Research Board (TRB) truck size and weight studies (TRB 1986; TRB 1990a; TRB 1990b) and the Brookings Institution highway user fee study (Small et al. 1989) cited in Chapter 1. Nevertheless, there are some uncertainties or weaknesses in this approach, including the definition of the cost, the omission of certain cost categories, and problems with data on pavement cost and performance.

Assumptions About Resurfacing Policies

One obvious potential problem with the approach is whether the assumptions about the resurfacing policies of highway agencies are reasonable. Most highway agencies in the United States do have policies to resurface roads when pavement conditions have deteriorated to certain levels, and therefore they should resurface earlier if truck traffic accelerates pavement deterioration. Resurfacing intervals may not always be determined by pavement conditions, however, perhaps because of budget crises or other limitations. Where this is the case, the marginal pavement cost of truck traffic would be the increase in vehicle operating costs and delays to motorists because of added pavement roughness plus the increase in the costs to the agency of patching and other maintenance done instead of resurfacing.

Even if highway agencies resurface regularly when pavement conditions deteriorate, the particular rules assumed for when and how to resurface may not be optimal. The pavement cost estimates used in this study assumed that a highway agency follows customary practice on the timing and thickness of the resurfacing. However, there is reason to believe that customary pavement designs are thinner than would be desirable to min-

imize life-cycle costs. In particular, the pavement design relationships accepted by most highway engineers imply that pavement durability increases rapidly with pavement thickness (proportionally to the seventh power of thickness) (Skinner et al. 1986). If these relationships are correct, a small incremental cost in a resurfacing or new construction project should buy a very large increase in durability, possibly even to the point at which resurfacing would never be needed for the life of the highway.[2] If thicker pavements reduce dramatically the life-cycle costs of pavement construction and maintenance, then they would also reduce dramatically the marginal costs of pavement damage by truck traffic.

The estimates in this study assume actual pavement design practices rather than optimal practices because this approach is consistent with the short-run marginal cost framework. It might be argued that truck operators should be charged according to the costs that would be incurred if the highway agency adopted best practices in the future rather than if the agency continued present, possibly deficient, practices. (Indeed, the same argument could be made about congestion costs and other costs that are influenced by highway agency actions.) However, such a pricing scheme would not lead to efficient use of the roads if the highway agency persisted in its practices.

Other Highway Infrastructure Costs

Pavement costs are only a minority of the costs of building and maintaining a highway. Truck traffic influences other categories of cost besides pavement. Truck characteristics may determine the curvature of entrance ramps, steepness of grades, and layout of intersections. (The relation of truck traffic to bridge costs is discussed in the next section.) These design-related costs are ignored here because they are unaffected by marginal changes in truck traffic for existing roads. In other words, costs related to geometric design and bridge load-bearing capacity can be regarded as sunk costs of roads in place. Unlike the value of a pavement, whose life is shortened by each passage of a truck, the value of a highway agency's investment in grading a road so that trucks can negotiate curves and hills does not decline with each passing vehicle.

The special size and performance characteristics of trucks that affect road geometry are reflected in other components of marginal costs, however, particularly delay and accidents. An additional truck on a road increases traffic delays more than an additional car, for example, because the truck is larger, has slower acceleration, and is less maneuverable.

These delay and accident costs are the short-run counterparts of the long-run road geometry costs.[3]

Data Problems

The data and models required to estimate marginal pavement cost for a road as the change in present value of future resurfacings are

- Initial pavement characteristics for the road,
- Relationship of resurfacing cost to road class and resurfacing thickness,
- Relationship of pavement life to resurfacing thickness, and
- Initial traffic on the road, measured in units of equivalent single-axle loads (ESALs) and ESAL ratings of the added truck traffic. (The ESAL rating of a truck is the number of passages of a single-axle load on the road that would consume the same amount of the remaining useful life of the pavement as the truck.)

Pavement Characteristics The state highway agencies collect voluminous data on pavement condition to plan their resurfacing programs and report data annually on a sample of roads to the Federal Highway Administration (FHWA). However, historical data on original pavement design and past resurfacings are less accessible and often incomplete. To avoid having to use actual pavement condition data, in past studies it has sometimes been assumed that all pavements are designed according to procedures recommended by the American Association of State Highway and Transportation Officials (AASHTO) to carry the traffic that they currently carry. This assumption leads to uncertainties of unknown magnitude in estimates of pavement wear costs. In particular, assumptions concerning minimum-thickness pavement and resurfacing designs for low-volume roads strongly affect estimates of marginal pavement costs on these roads.

Pavement Life Relationships The results of the American Association of State Highway Officials (AASHO) Road Test are often summarized as showing a fourth-power relationship between axle weight and pavement wear and a seventh-power relationship between pavement thickness and pavement life. The Brookings Institution study on road charges reestimated these relationships using the original road test data and found

exponents generally lower than the original AASHO analysis (Small et al. 1989, 25–28).

Preliminary analysis of data from the Long-Term Pavement Performance Study, a major reassessment now under way of the relationship of pavement performance to design and traffic, suggests that the AASHTO pavement design relationships substantially overestimate pavement lives—but the results do not yet show whether observed discrepancies are due to problems in the ESAL ratings of different truck configurations, to problems in the relationships between ESALs and pavement life, or to errors in historical truck traffic data or design data for test sections (Rauhut and Darter 1994).

Optimum pavement design depends on the extent to which factors that occur independently of cumulative traffic loadings cause pavement deterioration. Independent factors include weathering and aging of materials. Assumptions about the form of the relationship of pavement life to traffic and independent factors can be constructed to either magnify or cancel the apparent economic benefits of thicker pavements. If weathering interacts with traffic-induced wear (i.e., the less traffic-induced wear a road has experienced, the less susceptible it will be to weather-induced wear), the presence of weathering increases the marginal cost of traffic loading (Small et al. 1989, 19–21, 29–31). However, if independent factors do not interact with load-induced wear, their presence reduces the optimum pavement thickness and resurfacing interval (Skinner et al. 1986, 6).

ESAL Ratings Pavement damage caused by a truck depends on the truck's tire pressures and the behavior of its suspension. These factors are not considered in the standard pavement wear model used in pavement design and in the case study pavement cost computation. Estimates of the reduction in pavement wear that could be obtained by redesigning suspensions to reduce the peak dynamic loads range up to 40 percent; the effect of an extra 20 psi in tire pressure is estimated to be as much as a 300 percent increase in pavement wear (Gillespie et al. 1993, 50–51). Estimates of these effects are speculative, since they have never been measured experimentally. These effects, if they are large, call into question the validity of available simple pavement wear models (Klingenberg et al. 1989).

Unit Cost Data Past studies of marginal pavement wear cost have tended to accept uncritically the published average unit cost data for re-

pair and reconstruction (e.g., average cost per kilometer for various types of resurfacing projects). Unit cost estimates typically are derived from engineering cost estimation rules of thumb or from highway project accounting data. Separating pavement resurfacing costs from other cost components in highway agency project records is difficult, because resurfacing often is conducted simultaneously with improvements to reduce accident hazards or increase capacity. A careful statistical analysis of the factors determining the resurfacing project cost could reduce the uncertainty of marginal cost estimates.

Traffic Data Data on vehicle kilometers, axle weights, axle configurations and other truck characteristics, and prevalence of illegal overloads are necessary for predicting pavement wear and related costs. These data are unavailable or of poor quality for many roads.

Highway Bridges

The marginal cost of freight traffic for highway structures is the added cost for maintaining or replacing bridges, ramps, and overpasses that would arise from an additional unit of freight traffic on the road. The cost includes wear of the bridge deck surface and fatigue of the bridge structure. (Bridge deck wear cost can be estimated along with pavement wear costs for the entire highway and need not be considered separately.) The change in user costs caused by traffic-induced bridge damage, including the cost of traffic delay during bridge maintenance work, is also a marginal cost of traffic (Weissmann and Harrison 1991).

Bridge fatigue cost generally is regarded to be small relative to other highway agency costs of increased traffic. In contrast to a pavement, which is designed to fail eventually as a result of fatigue after a specified number of loads pass, a bridge is designed with the expectation that it will last indefinitely, provided that it is not exposed to a single load greater than its load-bearing capacity. Therefore, the critical design parameter is the heaviest load expected on the bridge rather than the cumulative number of loadings expected over its intended life. (For some bridges, the design is entirely determined by the weight of the bridge itself or by loads experienced during construction.) In reality, some bridges do fail (or reach a state at which safety demands substantial repairs) as a result of fatigue, but most bridge replacements are for reasons other than fatigue.

Estimating Method

The TRB studies of truck size and weight estimated that bridge fatigue cost is $50 million annually nationwide (TRB 1990b, 147–149). This estimate includes the net cost of bridge replacements necessitated by fatigue damage and the cost of ongoing maintenance to repair or avoid fatigue damage. The net cost of bridge replacements is the difference between the present value of future replacement costs (including traffic delay cost) and the present value of replacement costs if no fatigue damage occurred. The cost estimate was based on actual highway agency bridge replacement or repair practices.

The TRB studies predicted that fatigue cost would rise substantially in the future as a result of aging of the stock of bridges. The constant annual expenditure required to offset all future bridge fatigue costs was estimated to be $160 million/year.

The rate of fatigue damage to a bridge depends on the frequency of vehicle passages and on vehicle lengths and weight distributions. In the TRB study estimates, it is assumed that for a given steel bridge carrying vehicles of a given weight distribution and length, total fatigue damage cost is proportional to the cumulative number of passages of the vehicles over the bridge. Under this assumption, the average fatigue damage cost per passage of a truck over a bridge equals the marginal cost. Costs for vehicles of various lengths and weights are estimated as multiples of the cost of a standard vehicle. For vehicles of a given length, the equivalency factor is proportional to the third power of weight. The average cost (on the basis of the $160 million estimated constant annual cost) is $0.01/passage of a loaded tractor-semitrailer over a steel bridge. Fatigue damage to concrete bridges is not significant.

Sources of Uncertainty

Difficulties in defining marginal bridge fatigue cost are analogous to those connected with the definition of pavement wear cost—in particular, whether the highway agency should be assumed to be obliged to replace a bridge whose life has been shortened by fatigue, so that the cost of moving the replacement expenditure closer in time is a marginal cost of each vehicle passage. The definition of marginal bridge fatigue cost stated earlier includes the cost of accelerated bridge replacement on the same grounds that accelerated pavement repair is included in marginal pavement cost.

The major empirical sources of uncertainty are lack of (*a*) data on the cost of bridge fatigue to highway agencies and users and (*b*) a detailed model relating bridge loading to fatigue damage and cost; the cost estimate is speculative because it is based on limited data and a simple cost model. One other fatigue cost study, for Illinois bridges, estimated a higher cost (Mohammadi et al. 1991).

Waterway Operation and Maintenance

Waterway costs include government expenditures for operating and maintaining the inland and intracoastal waterways, primarily U.S. Army Corps of Engineers expenditures for the facilities under its jurisdiction. Inland ports and terminals are nearly all privately operated, although state and local governments provide some port facilities. Marginal cost, in the case studies, is the change in the cost to the government of operating the system caused by an additional use of the system by a tow of barges. In this definition, marginal cost does not depend on the capital cost of the waterways system (the interest cost on resources invested in the system and depreciation of the plant). Note that there is no component of waterways marginal cost that is analogous to the cost of accelerated highway pavement wear caused by an increase in truck traffic, because the physical durability of waterways structures and maintenance dredging costs are assumed to be independent of the rate of use.

Estimating Method

Marginal cost is calculated by first estimating a total cost function—a relationship between the total cost of the system per unit of time and the number of uses of the system per unit of time—and then computing from this relationship the change in total cost with change in use. The total cost relationship is derived statistically from data on total costs and traffic volume.

The cost function used in the case studies estimates waterway operating and maintenance cost as a function of ton miles of traffic and numbers of lock passages, using waterway segment operating and maintenance cost and traffic data. The estimated marginal cost is $0.03/ton/lock passage plus $0.0002/ton-mi [$0.03/(metric ton)/lock passage plus $0.0001/metric ton–km]. This estimate reflects all Corps of Engineers expenditures for lock

and channel operation and maintenance, but it excludes Coast Guard expenditures for navigation aids, a relatively minor component.

This estimate is roughly consistent with the findings of two previous studies of waterway marginal costs. One, by the Congressional Budget Office, estimated annual costs of waterway segments as a function of the annual ton miles of traffic, the number of lock sites in each segment, and the length of the segment.[4] The observations used to estimate this relationship were data on traffic volumes and operating costs for waterway system segments in a year. The estimated relationship predicts that one additional ton mile of freight increases total cost by $0.0004, so marginal cost is $0.0004/ton-mi ($0.0003/metric ton–km). Another statistical estimate of the cost function for operating the waterways concluded that the marginal cost to the government was higher (Boger 1979).

Sources of Uncertainty

The estimate of the cost function used in the case studies is oversimplified and utilizes insufficient data. However, the Corps of Engineers collects the cost and traffic data that would be needed to produce a more reliable estimate of the waterways operating and maintenance cost function. The principal difficulties in using these data to estimate marginal cost would be econometric—correctly inferring the best estimate of cost from the data. Costs vary greatly among the segments of the system; data are available that support separate estimates of costs and subsidies for each lock and each channel segment.

CONGESTION

When an additional vehicle makes a trip on a congested road or an extra tow uses a congested waterway, its presence delays other users of the road or waterway. This added time to other road or waterway users is an external cost of the added trip. On a road, the added delay occurs because the average speed of vehicles will begin to decrease once the density of vehicles on the road surpasses some level and because delay caused by vehicle breakdowns or accidents tends to increase as traffic increases. On a waterway, delay occurs when queues form at locks. Congestion delays occur on railroads also, but costs of delays to trains are internal because one carrier is responsible for all the freight on the rail system. (A railroad may occasionally use another company's tracks, but compensation to the

owner of the tracks includes compensation for delays to the owner's trains.) Increasing train traffic would also increase delay to highway users at grade crossings. This cost has not been estimated, although the rail marginal accident cost estimates include costs of accidents at crossings.

The basic steps in estimating marginal external delay follow:

1. Estimate the relationship between traffic volume and delay. This relationship depends on the type of facility (e.g., roads of different geometry or locks of different sizes), traffic volumes, and vehicle characteristics (e.g., trucks versus cars and barge tows versus recreational boats).
2. Estimate the dollar value of 1 min of delay.
3. Estimate the delay cost of an added trip on the basis of the relationship between volume and delay and the value of delay.

The application of these steps to roads and waterways is described in the following two sections.

Highways

Estimating Method

Highway congestion cost can be estimated from the empirical relationship between average speed and traffic volume on a road. Figure 3-1 shows the typical form of the relationship between speed and volume on a limited-access highway. The solid lines in Figure 3-1 illustrate normal conditions of stable traffic flow; in such cases, speeds decline gradually as traffic volumes increase and fall rapidly only when traffic volumes approach the maximum capacity of the highway. Under ideal conditions (e.g., absence of cross traffic, modern geometric design, flat terrain), maximum volume (or capacity) is on the order of 2,000 vehicles per hour per lane on a multilane road and 2,800 vehicles per hour in both directions combined on a two-lane road.

If entering traffic volumes exceed the maximum capacity even momentarily, or if a traffic accident or other incident disrupts traffic flow, the highway may be forced into unstable flow, which is shown as the dashed line in Figure 3-1. Highway planners and engineers try to avoid unstable flow because it is highly inefficient; in the case illustrated in Figure 3-1, for example, the highway can serve 1,000 cars per hour at 50 mph (80 km/hr) if it stays in stable flow, but it will serve that same volume at only 7 mph (11 km/hr) if it is forced into unstable flow.

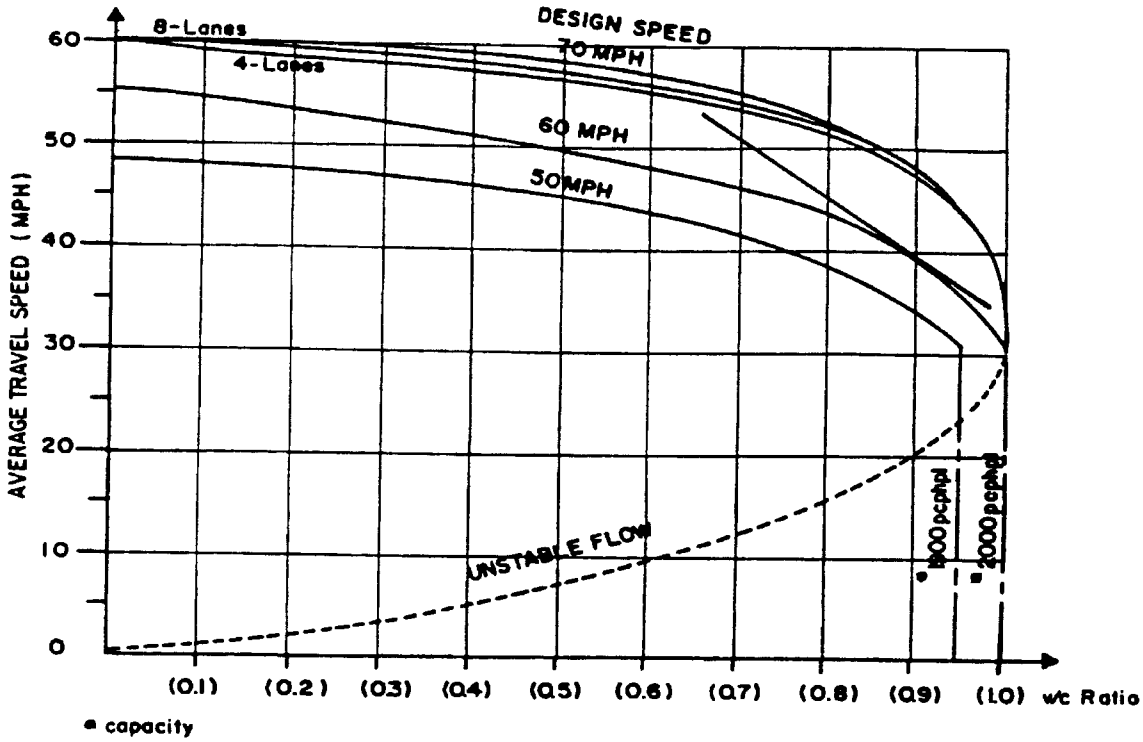

FIGURE 3-1 Speed-volume curves (TRB 1992, 3–5). Note: (mph) × 1.61 = (km/hr).

Marginal external delay cost on a road (aside from delays related to vehicle breakdowns or accidents) can be computed for stable flow conditions as a function of traffic volume on the road and the slope of the speed-volume curve at the point corresponding to the volume. The cost is the time added to all other trips on the road as a result of the reduction in average speed caused by the addition of one vehicle to the road, per kilometer of travel of the added vehicle.

A truck consumes more of the effective capacity of a road than a car does because trucks are longer than automobiles, have lower acceleration, and are more difficult to pass. In traffic planning models, the impact of a truck is treated as a multiple of the impact of an automobile. This multiplier is called the passenger car equivalency (PCE) factor, and it depends on road characteristics and terrain. Values reportedly range, for example, from 1.8 in level terrain to 8.0 in mountainous terrain on freeways, and from 1.6 on the level to 4.5 on a 1-mi (1.61-km), 4 percent upgrade on a two-lane rural road with an average speed of 50 mph (80 km/hr) (TRB 1994, Tables 3-3 and 8-9).

Dollar values of time losses are estimated from studies that examine choices that travelers make between alternative routes or modes; if a traveler chooses a toll road that charges $1 in order to save 10 min, for example, one can infer that the traveler values travel time savings at $6/hr. A recent review of travel time valuation studies found estimates in the range of 40 to 110 percent of the average wage rate (Miller 1989).

The delay cost arising from increased vulnerability to traffic flow breakdown as volume increases must be estimated separately, because conventional speed-volume curves apply to free-flow conditions only. Recent analyses by FHWA, using its urban freeway delay model, have concluded that more than 60 percent of delay on urban freeways is nonrecurring—that is, it is the result of discrete events (e.g., accidents or breakdowns) rather than of reduced speed caused by high traffic volume under free-flow conditions (FHWA 1986; GAO 1989, 50–60). If it is assumed that the same percentage holds for marginal delay cost (by no means a certain assumption), then for every 1 min of delay that a truck on an urban freeway causes because its presence increases traffic volume and thus reduces speed, it causes 1.5 min of delay during episodes caused by breakdowns or accidents. This marginal nonrecurring delay may be delay caused by breakdowns or accidents of the truck itself, or the addition to delay caused by the presence of the truck during nonrecurring delay events caused by breakdowns or accidents of other vehicles.

Sources of Uncertainty

The form of the speed-volume relationship, the magnitude of nonrecurring delay, and PCE factors for trucks are major sources of uncertainty in congestion cost estimates.

Speed-Volume Curve

In early traffic engineering literature, parabola-like speed-volume curves and curves showing nearly linear decline of speed from the lowest volumes to capacity were common. These forms imply significant delay costs well below maximum volume. However, the current *Highway Capacity Manual* (the standard engineering manual for traffic planning) shows nearly horizontal curves for multilane highways (i.e., no slowing of traffic and zero delay costs) until volume reaches at least 70 percent of capacity (TRB 1994, Figures 3-2 and 7-1). If the later curves are correct, then the only significant source of delay, except at very high volumes, might be incidents leading to nonrecurring delay.

Nonrecurring Delay

No estimates of the ratio of recurring to nonrecurring delay on roads other than urban freeways are available, and no studies have been located that examine marginal, as opposed to average, nonrecurring delay cost. There are no grounds for believing that the average ratio is lower on roads other than urban freeways; indeed, on low-volume roads it is conceivable that a higher portion of all delay is of the nonrecurring variety.

PCE Factors

Trucks vary greatly in size and performance characteristics; the effect on traffic flow of a very large, slow truck would be much greater than standard PCE ratings would imply. Some simulation model results have suggested that truck PCEs in conditions of high traffic volume may be substantially greater than the values recommended by AASHTO for traffic planning (Mingo 1991).

Waterways

Estimating Method

A vessel using the inland waterways causes delay costs for other waterway users if it arrives at the locks during periods when the rate of arrival of vessels approaches or exceeds the rate at which the locks can lift or lower them. The average delay for a tow awaiting passage at all locks on the inland waterways was 56 min in 1990. At the 29 locks and dams of the Upper Mississippi from Minneapolis to St. Louis, 1990 total delay time was 193,000 vessel-hr (COE 1992a, 21, 125).

The marginal external delay may be estimated with a simulation model using data on distributions of arrival and processing times at locks. The Corps of Engineers maintains vessel-by-vessel data on lock passage and waiting times in its Lock Performance Monitoring System that could be used in a very detailed simulation (COE 1992a, Appendix B). The case studies use a very simplified model.

The cost of an hour of delay of a barge tow is evaluated as the average hourly operating costs of the barges and towboat plus 1 hr of inventory carrying cost for the cargo. The Corps of Engineers conducts periodic surveys of towboat and barge operating costs (COE 1993). The inventory carrying cost of cargo, calculated at a normal interest rate, is a negligible component of delay cost.

Recreational boat traffic, substantial at many locks, complicates estimates of marginal delay costs. The effect of the arrival of a freight vessel at a lock on delay of recreational vessels is different from the effect on delay of other freight vessels because, according to customary practices, recreational vessels are often given priority at locks (COE 1992b, B-8). Recreational boats also differ from freight vessels in the hourly cost of delay. The case studies take account of the presence of recreational boats in a very approximate manner, as described in Appendix C.

Sources of Uncertainty

The major sources of uncertainty are in the estimates of the costs of delay for various kinds of vessel traffic through the locks and in understanding the behavior of the queues at locks.

The simple probabilistic model of marginal delay cost that is used in the case studies assumes that barge arrivals are random, independent

events. If barge operators or lock operators already have any strategies for managing queueing to reduce delay costs—for example, by moving high-priority cargoes ahead in queues—delay costs would be lower than those estimated.

The method of valuing delay may not capture adequately the short-run opportunity costs of delays to barge operators or shippers; barge rates sometimes double during peak periods, indicating that some shippers do experience high delay cost (Baldwin et al. 1983).

Accurately estimating how the mix of recreational and commercial vessels in lock queues affects delay cost would require a detailed examination of the handling of recreational boats by lock operators as well as data on the cost of delay to recreational users.

ACCIDENTS

The marginal accident cost of freight traffic is the change in total accident costs that would arise from one additional freight shipment on a road, railroad, or waterway. Accident costs include property damage, injuries and lives lost, and delay costs to other users of the system caused by the accident.

Marginal accident cost is defined analogously to congestion delay cost. The marginal delay cost of a trip has two components: the time required for the added vehicle to make the trip and the change in travel time to all other users of the facility as a result of the added trip. The marginal accident cost has two analogous components: the expected accident loss from the added trip is the risk of accident involvement that the added vehicle itself incurs, plus the change in risk to all other vehicles using the facility. However, whereas for congestion all of the added vehicle's own time is an internal and all of the delay to other vehicles is an external cost, the situation is more complex for accidents. Part of the cost of the added vehicle's own involvement in accidents may be borne by others (for example, medical costs of an uninsured truck driver or the delay cost of accidents) and therefore is external. Moreover, only part of the costs of other vehicles' involvements are external since the vehicle operator is legally liable for some of the costs of the accident involvements of others that result from its trip.[5]

Estimating the marginal external accident cost of freight traffic consists of the following steps:

1. Estimate the relationships between traffic volume and accident frequency on the facility. Separate relationships will be required by type of accident event (e.g., on a waterway, barge-only accidents, barge–pleasure boat accidents, etc.) and by severity (e.g., fatal, injury, and property damage accidents). Categorizing the accident rate relationships in this way is necessary because the various categories may differ greatly in the form of their dependence on traffic volumes, in accident cost, and in the incidence of accident costs among the parties involved.

2. Calculate, on the basis of these relationships, the change in the expected number of accidents in each category that would be expected as a result of an increase of one unit of freight traffic on the facility (e.g., one added shipment).

3. Evaluate these changes in accident frequencies in dollars. The basis for valuation of changes in the risk of loss of life or injury should be observations of people's willingness to pay to avoid small changes in risks. The change in frequency of accidents multiplied by the cost per occurrence is the marginal cost.

4. Estimate the parts of this added cost that are internal and external. The internal part of the marginal accident cost is the increase in accident costs borne by the vehicle operator that would be expected as a result of an added trip. The marginal external accident cost is the difference between marginal accident cost and marginal internal cost.

This definition of marginal accident cost may appear to conflict with intuition about accident risk and responsibility. The definition implies that there is no simple relationship between the average accident rate and marginal accident cost—the marginal accident cost may be zero even if the average accident costs per vehicle kilometer or per ton kilometer on the facility are substantial. The definition of marginal accident cost does not entail allocating cost among the vehicles involved in accidents on the basis of fault. The cost of one extra trip is the expected net increase in the cost of all accidents compared with the costs if the trip had not been made, regardless of what party would be regarded as at fault in any particular accident. Legal liability rules affect only the fraction of this cost that is internal.

Highways

The most important component of the average accident cost of truck traffic is the risk of death to car occupants. However, the change in this

risk to car occupants caused by an added kilometer of truck travel will be zero unless the car occupant fatality rate per kilometer of car travel increases with increasing truck volume. If this rate is unchanged by the added truck kilometer, car occupants' risk of death is unaffected by the added truck travel. Part of the cost of adding a truck to the traffic stream is the change in the risk of accidents that the truck is not involved in but that occur because higher volume increases risk or because of actions that drivers take to avoid trucks. Conversely, some accidents involving a truck would have happened in the absence of the truck and thus do not contribute to the marginal cost of truck travel.

The accident cost of adding a truck to the traffic stream could even be negative, if the presence of the added truck reduced the rate or severity of accidents by increasing traffic congestion and reducing traffic speeds. Because of the form of the relationship between traffic volume and accident costs, it is possible that the external accident cost of one extra truck trip could be zero but that at the same time the private benefit of a carrier expenditure to improve truck safety (e.g., hiring better drivers) could be less than the social benefit.

Estimating Method

In the case studies, marginal accident costs are estimated by making assumptions about the effects of traffic volumes on accident involvement rates. The assumptions appear plausible, but their validity is highly uncertain because virtually no data are available on the needed relationships. The most important of these assumptions (which are presented in Appendix C) is that the rate of truck involvements, per truck kilometer, in fatal accidents with a vehicle other than a truck is independent of truck traffic volume. According to this assumption, if the number of trucks on a road increases and the number of cars remains unchanged, a car's risk of being in a car-truck fatal accident increases. Sensitivity analyses presented in Chapter 4 test how changing the assumed relationships would change the external cost estimates.

Sources of Uncertainty

A few studies have attempted to measure the effects of traffic volume on accident rates, using time series data (i.e., comparing variations in accident rate with variations in volume on a single road) or cross-sectional

data (i.e., comparing accident rates with traffic volumes across a sample of roads). The research has been inconclusive (Hall and Pendleton 1989), because accident causation as a whole is complex and poorly understood and a great number of other influences must be controlled for the effect of a single factor such as traffic volume to be estimated.

Figure 3-2 is a graph from an early study using cross-sectional data. The smooth curve represents the author's hypothesis that increasing volume ought to increase accident risk to each vehicle on a road, up to some point where decreasing speed caused by increasing volume causes a decrease in the rate. Figure 3-3 is from a recent European study using time series data; it shows fatal and injury accident rates fairly flat but property damage accident rates rising sharply with increasing volume, with the increase continuing up to very high volumes. The authors note that the apparent tendency for the casualty rate to decline with increasing volume in the low-volume range of the curve reflects, at least in part, higher accident rates during hours of darkness, when traffic volumes are low. Apparently no study has empirically examined accident rate as a function of volumes of several vehicle types (e.g., trucks and cars).[6]

Even ignoring the question of the relationship of accident rate to traffic volume, average truck accident rates per kilometer of truck travel are poorly known. The main source of difficulty is that data on kilometers of

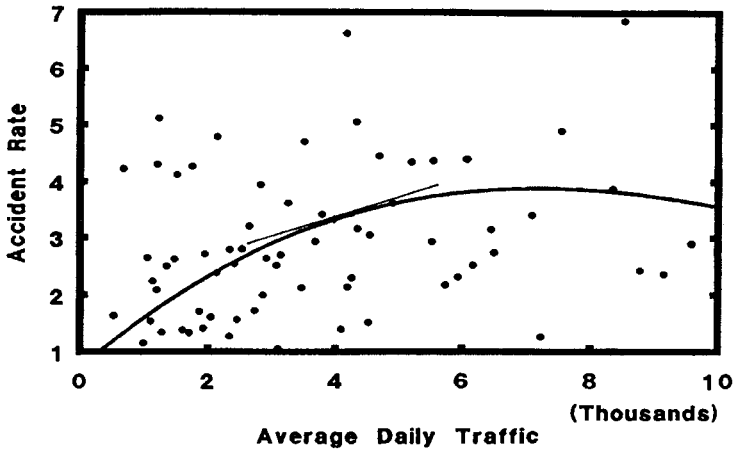

FIGURE 3-2 Relationship between accident rate and traffic volume on two-lane roads (Veh 1937); accident rate = accidents per 1 million vehicle-mi. Note: Accidents per 1 million vehicle-mi × 0.621 = accidents per 1 million vehicle-km.

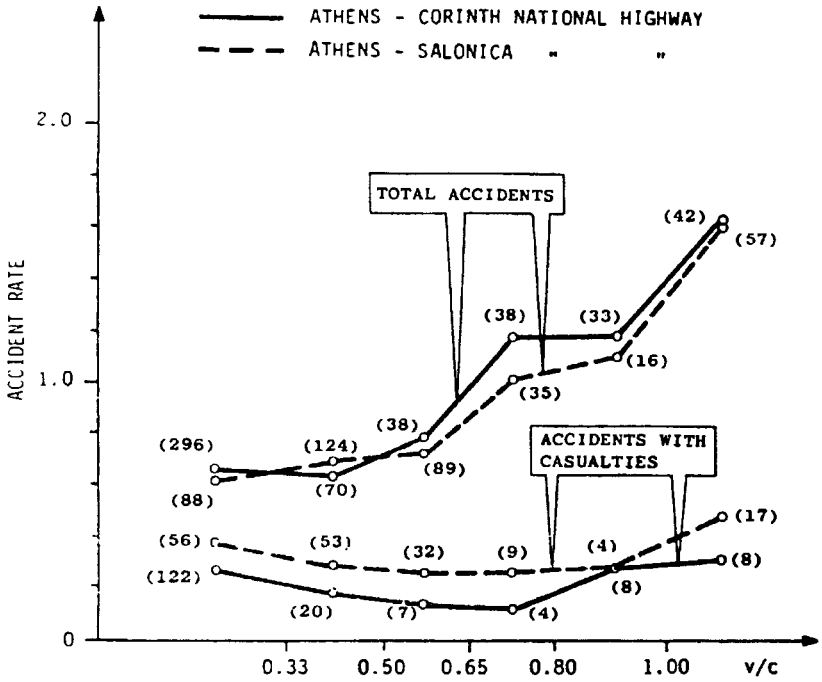

FIGURE 3-3 Accident rates versus traffic volume (Frantzeskakis and Iordanis 1987, 34); accident rate = accidents per 1 million vehicle-km.

truck travel, especially data disaggregated by class of road, are not reliable (TRB 1990c).

Rail and Waterways

The marginal external accident cost of rail traffic is the rate of increase in injury, death, or property losses to members of the public, for which they do not receive compensation from railroads, with increasing traffic on a rail line. The major source of external rail accident costs is railroad-highway grade crossing accidents. All costs of damage to railroad property and cargo and of injury to railroad employees are assumed to be internal as a consequence of the railroads' responsibility for their own rights-of-way.

No data have been located that relate the total cost of accidents on a rail line to traffic volume on the line. The case studies assume that accident losses are proportional to traffic, so that the increase in losses from adding a ton kilometer of freight equals the average accident loss per ton

kilometer. A sensitivity analysis presented in Chapter 4 shows the effect of assuming that accident losses rise more slowly than proportionally with ton kilometers.

The circumstances of freight accidents on waterways are almost exactly analogous to those on highways—barge tows share a public right-of-way with noncommercial users. In principle, the marginal external costs of waterway freight traffic would be estimated following the same steps as those outlined for trucks. No data have been found to support estimates of the rate of collisions involving commercial and noncommercial vessels.

AIR POLLUTION

The marginal air pollution cost of freight traffic is the cost of the damage caused by the pollutants produced by an additional freight shipment. Damages include effects on health, visibility, materials, and agriculture and the cost of climate change caused by emissions that contribute to the greenhouse effect.

Adding a freight trip on a route will affect the volume of pollutant emissions through two mechanisms. First, the added vehicle itself will emit pollutants. Second, the addition of the vehicle will affect the volume of pollutants emitted by other vehicles on the facility because (as the earlier section on congestion describes) it affects the average speed of all vehicles. In the case of highways, reducing traffic speed reduces emissions per vehicle kilometer over some range of speeds; but vehicles in very slow, stop-and-go-traffic produce more pollutants per kilometer than vehicles in freely flowing traffic. Also, increasing congestion will discourage some trips.

The case studies estimate only the cost of the pollution emitted by the added vehicle and ignore the effect on emissions of other vehicles. The underlying relationships among traffic volume, vehicle speed, and emissions are complex and little known, so the magnitude and even the sign of the net effect on emissions is difficult to predict (TRB 1995). In the case studies with relatively low estimated congestion delay cost, the effect is probably small compared with the pollution from the added vehicle itself.

Estimating Method

The steps in estimating the dollar damages from air pollutant emissions are the following:

1. Estimate the emissions from the source. For truck, rail, and barge transportation, these are principally diesel engine emissions of hydrocarbons, nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter less than 10 microns in diameter (PM10).

2. Estimate the contributions of emissions to ambient concentrations of ozone, ambient PM10, CO, nitrogen dioxide (NO_2), and greenhouse gases. Ozone is formed by chemical reactions in the atmosphere involving hydrocarbons, oxides of nitrogen, and sunlight. Ambient PM10 comprises particles formed by chemical and physical processes in the air involving NO_x, sulfur dioxide (SO_2), hydrocarbons, and other gases (secondary PM10), as well as PM10 particles that are emitted from engines.

3. Estimate, for health effects, the number of people exposed to various ambient concentrations over time. Exposure for nonhealth effects depends on the nature of the effect (e.g., changes in exposure for various crops that are sensitive to ozone damage).

4. Establish the relationships between exposure to each pollutant and the various health and welfare effects, and predict the physical effects of the emissions on the basis of these relationships.

5. Place dollar values on health and other effects. As with accident risks, the proper basis for valuation is observation of people's willingness to pay to avoid small changes in risks.

To compute marginal cost in the case studies, these five steps are applied to estimate the cost of the added emissions produced in the course of one extra freight shipment. The simplest models are used to relate the change in emissions to change in exposure and change in exposure to cost.

Sources of Uncertainty

The major sources of uncertainty in estimates of the pollution cost of freight traffic are the following:

- Virtually no data exist on actual in-use, on-the-road emissions by diesel heavy trucks or locomotives.
- The contribution of road dust stirred up by the passage of motor vehicles to ambient PM10 is not understood.
- It is uncertain whether all constituents of ambient PM10 contribute more or less equally to observed health effects or certain fractions—for example, motor vehicle emissions, sulfates, or organic constituents—are particularly toxic (Dockery et al. 1993).

- Modeling the formation of secondary PM10 is imprecise.
- The impact of pollution on climate change and the cost of climate change are poorly understood. All estimates of global warming costs are speculative.
- The value, to the individuals at risk, of changes in the risk of premature death caused by exposure to air pollution is uncertain. This study uses estimates derived from studies of how individuals value the risk of accidental death, which may differ from how people view death from other causes. Also, the case studies assume, in comparing the cost of risks from various sources, that two changes in risk that cause the same change in expected number of person years of life should be assigned the same cost. This assumption implies that the estimated cost per expected death is lower if a change in risk affects death rates of old people predominantly than if it affects all ages similarly. The studies of how individuals value risks that are the basis of the case study estimates do not provide information about how valuation of personal risks depends on the person's age.
- The marginal pollution cost arising from the effect of an added vehicle on the speed of other vehicles and on congestion is poorly understood.

Sensitivity analyses presented in Chapter 4 indicate the magnitudes of uncertainties introduced by some of these factors.

PETROLEUM CONSUMPTION

Because petroleum supply depends in part on imports and because historically the supply has been subject to disruptions and sudden price changes, the private price of petroleum products may not be equal to the social cost. The possible external costs of import dependency considered here are in addition to, and independent of, the external pollution costs of burning petroleum products.

Two reasons to assign an external cost of petroleum consumption have been proposed. The first is that the United States as a whole possesses enough market power in the world petroleum market that a coordinated decrease in U.S. energy purchases would decrease the world market price of oil. The United States would lose the net value to it of the oil that was no longer purchased but would gain because the oil it continued to import would be bought at a lower price. Provided that the United States has any market power, there is some range of tariffs for which the U.S. gain

more than offsets the U.S. loss. The tariff that maximizes the net gain is the external cost of petroleum consumption.

This external cost arises because each purchase of petroleum imposes a cost on other purchasers by increasing the price of petroleum. This is an effect of any purchase of any commodity, but if the good in question is produced domestically, the price effect is just a transfer from U.S. consumers to U.S. producers that does not affect total domestic income. If the good is imported, the price effect is a resource cost to the residents of the United States. This argument in favor of import tariffs applies equally to any imported good, not just petroleum.

Most estimates suggest that the size of this external cost is small. Some analysts question whether the U.S. government is politically and technically capable of setting a tariff so that it does more good than harm (Broadman and Hogan 1988, 7–29). One analysis has concluded that in fact the market power of the United States is very weak; therefore a moderate reduction in U.S. imports would have little effect on the world price and the optimum tariff is near zero (Nesbitt and Choi 1988, 31–59). The most prominent advocates of the tariff estimated in 1988 that the optimum tariff to take advantage of U.S. market power would be $3 to $6/barrel (bbl), or $0.02 to $0.04/L ($0.07 to $0.14/gal) (Broadman and Hogan 1988, Table 2).

This market power–related external cost exists only if the perspective of the cost estimate is that of U.S. residents exclusively. The effect of a U.S. oil import tariff aimed at reducing the cost of imported oil would be just to transfer resources from foreign oil producers to U.S. and foreign customers. Adopting the parochial perspective would require excluding other external costs that are imposed on foreigners, most notably most of the projected cost of global warming. Consistency requires taking either a parochial perspective—and including the market power–related external cost but not much of the global warming external cost—or a global perspective—and including global warming but excluding the market power external cost. The case studies take the global perspective, although, as a practical matter, the effects of doing so are small since the estimated energy price and global warming external costs are relatively modest and comparable in size.

The second possible source of external cost of petroleum consumption is the lost output from the U.S. economy from radical, unforeseen price changes or supply disruptions. This energy security cost is external only if it is believed that the private market will not store sufficient fuel inventories to cushion against possible price changes or curtailments.

This energy security cost can be reduced by storing oil, as the United States does in the strategic petroleum reserve (SPR). The cost of storing the optimum reserve (above the reserve that private parties are willing to hold) is the external energy security cost. One analysis in 1982, when the price of oil was $30/bbl, estimated that the proper level of the tariff to pay for the SPR would be $3/bbl (Adelman 1993). At today's oil price, this estimate is equivalent to a tariff of $2/bbl, or $0.01/L ($0.04/gal).

Over the past two decades, U.S. energy supply sources have diversified and the economy has become less vulnerable to the effect of petroleum supply disruptions, closing any gap between the market value of petroleum and its social cost. Consequently, some analysts have estimated that the marginal external cost of petroleum consumption (aside from pollution costs, which are estimated separately in this study) is approaching zero (Hill 1995; Bohi and Darmstadter 1994).

NOISE

The exposure of people to noise is a cost of freight transportation. People describe noise as a nuisance in surveys (NRC 1977, Appendix B), and prolonged exposure to loud sound causes hearing loss (although exposure to traffic noise is unlikely to be severe enough to damage hearing) (Nelson 1978, 11). The costs are reflected in the effects of transportation noise on property values and in the willingness of highway authorities to include noise mitigation in highway construction projects. In general, transportation operators are not responsible for these costs (although they do incur costs for noise mitigation and may be liable for some damage); therefore, noise costs are external costs.

For most U.S. residents, the predominant source of outdoor noise is road traffic. Trucks dominate traffic noise emissions in many circumstances. Medium and heavy trucks are 10 to 18 dB louder than cars and emit about two-thirds of all traffic noise energy.[7] Train noise emissions are highly variable, depending on speed, length, type of power supply, and track construction and condition (Rallis 1977, 69–71).

Empirical studies of the cost of noise use differences in housing prices to infer the value that people place on noise. The most thorough review of noise evaluation studies concluded that the average of the most reliable studies was that a 1-dB increase in noise causes a 0.4 percent decrease in housing value (Nelson 1982). If the cost of noise is indeed proportional to the noise level in decibels, then marginal noise cost depends on the existing noise level—the marginal noise cost of one added truck on a

heavily traveled road or in some other noisy environment will be less than the marginal cost of a truck added in a quiet location.

The noise cost of an increment of freight traffic may be estimated analogously to the cost of air pollution:

1. Measure noise energy emitted by the passage of the added vehicle.
2. Estimate, on the basis of emissions of individual vehicles and the physical features of the site, the change in the location of noise level contours in the vicinity of the right-of-way.
3. Estimate, using data on population and land use along the right-of-way, the change in exposure of people to noise.
4. Impute a dollar value to the change in exposure.

The case studies do not actually model the change in noise exposure caused by the added shipment; instead, they use estimates of average cost per truck kilometer for urban and rural areas from another analysis.

USER FEES

Government expenditures for highway and waterway freight facilities are offset partly or entirely by taxes and fees paid by the users. The fee paid usually is related only imperfectly to the magnitude of costs imposed by a marginal user of the facility. For example, pavement wear costs caused by a truck depend on the weights of its axles, the distance that it is driven, and the condition of the roads that it uses. The truck operator pays an excise tax proportional to fuel purchases and also pays annual fees that may depend on gross weight but (except in a few states) do not depend on axle weights or distance traveled. The truck operator also pays other taxes—for example, payroll and income taxes—that are paid by all businesses but may be correlated to how much the truck travels.

The difference between total costs and total fees paid by a class of vehicles, or between the average fee and average or marginal cost, is not a reliable measure of the efficiency effects of the tax or user fee system. The most efficient pricing scheme may entail an aggregate subsidy (if economies of scale prevail) or generate a surplus. However, a fee system that generated total revenues equal to total costs but did not present users with prices reflecting the costs of their consumption decisions would lead to inefficiency. The measure that is relevant for determining whether roads and waterways are being used efficiently is the marginal subsidy—the change in total cost to the public authority and to users caused by an

additional use of the system, less the change in tax and fee payments that would be incurred by an additional use. Inefficiency will occur when a marginal subsidy occurs.

The main difficulty in estimating the marginal subsidy is defining the effective subsidy when fees are partially but imperfectly related to marginal cost. Such approximate or simplified user fee schemes are a necessary compromise—they trade off the efficiency gain of a more refined scheme against the administrative cost of collecting the fees. However, the net economic benefit of truck travel under the simplified or approximate fee scheme will be lower than under the ideal. The loss in benefit will depend strongly on the circumstances.

For many policy applications, the more important question is whether the existing fee scheme is distorting the market and leading to economic losses, rather than whether the scheme is generating subsidies. To determine whether an existing user fee scheme is encouraging efficiency, the market must be analyzed and a prediction made of demand response to the existing fees versus the ideal fee scheme. The magnitude of the loss of net economic benefit is the measure of whether the simplified scheme embodies subsidies that are economically harmful.

A simple way to define the marginal user fee that might at first seem appropriate would be to consider taxes that vary closely with distance traveled to be effective as marginal fees, and annual fees and excises on equipment purchase to be ineffective. However, such a rule of thumb can lead to misinterpretation of the effects of user fees. For example, when a truck operator is considering whether to accept a backhaul load for a trip that otherwise would be taken empty, the fuel tax has virtually no effect on the decision (because the difference in fuel consumption between a loaded and an empty truck is small). The fuel tax on the return trip is, in effect, a marginal tax on the fronthaul trip, and the marginal tax on the backhaul is nearly zero. In another market circumstance, when a trucking firm is considering bidding on a multiyear hauling contract for a large shipper, annual registration fees and excises on equipment purchase are effective marginal costs that influence the firm's pricing decision.

The case studies estimate average user fees per vehicle kilometer as a stand-in for a true marginal calculation. The payments included are those conventionally regarded as user fees: government fees and special excise taxes applicable only to transportation. Note that the definition of the marginal user fee depends on who pays the tax and on how it is collected, but not on the use to which tax revenues are put.

Railroads pay a federal excise tax on diesel fuel, which has been counted in the case studies in Chapter 4 as a user fee (and consequently

as an offset to external costs of rail), even though railroads receive no services from the government comparable to the infrastructure provided to trucks and barges. Freight railroads also have received some recent direct subsidies from federal and state governments. These have been very small compared with total railroad revenues, typically capital grants whose magnitude would not be affected by a marginal change in the volume of freight traffic. Consequently, they have been ignored in the Chapter 4 case studies.

NOTES

1. If road wear depends entirely on traffic, traffic volume is constant, and the highway agency restores the road to its original condition each time it reaches a predetermined terminal serviceability, then the average (over a resurfacing cycle) of the marginal pavement-related user cost of traffic is zero (Newberry 1988).
2. A Brookings Institution study considered the optimization of road expenditures with respect to varying the overlay thickness, but not with respect to varying the terminal serviceability that triggers an overlay. That study predicted pavement maintenance savings of 75 percent from adoption of optimum pavement thickness (Small et al. 1989, Table 3.3).
3. In essence, the truck's different size and performance characteristics cause both short-run and long-run costs. In the long run—or, more accurately, when the road system is being expanded—the truck's characteristics cause increased expenditures for more gradual curvatures and grades. In the short run, when the physical capacity of the road system is fixed, the truck's characteristics cause added congestion and accident risk. Ideally, highway agencies would decide how much to invest in more gradual curves and grades by trading off the increased capital expenditure against the savings in delay and accident costs. See Chapter 2 for a discussion of the relationship between short-run marginal costs and long-run marginal costs with facility expansion.
4. A Congressional Budget Office report states, "Regressions . . . were run using data from 1985, 1988, and the 1977–1988 average; . . . All of the regressions gave similar results" (CBO 1992, 57–58).
5. Jansson (1994) observes the following: on a road that produces Q vehicle-km of travel per unit of time and on which each vehicle has an accident involvement rate of r involvements per vehicle kilometer, the total accident cost per unit of time is $C = arQ$, where a is the cost to society of an accident involvement. Then the marginal accident cost of an increase of 1 vehicle-km is $dC/dQ = ar + aQ(dr/dQ)$.

   If $dr/dQ = 0$, the accident risk to other road users is unaffected by the marginal vehicle kilometer, although the added vehicle kilometer can still incur an external cost. In this case, the marginal accident cost is ar, the cost of a vehicle's own accident involvements. The marginal external cost is ar less the expected cost to a vehicle operator of being involved in an accident.

The term *ar* can have an external component representing social costs of a vehicle's own involvements that are not borne by the vehicle's operator. This external component would include, for example, the costs of traffic congestion, road repair, or ambulance service caused by an involvement.

If fault-based liability applies, some part of the second term, $aQ(dr/dQ)$, is internal.

6. Jansson (1994) examines the mixed traffic problem theoretically.
7. Citing EPA 1974 estimates (Nelson 1978, 19).

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ABBREVIATIONS

CBO	Congressional Budget Office
COE	U.S. Army Corps of Engineers
FHWA	Federal Highway Administration
GAO	General Accounting Office
NRC	National Research Council
TRB	Transportation Research Board

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4

CASE STUDY FREIGHT SHIPMENTS

The primary purpose of the case studies presented in this chapter is to illustrate, with concrete examples, the challenges of defining and measuring external costs and subsidies. Case studies are a way to confront and explore the limitations of available models and data and to begin to identify, through the use of sensitivity analyses, the critical parameters and main sources of uncertainty in the estimates. In addition, the case studies are intended to provide preliminary indications of the categories of costs that are likely to be most important in determining subsidies as well as the types of freight activities that are most and least likely to be subsidized.

The case studies are cost estimates for individual shipments rather than for aggregations of freight movements by mode or region. Each case study is for a specific category of commodities shipped between a specific origin and a specific destination. Each is similar to an actual freight movement made today or to a movement that is physically possible but currently not used by shippers because they prefer other options.

Estimating costs for individual case shipments ensures the inclusion of critical local or industry-specific factors that might be overlooked in an aggregate analysis. Such factors may include the importance of local pickup and delivery trips compared with that of linehaul freight as sources of congestion and environmental costs, importance of local conditions in urban areas in determining the magnitudes of environmental and congestion costs, and freight or logistical options that exist only in particular industries in particular locales.

The results of these exploratory case studies may appear to have implications for freight transportation policy, but that is not their purpose; great care must be taken to avoid invalid generalizations because of the very approximate nature of many of the estimates. Most of the estimates rely on published studies of relationships between freight activities and private or social costs. As explained in Chapter 3, an effort has been made

to select cost relationships and data from the literature that are plausible or represent a consensus view, as well as relationships that are simple enough to be easily applicable within the limited scope and objectives of the case studies. It has not been possible in this study to critically review all the research underlying the published cost estimates used; therefore, the use of data or a cost relationship from a certain source does not indicate a conclusion that the source is reliable. Some of the most important categories of costs, including accident and pollution costs, are also the categories for which the shortcomings of data and models are so great that the reliability of the estimates must be suspect.

In addition, the results may be a misleading basis for generalization because the cases have not been selected to be representative of all freight movements. The results show how costs depend strongly on circumstances; for example, in one case, congestion costs vary by several hundred dollars depending on the starting time assumed for the trip. In fact, the cases probably underestimate this variability, because the estimates sometimes use national average values for cost parameters rather than values specific to the routes and times of travel. For example, national average highway accident rates by road class are used, even though in reality rates vary from road to road and by time of day.

Finally, the method and objective of the case studies (either these exploratory cases or any future, more careful and comprehensive analysis) should not be misinterpreted as a means of determining that particular modes, routes, or technologies are more desirable for society than others. Although the studies estimate certain social costs of the shipments, they are not benefit-cost analyses because they ignore other costs. Estimates of carrier costs are provided, but they are based on crude national averages and intended only to indicate whether subsidies are large relative to freight rates. There are also no estimates of the relative advantages or benefits of the different modes or routes for the shipper. Shippers may be willing to pay more to use a particular mode or route because it is faster, more reliable, or less prone to damage; it offers more flexible or convenient schedules; or it allows smaller shipment sizes. As explained in Chapter 5, the intended policy applications of estimates of subsidies in freight transportation do not involve conducting cost-benefit analyses of alternative freight systems.

Even if a case study result is accepted as accurate, the only conclusion that can be drawn from an estimate of a relatively high subsidy is that the freight service in question probably could be made more efficient. Carriers and shippers might respond to a policy of eliminating subsidies in a variety

of ways, including reducing the external or other costs of the freight shipment or mode or paying the higher charges to continue using it.

In the case study summary tables in this chapter, results are presented in units of marginal subsidy per truckload kilometer: the sum of all marginal external costs and the marginal cost of government-provided roads and waterways less user fees paid to government for the shipment, divided by the number of truckload kilometers constituting the shipment. This ratio facilitates the comparison of costs among trips of different lengths and modes; no implication is intended that charging carriers such an "average marginal cost" per kilometer would be an appropriate arrangement for eliminating external costs and subsidies. If user fees were to be considered as a means of offsetting subsidies, rate bases for efficient charges might be equivalent single-axle load (ESAL) kilometers, passenger-car-equivalent kilometers, number of accidents, number of breakdowns in traffic, grams of pollutants emitted, or other physical indexes of costs incurred; a flat fee per kilometer probably would not do a good job of encouraging more efficient freight transportation. Consideration of any such fee scheme would have to include a comparison of the administrative costs of the scheme with the intended economic benefits of improved pricing. However, this study has not evaluated alternative user charge schemes or other means of eliminating subsidies.

The first section in this chapter describes the case studies selected. The second section presents the results of each case study (a table at the end of the second section summarizes the results of all the cases). The final section of the chapter presents the results of sensitivity analyses to determine the magnitude and sources of uncertainty in the estimates. Appendix C explains the computations and identifies data sources.

CASE STUDIES SELECTED

The four case studies are as follows:

1. A shipment of grain from an elevator at Walnut Grove, Minnesota, to the Mississippi River port at Winona, Minnesota. Three combinations of route and mode are considered:
   - 1A: by truck via US-14,
   - 1B: by truck via I-90 (a more circuitous route over better roads), and
   - 1C: by shortline railroad between the same points.

2. A shipment of grain from Walnut Grove to New Orleans by rail and barge:
   - 2A: by rail to Winona and by barge from Winona to New Orleans, and
   - 2B: by rail to St. Louis and by barge from St. Louis to New Orleans.
3. A freight container from the port of Long Beach, California, to Chicago:
   - 3A: by truck via fastest Interstate route, and
   - 3B: by rail linehaul with truck drayage.
4. A day-long trip of a grocery distribution truck from a warehouse to retail stores in metropolitan Hartford, Connecticut.

Table 4-1 gives basic information about each case. Tables in Appendix C present the values of input parameters assumed for vehicle fuel consumption and emissions, traffic characteristics, user tax rates, highway maintenance unit costs, average accident rates and accident costs, and regional population, air quality, and emissions data. In addition to these parameters, route segment–by–route segment descriptions were prepared for each case describing exact routings, road design features and traffic volumes (for truck segments), and urban and rural land use.

The costs estimated are those that would be incurred by one additional trip over the specified route carrying the specified commodity. Costs of empty backhaul travel (in cases where empty backhauls are assumed to occur) are included as a cost of the fronthaul. The results are presented in units of costs per truckload of cargo, in total for the entire freight movement. Costs for rail and barge movements were computed as the cost of one additional train or tow and then prorated on the basis of weight to cost per truckload. The costs and revenues estimated are the following:

- *Congestion*: the delay cost to others caused by the additional trip on a congested road or waterway (rail delay costs are assumed to be internal to the rail carrier).
- *Accidents*: external costs of added deaths, injuries, property damage, and accident-related delay that occur because the added shipment was made.
- *Air pollution*: costs of the emissions produced in the course of the shipment.
- *Energy consumption*: quantity of petroleum consumed in the course of the shipment, multiplied by a valuation of the difference between the

TABLE 4-1 CASE STUDY DESCRIPTIONS

Case Study	Origin	Destination	Transportation Modes	Vehicle Description	States	Loaded Kilometers		
						Rural	Urban	Total
1A	Walnut Grove, MN	Winona, MN	Truck	5-axle tractor semi	MN	321	29	350
1B	Walnut Grove, MN	Winona, MN	Truck	5-axle tractor semi	MN	409	0	409
1C	Walnut Grove, MN	Winona, MN	Truck/rail	Grain railcar	MN	311	10	320
2A	Walnut Grove, MN	New Orleans, LA	Rail/barge	Grain railcar 15-barge tow [20 412 metric tons (22,500 short tons)]	MN, IA, MO, TN, LA	2237	198	2435
2B	Walnut Grove, MN	New Orleans, LA	Rail/barge	Grain railcar 15-barge tow [20 412 metric tons (22,500 short tons)]	MN, IA, MO, TN, LA	2078	171	2248
3A	Los Angeles, CA	Chicago, IL	Truck	5-axle tractor semi	CA, NV, AZ, UT, CO, NE, IA, IL	3237	512	3749
3B	Los Angeles, CA	Chicago, IL	Truck/rail	Container railcar 5-axle tractor semi	CA, AZ, NM, TX, OK, KS, MO, IL	3182	313	3495
4	Hartford, CT	Hartford, CT	Truck	4-axle tractor semi	CT	0	91	91

NOTE: The case studies are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

social and private costs of petroleum consumption (excluding costs associated with air pollution).

- *Noise*: cost of noise exposure caused by the trip.
- *Public infrastructure*: the increase in costs of the operating agency (the highway agency for truck, the Corps of Engineers for barge) caused by the added shipment (rail segments of the case study routes entail no public infrastructure cost).
- *User fees*: fuel taxes, registration fees, weight-distance taxes, and excises on truck and truck equipment purchases paid by the vehicle operators for the truck and barge segments of the case study routes.

All the costs are defined more fully in Chapter 3.

CASE STUDY RESULTS

In the first four subsections the rationale for selecting each of the case studies is explained and results of the estimates are summarized. The final subsection contains a summary of the case studies.

Case Study 1 (Table 4-2)

Case Study 1 (shipment of grain in Minnesota by truck or rail) is an example of a bulk commodity movement with modal competition. The case considers two alternative truck routes—a direct route via two-lane roads and a more circuitous route on an Interstate highway—since route selection is one shipper/carrier decision that might be changed if shippers and carriers were responsible for all costs.

Table 4-2 gives costs for the rural and urban route segments separately as well as for the entire route. The definition of urban excludes small cities (those with populations below 50,000), so this case is almost entirely rural. Costs shown are costs for an entire trip per truckload of freight. The table is organized as follows:

- The first five rows show marginal external costs per truckload for congestion delay (highway and barge), accidents, air pollution, energy, and noise.
- The sixth row is marginal pavement and bridge costs. (In Case 2, involving barge freight, this row includes government waterway operating and maintenance costs.)

TABLE 4-2 CASE STUDY 1: GRAIN SHIPMENT FROM MINNESOTA TO MISSISSIPPI RIVER PORT

	Case Study 1A			Case Study 1B			Case Study 1C		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Costs initially not borne by carrier ($/truckload)									
Marginal external cost									
Congestion	7.72	1.22	8.94	6.25	0	6.25	0.00	0.00	0.00
Accidents	43.06	2.98	46.04	26.11	0	26.11	8.91	0.28	9.19
Air pollution	5.94	0.60	6.54	6.75	0	6.75	1.34	0.09	1.43
Energy security	2.85	0.25	3.10	3.63	0	3.63	0.37	0.01	0.39
Noise	0.00	2.31	2.31	0.00	0	0.00	0.00	0.78	0.78
Marginal cost of public infrastructure	35.32	3.31	38.63	61.02	0	61.02	0.00	0.00	0.00
Total	94.90	10.67	105.57	103.77	0	103.77	10.62	1.16	11.78
Less: user fees paid by carrier to government ($/truckload)	46.97	4.19	51.16	59.90	0	59.90	0.63	0.02	0.65
Equals: net subsidy ($/truckload)	47.93	6.48	54.41	43.87	0	43.87	9.98	1.14	11.13
Net subsidy per truckload kilometer ($)	0.15	0.23	0.16	0.11	0	0.11	0.03	0.12	0.03
Carrier's average cost ($/truckload)			454.16			531.70			124.87
Subsidy as percentage of carrier's cost			12.0			8.3			8.9

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail

- The seventh row is the sum of all marginal external costs and the marginal cost of public infrastructure (i.e., the sum of rows one through six).
- The eighth row is user fees paid by the truck operator to government for the trip (in Case 2, user fees paid by the barge operator).
- The ninth row is the subsidy (Row 7 less Row 8).
- The tenth row is subsidy divided by the loaded kilometers for the trip.
- The eleventh row is carrier average cost, a typical freight rate for the shipment.
- The twelfth row is the subsidy as a percentage of carrier average cost (Row 9 divided by Row 11, multiplied by 100).

The overall pattern of external costs is one that prevails throughout most of the case studies: for truck, external accident cost is the largest component of the subsidy; congestion and air pollution costs are smaller and roughly comparable in magnitude. For rail, external accident costs dominate. Truck marginal external costs are higher than rail in all categories. However, both truck and rail receive subsidies, and the rail and truck net subsidies are similar percentages of their respective carrier average costs.

As the sensitivity analyses presented later in this chapter will show, the estimates of external costs are very uncertain. Accident costs are uncertain because the effect of truck traffic on risks of other drivers is poorly understood and because little information is available on the fraction of total accident costs that is borne by truck owners. Pollution costs are uncertain because the modeling of the relationship between emissions and exposure in the case studies is simplistic and because the health effects of particulates are poorly understood. The conceptual basis for defining the energy external cost is controversial. Finally, highway congestion cost is uncertain because data on the relationship between speed on a road and truck traffic are poor.

According to the estimates, the truck operator using the two-lane road pays user fees that exceed the highway agency's marginal pavement and bridge wear costs: highway agency costs for the truck trip are $39 and the truck pays $51 in user fees. The assumption that the truck returns empty to its origin contributes to this result—the truck traveling empty pays nearly the same user fees as when traveling loaded but generates much lower pavement and bridge costs. However, the truck is receiving a marginal subsidy when external costs are included.

The truck operator's user fees on the Interstate almost equal marginal pavement and bridge costs. It might be expected that the truck's pavement and bridge costs would be lower on the Interstate since Interstates are built with heavier pavement than most rural two-lane roads. However, trucks are assumed in the computation to travel predominantly in the right-hand lane of the Interstate, and resurfacing of all lanes is triggered as soon as the right lane wears out. In effect, the truck wears out only one lane of the Interstate, but it is charged with resurfacing both lanes.

The estimates of truck and rail costs are affected by assumptions about backhauls. In Case Study 1, it is assumed that the truck returns empty to its origin. This is plausible for this type of freight movement. The Case 1 rail cost estimates assume national average equipment utilization rates. This also may be plausible, since nationwide about 40 percent of railcar kilometers are empty.

Case Study 2 (Table 4-3)

Case Study 2 compares two alternative rail-barge routes for grain traveling from Minnesota to New Orleans: one route is via the nearest river port to maximize the barge share of the trip; in the other route the grain moves by rail to St. Louis, bypassing the congested locks of the Upper Mississippi, and is then loaded on barges. The purposes of the case are to examine external costs and subsidies of barge and rail freight and to illustrate the importance of lock delay costs for barges.

The computations indicate that the user fees paid by barges nearly cover marginal operating and maintenance costs of the U.S. Army Corps of Engineers for the route that includes the Upper Mississippi locks (2A) and more than cover these costs for the route bypassing the locks (2B). (User fees in Table 4-3 include rail and barge fuel taxes. The barge fuel tax is $15/truckload of freight in Case 2A and $8 in Case 2B. The public infrastructure cost in the table is entirely for waterways.) The barges appear to pay less than the Corps's marginal operating and maintenance costs on the Upper Mississippi but more than the Corps's costs on the Lower Mississippi. The marginal cost of waterway use to the Corps of Engineers is estimated to be much smaller than the Corps's average cost, so the waterway system is not self-supporting. [Average operating and maintenance costs for the Case 2A route are $80/truckload of freight and average construction expenditures are $50/truckload (COE 1992, Tables 24 and 25).] Nevertheless, from the marginal cost perspective, the main source of subsidy is not the Corps's costs but the external delay cost.

TABLE 4-3 CASE STUDY 2: GRAIN SHIPMENT FROM MINNESOTA TO NEW ORLEANS

	Case Study 2A			Case Study 2B		
	Rural	Urban	Total	Rural	Urban	Total
Costs not initially borne by carrier ($/truckload)						
Marginal external cost						
Congestion	108.34	0.00	108.34	0.00	0.00	0.00
Accidents	8.95	0.28	9.23	28.83	1.57	30.40
Air pollution	12.86	2.29	15.15	10.70	2.63	13.33
Energy security	2.69	0.24	2.93	2.50	0.21	2.70
Noise	0.00	0.78	0.78	0.00	2.76	2.76
Marginal cost of public infrastructure	18.55	0.00	18.55	2.47	0.00	2.47
Total	151.39	3.59	154.98	44.49	7.17	51.66
Less: user fees paid by carrier to government ($/truckload)	15.45	0.02	15.47	8.97	0.02	8.99
Equals: net subsidy ($/truckload)	135.94	3.57	139.51	35.53	7.15	42.67
Net subsidy per truckload kilometer ($)	0.06	0.02	0.06	0.02	0.04	0.02
Carrier's average cost ($/truckload)			442.73			591.65
Subsidy as percentage of carrier's cost			31.50			7.2

NOTE: Case study descriptions are as follows:

2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans

Case Study 3 (Table 4-4)

Case 3 illustrates external costs and subsidies for movements of longhaul general commodities freight by truck and rail. The overall pattern of costs and subsidies is similar to Case 1, except that the truck route in this case generates a very large congestion delay cost (nearly $300 for the trip). This delay cost illustrates the inherent variability of marginal subsidies—nearly all the delay cost occurs on a few short segments of the 3700-km (2,300-mi) trip that happen to be highly congested when the truck reaches them. One of the sensitivity analyses presented later in this chapter shows that this cost largely disappears if the truck is assumed to depart at a different time of day.

The routes include substantial urban travel [512 km (318 mi) for truck and 313 km (195 mi) for rail; see Table 4-1], so the case also provides a comparison of urban and rural costs. Urban external costs per kilometer are higher than rural costs; truck air pollution cost is $0.03/km ($0.05/mi) on urban roads versus $0.01/km ($0.02/mi) on rural roads, for example; and marginal external truck accident cost is $0.05/km ($0.09/mi) on urban roads versus $0.02/km ($0.03/mi) on rural roads. The truck's overall marginal external and government infrastructure costs per kilometer (before user fees) are eight times greater on urban roads than on rural roads.

Perhaps surprisingly, truck and rail have similar estimated marginal external accident costs. In part this is because the truck travel is mainly on rural Interstates, which have truck fatal accident rates well below the average for all truck travel. Rail accident cost is estimated simplistically in the case studies as a single national average cost per ton mile, whereas the estimate of truck marginal external accident cost depends on road class, urban or rural location, and traffic volume.

As in Case 1, comparisons between truck and rail are affected by backhaul assumptions. In Case 3, truck costs are for the one-way loaded travel plus an empty segment equal in length to 15 percent of the loaded kilometers. Rail utilization is assumed to be at the national average rate, as in Case 1.

The truck in Case 3 is lighter than the truck in Case 1 [28 123 kg (62,000 lb) versus 36 287 kg (80,000 lb)], so, despite the lower rate of empty travel, user fees exceed marginal pavement and bridge costs by a larger margin in Case 3 than in Case 1.

TABLE 4-4 CASE STUDY 3: CONTAINER FREIGHT, LOS ANGELES TO CHICAGO

	Case Study 3A			Case Study 3B		
	Rural	Urban	Total	Rural	Urban	Total
Costs not initially borne by carrier ($/truckload)						
Marginal external cost						
Congestion	27.94	267.86	295.81	0.00	0.75	0.75
Accidents	61.39	28.04	89.43	69.79	7.93	77.72
Air pollution	48.50	15.15	63.65	26.74	8.09	34.83
Energy security	14.37	2.27	16.64	4.83	0.53	5.36
Noise	0.00	20.68	20.68	0.00	12.65	12.65
Marginal cost of public infrastructure	129.41	12.06	141.47	0.00	1.81	1.81
Total	281.61	346.06	627.67	101.36	31.77	133.12
Less: user fees paid by carrier to government ($/truckload)	245.92	39.22	285.14	8.21	2.29	10.50
Equals: net subsidy ($/truckload)	35.69	306.84	342.53	93.15	29.47	122.62
Net subsidy per truckload kilometer ($)	0.01	0.60	0.09	0.03	0.09	0.04
Carrier's average cost ($/truckload)			2,469.06			1,049.44
Subsidy as percentage of carrier's cost			13.90			11.70

NOTE: Case study descriptions are as follows:

3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad

Case Study 4 (Table 4-5)

Case 4 illustrates costs of an urban goods distribution activity, an important category of truck travel. The subsidy per truckload kilometer is the highest among the cases ($0.22), largely for two reasons. First, the ratio of empty to loaded kilometers is relatively high [the truck drives 114 km (71 mi) empty and 91 km (57 mi) loaded]. Second, the trip is entirely within an urban area, so congestion and noise costs are more important than in most of the other truck cases. Time of day probably has a large effect on the costs of urban delivery trips. For example, nighttime deliveries would be expected to have lower congestion cost (although noise cost might be higher at night in some locations). One of the sensitivity analyses that follow in this chapter shows the effect of time of day.

Summary of Case Studies

The level of subsidy is remarkably similar across the cases when subsidies are expressed as a percentage of carrier costs (Table 4-6). The estimated

TABLE 4-5 CASE STUDY 4: LOCAL GROCERY DISTRIBUTION, HARTFORD, CONNECTICUT, VIA TRUCK

	TOTAL
Costs not initially borne by carrier ($/truckload)	
Marginal external cost	
Congestion	8.95
Accidents	11.62
Air pollution	4.89
Energy security	0.91
Noise	8.28
Marginal cost of public infrastructure	9.99
Total	44.63
Less: user fees paid by carrier to government ($/truckload)	24.16
Equals: net subsidy ($/truckload)	20.47
Net subsidy per truckload kilometer ($)	0.22
Carrier's average cost ($/truckload)	284.10
Subsidy as percentage of carrier's cost	7.20

NOTE: The route is entirely urban.

TABLE 4-6 SUMMARY OF CASE STUDY ESTIMATES

CASE STUDY	NET MARGINAL SUBSIDY ($/TRUCKLOAD)	CARRIER AVERAGE COST ($/TRUCKLOAD)	SUBSIDY AS PERCENTAGE OF CARRIER COSTS	SUBSIDY ($/TRUCKLOAD KILOMETER)
1A	54	454	12	0.16
1B	44	532	8	0.11
1C	11	125	9	0.03
2A	137	443	31	0.06
2B	40	592	7	0.02
3A	343	2,469	14	0.09
3B	123	1,049	12	0.04
4	20	284	7	0.22

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

marginal subsidy is between 7 and 14 percent of carrier costs in seven of the eight subcases, a striking result considering the variety of cases examined. In the subcase with the highest subsidy as a percentage of carrier average cost (the barge movement from Winona, Minnesota), and also in the subcase with the highest percentage subsidy among the truck and rail subcases (the truck container movement), congestion delays account for the largest component of the subsidy.

The marginal social cost approach used in this study generally implies larger shipper subsidies than the conventional government cost recovery approach, at least in the cases examined here. Table 4-7 compares subsidies calculated using the marginal social cost and the government cost recovery approaches for the case study shipments; the format of Table 4-7 is similar to that of Table 2-2, in which the two approaches are explained and compared. The column labeled "government cost recovery" contains estimates of the capital and operating costs of the public facility that would be allocated to each case study shipment according to methods of recent government highway and waterway cost allocation studies. As the table indicates, allocated costs under the traditional government cost recovery approach generally exceed marginal costs of government services and facilities, but this gap is more than made up by the external costs

TABLE 4-7 COMPARISON OF MARGINAL COST WITH COST RECOVERY FRAMEWORK: TRUCK AND WATERWAY CASES

	CASE 1A		CASE 1B		CASE 2A		CASE 3A		CASE 4	
	MARGINAL SOCIAL COST	GOVERNMENT COST RECOVERY	MARGINAL SOCIAL COST	GOVERNMENT COST RECOVERY	MARGINAL SOCIAL COST	GOVERNMENT COST RECOVERY	MARGINAL SOCIAL COST	GOVERNMENT COST RECOVERY	MARGINAL SOCIAL COST	GOVERNMENT COST RECOVERY
Costs not initially borne by carrier ($/truckload)										
External cost										
Congestion	9		6		108		296		9	
Accidents	46		26		9		89		12	
Air pollution	7		7		15		64		5	
Energy security	3		4		3		17		1	
Noise	2		0		1		21		8	
Cost of provision of infrastructure	39	82	61	96	19	104	141	438	10	24
Total	106	82	104	96	155	104	628	438	45	24
Less: user fees paid by carrier to government ($/truckload)	51	51	60	60	15	15	285	285	24	24
Equals: net subsidy ($/truckload)	54	31	44	36	140	89	343	153	20	−0
Carrier's average cost ($/truckload)	454	454	532	532	443	443	2,469	2,469	284	284
Subsidy as percentage of carrier's cost	12	7	8	7	32	20	14	6	7	−0

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
4 Local grocery distribution, Hartford, Connecticut, via truck

included under the marginal social cost approach. Marginal user fees, as defined in this study, are generally the same as the revenues credited to highway and waterway users in the cost allocation studies.

SENSITIVITY OF ESTIMATES TO CHANGES IN ASSUMPTIONS

One of the objectives of the case studies is to determine which uncertainties in assumptions and input parameters have the greatest effect on the estimates, so as to assess the reliability of the cost estimates and indicate areas where research is needed before more reliable estimates can be made. The tables in this section indicate that plausible changes to case study assumptions and input parameters can have very large effects on the cost estimates. The following assumptions and input values were tested:

1. Value of a change in the risk of death,
2. Unit costs of human exposure to air pollution,
3. Health effects of fugitive dust emissions,
4. Relationship between traffic volume and accident rates,
5. Relationship between traffic volume and average speed on roads,
6. Time of day of the case study truck trips, and
7. Relationship between traffic volume and pavement deterioration.

The variability in cost estimates shown in the sensitivity analyses arises from two distinct sources. First, estimates are uncertain because of lack of information about physical processes and cost relationships. For example, vehicle pollutant emission rates and the health effects of many pollutants are not well known. Second, estimates are sensitive to assumptions because the real world is inherently diverse. For example, congestion costs in fact vary greatly depending on traffic conditions along a route, and pavement wear costs depend on pavement conditions. These two sources of variability have different implications for the requirements of any future, more thorough analysis of subsidies in freight transportation. Most of the sensitivity analyses primarily address uncertainties resulting from poor data and models. The analysis of the effect of the assumed time of day of truck trips is an illustration of the sensitivity of costs to the diversity of actual conditions.

Value of Life (Table 4-8)

As explained in Chapter 3 and Appendix C, the case studies assume that in evaluating small changes in risk of death in an automobile accident, the appropriate value of a statistical life saved is $2.2 million. This value is taken from the Urban Institute study cited in Appendix C, which based its estimate on a review of studies of how individuals assign monetary value to situations or actions that expose them to different risks of death (for example, wage premiums paid to workers in hazardous jobs or people's willingness to pay for safety equipment) (Miller et al. 1991). Other reviews of the same literature have estimated values for increases of risk of death to young adults (that is, to persons of similar age as the age distribution of motor vehicle deaths in the Urban Institute study) to be somewhat higher, about $4 million to $5 million for each life saved (Small and Kazimi 1995; Harrison et al. 1992, 27–35).

The value of reducing a hazard depends on the average years of life lost to persons who die as a result of the hazard in question and on the rate at which individuals discount the value of avoiding an increased risk of loss of life in the future compared with the value of avoiding an immediate risk. In the case studies, the costs that entail increased risk of death are accident costs and air pollution costs. As explained in Appendix C, the valuations of these risks assume that, on the average, 43 years of life are lost to a person killed in a transportation accident and 12 years to a person who dies prematurely as a result of air pollution, and that the relevant discount rate is 5 percent. The combined effect of these assumptions is that the expected increase in deaths from increased exposure to pollution is valued at $1.3 million/death.

In the sensitivity analysis, the cost of increased risk of death is doubled to $4.4 million/death for increased risk in transportation accidents and $2.6 million for a premature death caused by pollution. These values are still well within the range of values commonly used in social cost analyses.

Doubling the assumed value of life more than doubles the estimated marginal external accident cost in most cases (Table 4-8). The percentage change in marginal external cost is greater than the percentage change in the average cost of an accident because compensation paid by transportation companies to persons other than employees for accident losses accounts, under the new assumptions, for a smaller percentage of the total accident cost, so a greater percentage of the total is external. Another effect of doubling the assumed value of life is to increase the marginal external air pollution cost by about 30 percent in most cases.

TABLE 4-8 EFFECT OF DOUBLING THE COST OF INCREASED RISK OF DEATH

	Marginal External Cost ($/truckload)						
	Accidents		Air Pollution		Subsidy per Truckload Kilometer		
Case Study	Original	Double Value of Life	Original	Double Value of Life	Original ($)	Double Value of Life ($)	Change (%)
1A	46	95	7	8	0.16	0.30	92
1B	26	55	7	8	0.11	0.18	67
1C	9	20	1	2	0.03	0.07	97
2A	9	20	15	19	0.06	0.06	11
2B	30	65	13	17	0.02	0.04	97
3A	89	176	64	83	0.09	0.12	31
3B	78	166	35	46	0.04	0.06	82
4	12	20	5	7	0.22	0.34	49

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

Doubling the value of life increases the estimate of marginal subsidy per truckload-equivalent kilometer by 49 to 97 percent in all the subcases except two: Case 3A (container carriage by truck), in which congestion and road wear costs are relatively large, and Case 2A, a predominantly barge movement in which the only appreciable external cost is delay at locks. The absolute change in the subsidy ranges from $0.01 to $0.23/truckload-mi; the absolute change for rail and barge cases tends to be lower than for trucks.

Most of the change in subsidy is due to the change in accident costs. It should be noted that a relatively small change in one cost component can have a large percentage impact on the marginal subsidy because the subsidy is the difference between marginal revenues and marginal costs; when revenue is close to cost, a small change in cost will cause a large change in the difference.

Unit Costs of Air Pollution Exposure (Table 4-9)

The original case studies use estimates of unit costs of damage caused by exposure to air pollution that are in the middle of the plausible range. This sensitivity analysis assumes low-range estimates of unit pollution cost. The original and low-range estimates are as follows:

	Cost of Exposure [($/person-year)/(μg/m³)]	
	Original	Low-Range
PM10	19.62	4.28
Ozone	0.15	0.01
Nitrogen dioxide	0.68	0.31
Sulfur dioxide	0.31	0.07
Carbon monoxide	0	0

In addition, costs of carbon dioxide and other greenhouse gases are assumed to be $0.035/gal of fuel consumed in the original cases and zero in this sensitivity analysis. The low-range estimates are from the same source as the original estimates (Harrison et al. 1993, 157–160) (with adjustment to make them consistent with the value of an increase in risk of death used in this study) and are intended to represent the likely range of uncertainty in pollution damage cost estimates. Note that the next

TABLE 4-9 EFFECT OF LOW POLLUTION EXPOSURE UNIT COSTS

	Marginal External Cost of Air Pollution ($/truckload)		Subsidy per Truckload Kilometer		
Case Study	Original	Low Unit Costs	Original ($)	Low Unit Costs ($)	Change (%)
1A	7	1	0.16	0.14	−10
1B	7	1	0.11	0.09	−13
1C	1	0	0.03	0.03	−10
2A	15	3	0.06	0.05	−9
2B	13	3	0.02	0.01	−26
3A	64	13	0.09	0.08	−15
3B	35	8	0.04	0.03	−22
4	5	1	0.22	0.18	−19

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

sensitivity analysis presented, which assumes a greater cost of particulates exposure, constitutes a high-range pollution cost estimate.

The effect of substituting the low unit pollution cost values in the cost estimates is that the marginal external cost of air pollution decreases by about 80 percent in most cases. The subsidy per truckload kilometer decreases by from 9 to 26 percent among the cases. The absolute change in subsidy is $0.02/km ($0.03/mi) or less, except in the urban truck case (Case 4), for which the change is $0.04/km ($0.07/mi).

Health Effects of Fugitive Dust Emissions (Table 4-10)

PM10 is generated by fugitive sources (including tilling, construction, wind erosion, mining, and dust from the surfaces of roads) as well as by combustion (as in engines) and industrial sources. In its national emissions inventories, the Environmental Protection Agency (EPA) estimates that fugitive PM10 is 90 percent of total PM10 emissions (EPA 1993, 3-32–3-34).

TABLE 4-10 EFFECT OF ASSIGNING NO HEALTH IMPACT TO FUGITIVE DUST

	Marginal External Cost of Air Pollution ($/truckload)		Subsidy per Truckload Kilometer		
Case Study	Original	No Fugitive Dust Impact	Original ($)	No Fugitive Dust Impact ($)	Change (%)
1A	7	34	0.16	0.23	50
1B	7	39	0.11	0.19	73
1C	1	9	0.03	0.06	70
2A	15	84	0.06	0.09	50
2B	13	70	0.02	0.04	144
3A	64	264	0.09	0.14	59
3B	35	147	0.04	0.07	91
4	5	12	0.22	0.30	35

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

In estimating the costs of motor vehicle particulate emissions, one of three mutually exclusive assumptions concerning the relative importance of fugitive and nonfugitive sources must be used: (*a*) fugitive dust affects health similarly to any PM10 component and is not attributable to vehicles, (*b*) fugitive dust has very small or no effect on health and can be ignored, or (*c*) fugitive dust affects health and is partially attributable to motor vehicles because traffic stirs road dust into the air. The cost estimates derived from each of these assumptions would be vastly different.

The case study computations assume that all PM10 emissions, regardless of source, have equivalent health and property damage effects and that fugitive dust is not attributable to vehicles (i.e., Assumption *a*). There are grounds for suspecting that particulates from nonfugitive sources may have greater health effects because these sources account for most of the smallest particles (less than 2.5 μm in diameter) and because their composition includes organic compounds and other substances that may be more toxic than the components of fugitive dust (Dockery et al. 1993, 1753).

The cases assume that all sources of PM10 are equally harmful because epidemiological data do not provide a quantitative estimate of the relative health effects of diesel particulates and the fugitive component of PM10 and because national data are not available on the contributions of fugitive and nonfugitive sources to ambient PM10. To the extent that diesel particulates are more harmful than others, the case studies underestimate the cost of particulate emissions.

This sensitivity analysis assumes that all of the health effects of PM10 are caused by exposure to emissions from nonfugitive sources (i.e., Assumption *b*). Under this assumption, the emissions produced by the case study vehicles represent a much larger percentage increase in total emissions of the harmful pollutant and therefore cause a much larger percentage increase in exposure cost.

The fraction of ambient PM10 that originates from nonfugitive sources is assumed in the sensitivity analysis to be equal to the fraction of all primary particulate emissions that is from nonfugitive sources. A single nationwide fraction is used, 5.9 million tons nonfugitive out of 51.4 million tons total PM10 emissions in the United States in 1992 (EPA 1993, Tables 3-5 and 3-6).

This sensitivity analysis is an upper-bound estimate of the importance of the relatively greater harmfulness of nonfugitive sources because it assumes fugitive PM10 has no health effects and because the ratio of population-weighted exposure to nonfugitive PM10 to exposure to all PM10 probably is greater than the 5.9/51.4 ratio derived from the national emissions inventory. Nonfugitive PM10 may survive in the atmosphere longer than fugitive PM10 because of its smaller average size, and nonfugitive PM10 accounts for a larger share of total PM10 emissions in urban areas than in rural areas. For example, data for Los Angeles indicate that ambient PM2.5 is 59 percent of PM10 by weight (Small and Kazimi 1995). (Most PM2.5 is nonfugitive and most nonfugitive PM10 is PM2.5.)

The effect of the changes in assumptions in the sensitivity analysis is to increase the health-related costs of motor vehicle particulate emissions by about a factor of 10. This increases marginal external air pollution costs by factors of 2 to 10 in the cases, and the subsidy by 35 to 144 percent. The absolute change ranges from $0.03 to $0.08 per truckload-km ($0.04 to $0.13 per truckload-mi).

A related source of uncertainty not investigated here is the role of road dust. The case studies include only the cost of tail pipe emissions of PM10 and of PM10 that is formed secondarily from tail pipe emissions. However, EPA estimates that emissions of PM10 from the surface of roads are several

times larger than tail pipe PM10 emissions from vehicles (EPA 1993, Tables 3-5 and 3-6). Presumably, some portion of this road dust is stirred up into the air by the passage of motor vehicles. If this mechanism is a source of ambient PM10 of the magnitude suggested by the EPA emissions inventory, and if PM10 from road dust is as hazardous as PM10 from tail pipe emissions (that is, if Assumption *c* is correct), then the cost of PM10 from road dust attributable to motor vehicle travel is several times greater than the cost of PM10 tail pipe emissions. One experimental study suggests, however, that road dust emissions from motor vehicle passage are smaller than tail pipe emissions under some circumstances (Balogh et al. 1993).

Relationship Between Traffic Volume and Accident Rates (Table 4-11)

As explained in Chapter 3, the marginal external accident cost of truck traffic depends critically on the effects of truck and car traffic volumes on

TABLE 4-11 EFFECT OF LOWER ACCIDENT RATE ELASTICITIES WITH RESPECT TO TRAFFIC VOLUME

Case Study	Marginal External Cost of Accidents ($/truckload)		Subsidy per Truckload Kilometer		
	Original	Low Elasticity	Original ($)	Low Elasticity ($)	Change (%)
1A	46	8	0.16	0.05	−71
1B	26	4	0.11	0.05	−49
1C	9	3	0.03	0.02	−53
2A	9	3	0.06	0.05	−4
2B	30	11	0.02	0.01	−49
3A	89	16	0.09	0.07	−21
3B	78	27	0.04	0.02	−41
4	12	2	0.22	0.12	−46

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

accident rates; these effects have not been measured satisfactorily. The original case study estimates assume that the rate of truck-nontruck accidents (of all severities) per nontruck kilometer increases proportionately with truck volume on a road (i.e., that the elasticity of the rate with respect to truck volume is 1). The assumptions in the case studies concerning the relationships between traffic volume and accident rates are explained in Appendix C.

In this sensitivity analysis (Table 4-11) it is assumed that the percentage increase in the truck-nontruck accident rate is half the percentage increase in truck volume (i.e., the elasticity is one-half). This alternative assumption implies that the rate of truck-nontruck accidents per truck kilometer decreases with increasing truck volume. The sensitivity analysis also assumes that the elasticity, with respect to truck traffic volume, of the rate of accidents not involving a truck per nontruck kilometer is half the elasticity in the original estimates. A similar assumption is made for rail in the sensitivity analysis: the increase in internal and external accident losses is assumed to be only half the increase that would occur if losses were proportional to ton kilometers.

The change in assumptions reduces the marginal external accident cost by more than 80 percent in all the cases that involve mainly truck travel; under the new assumptions, the average private cost of an accident to a truck operator nearly covers the marginal social cost of the accident. The marginal subsidy is reduced by 21 to 71 percent in the truck cases and by 4 to 53 percent in the rail cases. In absolute terms, the subsidy declines $0.02 to $0.10/km ($0.03 to $0.18/mi) in the truck cases and $0.01/km ($0.02 to $0.03/mi) in the rail cases.

Relationship Between Highway Traffic Volume and Speed (Table 4-12)

As explained in Appendix C, traffic engineers' understanding of the relationship between traffic volume and average speed has changed markedly in the past 30 years. The shapes of these curves appear not to have been measured reliably, and detailed information about how the curves depend on local road conditions is not available. This sensitivity analysis illustrates the effect of changing the assumed shape of the speed-volume curves on the estimate of marginal external delay cost in the truck cases.

The original estimates apply the four speed-volume curves shown in Figure C-1 to estimate congestion delay—a different curve is used for each of four basic highway types. The sensitivity analysis replaces the

TABLE 4-12 EFFECT OF STEEPER SPEED-VOLUME CURVES FOR INTERSTATES AND URBAN ROADS

Case Study	Marginal External Cost of Congestion ($/truckload)		Subsidy per Truckload Kilometer		
	Original	Steeper Curves	Original ($)	Steeper Curves ($)	Change (%)
1A	9	13	0.16	0.17	8
1B	6	10	0.11	0.12	8
3A	296	390	0.09	0.11	27
3B	1	2	0.04	0.04	1
4	9	26	0.22	0.41	82

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

This change does not apply to Cases 1C, 2A, or 2B.

baseline speed-volume curves on freeways and on two-lane rural roads with curves that have steeper slopes at low-volume ranges. (Specifically, the sensitivity analysis assumes that the slope of the two-lane rural speed-volume curve in Figure C-1 applies to freeways and that the slope of the urban signalized road curve in Figure C-1 applies to two-lane rural unsignalized roads.) Under these new assumptions, all speed-volume curves now exhibit substantial declines in speed with increasing traffic at low and moderate traffic volumes. These assumptions represent an upper bound on the magnitude of delay costs.

The increase in marginal external delay is from 30 to 300 percent in the cases involving mainly truck travel. The magnitude of the increase varies according to the mix of roads and traffic levels along each route. The percentage increase in subsidy is small, however, with the exception of the urban truck case (Case 4). A large fraction of the travel in Case 4 is on expressways with moderate traffic volumes, where the difference between the original and new speed-volume curves is greatest.

Two related and potentially important sources of uncertainty, not explored in this sensitivity analysis, are the relative effect of a truck, compared with a car, on traffic flow (i.e., the truck's passenger car equivalency); and the share of delay that is attributable to nonrecurring sources such as accidents and breakdowns.

Effect of Time of Day on Highway Congestion Cost (Table 4-13)

The external congestion delay cost caused by the added truck trip depends on the time of day of the trip because traffic volume varies by time of day. The original cases that commence with a truck trip all assume that the truck starts at 8 a.m. As the truck progresses through its trip, it encounters congestion on each road segment depending on the time of day that it arrives at the segment.

Table 4-13 shows the effects of starting each trip at 2 p.m. and 8 p.m. rather than at 8 a.m. The 8 p.m. start has the lowest delay time in all truck subcases. All truck trips except Case 3A are less than 10 hr long, so starting at 8 p.m. in these cases places all travel at night. The Case 3A trip (Los Angeles to Chicago) is 36 hr long, so starting it at 8 p.m. maximizes the portion of the trip driven at night. The most dramatic impact of the change in start times is in Case 3A, for which starting at night reduces the external delay cost by $215, or $0.06/km ($0.10/mi).

Changing the starting times of truck trips probably would significantly affect marginal external accident costs as well as delay costs. The case study estimating method cannot show this effect, however, because accident rates in the estimates are independent of time of day.

This sensitivity analysis illustrates how arbitrary assumptions in the construction of the cases, as well as uncertainty in data and relationships, affect the estimates. Because of such variability, it would be dangerous to regard any of the cases as typical of a class of freight traffic.

Relationship Between Truck Traffic Volume and Pavement Wear (Table 4-14)

As described in Chapter 3, the estimated pavement wear cost of added truck traffic in the case studies depends on assumptions about the "independent weather effect" and the design life of pavement construction and reconstruction. The independent effect of weather is represented by assuming that weather has an effect equivalent to the pavement wear effect of a specified number of annual passages of a standard truck axle over each road segment. This assumption also, in effect, specifies a minimum pavement design for all roads—no matter how light the truck traffic on a road, the highway agency is assumed always to construct pavements heavy enough to withstand at least the independent weather effect over the design life of the road. The independent weather effect is assumed

TABLE 4-13 EFFECT OF CHANGING STARTING TIME OF TRUCK TRIP

Case Study	Marginal External Cost of Congestion ($/truckload)			Subsidy per Truckload Kilometer		
	Original (8 a.m. Start)	2 p.m. Start	8 p.m. Start	Original ($)	8 p.m. Start ($)	Change (%)
1A	9	8	4	0.16	0.14	−11
1B	6	5	3	0.11	0.10	−7
3A	296	356	81	0.09	0.03	−63
3B	1	1	0	0.04	0.04	7
4	9	11	3	0.22	0.15	−32

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

This change does not apply to Cases 1C, 2A, or 2B.

TABLE 4-14 EFFECT OF MORE DURABLE PAVEMENT DESIGN

	Marginal Cost to Public Infrastructure ($)		Subsidy per Truckload Kilometer		
Case Study	Original	More Durable Pavement	Original ($)	More Durable Pavement ($)	Change (%)
1A	39	17	0.16	0.10	−39
1B	61	30	0.11	0.03	−70
3A	141	73	0.09	0.07	−20
3B	2	1	0.04	0.04	−1
4	10	5	0.22	0.17	−24

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

This change does not apply to Cases 1C, 2A, or 2B.

constant for all roads, so it mainly affects the estimated marginal truck costs on low-volume roads.

The design life parameter specifies the number of years between resurfacings that the road is designed to last, assuming traffic volume remains at its current level. The longer the design life, the heavier the pavement. The original case studies assume that the independent weather effect is equal to 100,000 ESALS/year and the design life is 7 years. In this sensitivity analysis, these parameters are set at 200,000 and 14 years, respectively. The sensitivity analysis very approximately represents the effects of a change in highway agency policy from present practices to one of building much more durable pavements. It also can be taken to indicate the range of uncertainty in the pavement wear cost estimates.

The result of changing these parameters is that the pavement wear cost of the added truck falls by $0.02 to $0.08 per loaded kilometer ($0.03 to $0.12 per loaded mile) in all the truck subcases. This cost is the change in present value of future resurfacings, and it reflects the net effect of higher cost for heavier pavement and longer intervals between resurfacings. The subsidy per truckload kilometer decreases by 20 to 70 percent in the predominantly truck cases.

It should be noted that the pavement cost model used in the case studies is too simplified to be able to predict the optimum resurfacing

frequency. In reality, pavement repair costs increase sharply once the pavement is allowed to deteriorate past some critical threshold.

Summary of Sensitivity Analyses

Tables 4-15, 4-16, and 4-17 summarize the air pollution, congestion, and accident cost sensitivity analyses, respectively. It is difficult to generalize about the results of the sensitivity analyses except to observe that it is possible to alter the estimate of almost any of the components of the marginal subsidy by factors of 2 or more by substituting values for selected input parameters that are within the plausible range of values for these parameters, given the present state of knowledge. Estimates are also sensitive to changes of assumptions in the construction of the case study scenarios, such as assumptions about travel time and whether a backhaul load is obtained. Considering both the degree of uncertainty in the as-

TABLE 4-15 CASE STUDY AIR POLLUTION COST ESTIMATES

	Marginal External Air Pollution Cost per Truckload				
		Change in Sensitivity Analyses (%)			Cost Under Original Assumptions ($/truckload-km)
Case Study	Original ($)	Double Value of Life	Low Unit Costs	No Fugitive Dust	
1A	7	16	−84	414	0.02
1B	7	14	−84	474	0.02
1C	1	20	−78	542	0.00
2A	15	28	−77	451	0.01
2B	13	29	−77	429	0.01
3A	64	31	−80	315	0.02
3B	35	33	−77	322	0.01
4	5	38	−80	145	0.05

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

TABLE 4-16 CASE STUDY CONGESTION COST ESTIMATES

Case Study	Marginal External Congestion Cost per Truckload: Original ($)	Change in Sensitivity Analyses (%): Steeper Speed-Volume Curves	Change in Sensitivity Analyses (%): 8 P.M. Start Time	Cost Under Original Assumptions ($/truckload-km)
1A	9	46	−56	0.03
1B	6	58	−45	0.02
3A	296	32	−72	0.08
3B	1	163	−73	0.00
4	9	189	−68	0.10

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

This change does not apply to Cases 1C, 2A, or 2B.

TABLE 4-17 CASE STUDY ACCIDENT COST ESTIMATES

Case Study	Marginal External Accident Cost per Truckload: Original ($)	Change in Sensitivity Analyses (%): Double Value of Life	Change in Sensitivity Analyses (%): Low Elasticity	Cost Under Original Assumptions ($/truckload-km)
1A	46	107	−83	0.13
1B	26	109	−83	0.06
1C	9	115	−64	0.03
2A	9	114	−64	0.00
2B	30	115	−64	0.01
3A	89	97	−82	0.02
3B	78	114	−65	0.02
4	12	71	−82	0.13

NOTE: Case study descriptions are as follows:

1A Grain shipment, Minnesota to Mississippi River port, truck via direct route
1B Grain shipment, Minnesota to Mississippi River port, truck via Interstate
1C Grain shipment, Minnesota to Mississippi River port, rail
2A Grain shipment, Minnesota to New Orleans, rail to Winona, barge to New Orleans
2B Grain shipment, Minnesota to New Orleans, rail to St. Louis, barge to New Orleans
3A Container freight shipment, Los Angeles to Chicago, via truck
3B Container freight shipment, Los Angeles to Chicago, via railroad
4 Local grocery distribution, Hartford, Connecticut, via truck

sumptions and data and the sensitivity of the subsidy estimates to changes in assumptions or data, the most critical gaps in understanding may be the relation of accident rate to traffic volume and the health costs of motor vehicle particulate emissions.

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ABBREVIATIONS

COE U.S. Army Corps of Engineers
EPA Environmental Protection Agency

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5

APPLICATIONS TO PRACTICAL POLICY PROBLEMS

Information about subsidies would provide a benchmark for determining the overall impact of government transportation programs on freight industry efficiency and whether the current structure of the freight industries is seriously out of balance. The information also would have practical value in guiding government decisions on user fees, investment plans, and environmental and safety regulations. Several types of applications are described in this chapter after three important limitations that must be recognized in applying estimates of subsidies are identified.

LIMITATIONS

The very severe limitations of the trial estimates presented have been stressed in this report; however, as will be described in Chapter 6, it would be feasible to produce reasonably reliable subsidy estimates in a somewhat more refined extension of the approach explored here. The estimates of whether freight users pay their way produced in such a study could be helpful as long as policy makers recognize that the estimates are bound to be uncertain, that they do not directly imply specific policies, and that practical and political limitations to policy reform can be accommodated.

Uncertain Estimates

Estimates of freight transportation subsidies are bound to include uncertainties or errors. Some of these uncertainties probably can be reduced by future research; the relationship between traffic volumes and accident rates, for example, although poorly understood today, appears to be a

highly researchable topic. Even apparently straightforward topics have proven surprisingly difficult, however, as illustrated by recent revisions (described in Chapter 3) to long-standing (and long-studied) estimates of the relationship between traffic volumes and average speeds. Moreover, many of the key uncertainties appear far more resistant to research, such as the risks and consequences of global warming.

Nevertheless, the fact that estimates are uncertain does not mean that it is impossible to use them responsibly. The key is to be mindful of the degree and character of the uncertainties involved. For example, if the conclusion that a particular category of shipment typically does or does not pay its marginal costs rests primarily on one cost component that is especially poorly understood and uncertain, policy makers should be cautious in their interpretation or use of the results. By contrast, if a shipment does or does not pay its way under a range of plausible assumptions about costs, then policy makers can be much more confident in their conclusions.

Explicit estimates of whether freight users pay their way, even if very uncertain, are needed because the alternative is implicit estimates. Assumptions, stated or unstated, about whether or not users are paying their way are central to all important policy debates in freight transportation. Advocates of restrictions on truck size and weight, for example, often argue that such policies are needed because large or heavy trucks do not pay for the full pavement, accident, and environmental costs that they impose on society. Opponents of restrictions make the opposite claims. Without explicit estimates, policy makers and the general public have little basis on which to judge these arguments. Yet choices are eventually made among the policy options, and these choices imply that government authorities accepted one set of assumptions about costs as more plausible than the others.

Indeed, explicit estimates may make it easier for public officials to recognize and cope with the uncertainties inherent in calculating whether users pay their way. Explicit estimates force policy analysts to be clear about their assumptions about key costs, and thus subject those assumptions to scrutiny, debate, and refinement. Disagreements about the estimates are inevitable given that the uncertainties are not likely ever to be completely resolved. The process of developing explicit estimates will narrow the range of disagreement. At the least, the source or cause of the disagreement will be clearer so that others can make more reasonable and independent judgments about whose figures are more credible.

Practical Constraints on Pricing

In the event that some freight users are not paying their marginal social costs, one obvious remedy is for the government to adjust fees, taxes, or other charges to close the gap. Such adjustments might pose practical difficulties, however, as noted in Chapter 2 and illustrated by the case studies in Chapter 4. Collecting charges that correspond to marginal social costs can be administratively complex and expensive, particularly because marginal social costs can vary greatly according to the specific route, equipment, timing, or direction of the freight movement. Charges set at marginal social costs do not necessarily generate enough revenue to finance the budgetary costs of the government agencies that provide transportation infrastructure or services. Finally, changes in freight user charges may be politically controversial, especially if large adjustments would be required to bring user payments in line with marginal social costs or if the imposition of new fees imposed administrative or time burdens on users.

These practical constraints do not mean that estimates of whether freight users pay their way cannot be useful. The constraints do not always apply. There will be situations, perhaps many, where collecting charges that closely approximate marginal social costs is administratively easy, consistent with government revenue needs, and politically acceptable.

Where completely closing the gap between user payments and marginal social costs is impractical, there usually will be more acceptable policy alternatives that achieve many of the same benefits. Charges that move fees toward marginal costs may have an efficiency payoff even if they do not make up the difference completely. Governments also wield a variety of policy instruments besides user charges that can affect the social costs or use of different freight modes, such as public infrastructure investments; environmental, safety, and motor vehicle size and weight regulations; and programs providing aid to private transportation industries. Information about the sources and magnitudes of subsidies and the potential efficiency benefits of reducing them is essential in assessing any of these pragmatic policy options.

Misuse of Estimates

Selecting the appropriate government response to problems arising from subsidies or external costs, however, will always require careful analysis. In particular, estimates of whether freight users pay their way do not

directly imply specific policy reforms. Under- or overpayment indicates a potential opportunity to improve performance, but additional analysis is necessary to identify what policy change, if any, would be best.

Consider, as an example, a finding that the users of a particular freight mode do not pay their full marginal social costs in certain circumstances. Suppose that it is politically unacceptable, administratively cumbersome, or otherwise impractical to levy an additional charge on those users. One might then infer that the use of the underpaying mode is excessive and should be suppressed, whereas use of other modes that do pay their way should be promoted.

Suppose, however, that further analysis revealed that freight users value the unique service characteristics of the underpaying mode so highly that they would have been willing to pay the full marginal cost if asked. Under such circumstances, it might be more efficient to allow the continued high usage of the underpaying mode rather than to force shippers to use alternatives that offer them inferior service.

Alternatively, suppose that analysis revealed that the social costs of the underpaying mode are high because it generates enormous air pollution or creates serious safety problems but that these costs could be significantly reduced at a fairly modest expense by equipping vehicles with additional emissions controls or safety features. Imposing charges based on these pollution or safety costs would cause freight operators to install the new equipment, since doing so would be cheaper than paying for the pollution and safety damage. But if such charges cannot be implemented, perhaps because they would be very complex to administer, then it probably would be more efficient to mandate installation of the emissions controls or safety devices rather than to otherwise suppress the underpaying mode.

The intent of these examples is not to argue that undercharging does not lead to excessive use—normally it does. However, the choice of which policy to pursue requires careful analysis, particularly if correcting the undercharging (or overcharging) directly is, for some reason, not practical.

POLICY APPLICATIONS

Within these general limitations, estimates of whether freight users pay their way can be applied in a variety of situations to support public policy decisions that affect freight efficiency. Applications include identifying promising areas for policy reform, refining existing user fees, guiding gov-

ernment investments and subsidies for freight services, and developing cost-effective regulations.

Note that none of these applications involves benefit-cost analysis comparing alternative freight modes and that none of the applications requires knowledge of the full benefits of particular freight transportation options. As explained in Chapter 2, the motivation for estimating external costs and subsidies is not to supplant private-sector decisions regarding freight mode or other freight technology options with government planning. The private-sector participants in freight markets know the benefits of these options and will make the best choices, so long as markets provide them with information about all costs.

Identifying Areas for Reform

A comprehensive examination of freight user payments and costs could identify the circumstances under which freight users are least likely to pay their way and thus where policy reforms might be most productive. If this analysis could be supplemented with projections of how freight markets would respond if external costs were internalized and subsidies eliminated, then it would be possible to estimate the efficiency losses to the economy from failures to charge users marginal social costs. These projected market responses might be derived from economic data on price elasticities of freight demand and mode choice as well as from technical information about equipment, logistical, or routing options available to shippers and carriers that would allow them to reduce the costs, once they were charged for them.

Such a benchmark analysis would indicate whether a major economic payoff could be expected if the technical, administrative, and political obstacles to eliminating the subsidies and internalizing the external costs could be overcome. It is possible today to predict qualitatively that if shippers and carriers paid prices closer to the marginal cost of freight shipments, the cost of freight transportation would decline and economic welfare would improve. But without estimates of whether freight users pay their marginal costs and how they would respond if they did, it is impossible to know whether the gains would be great or small relative to the total cost of freight, or whether they would be large enough to justify a major effort at reforming user fees and regulations, considering other priorities competing for government attention.

An important application of the benchmark analysis will be to decide whether government policies aimed at partial or incremental improvement

to freight efficiency are likely to have positive effects. For example, the U.S. Department of Transportation (DOT) has under way a new highway cost allocation study to examine the basis for federal highway user fees (FHWA 1995). The question that DOT will need to consider is whether the government can improve the efficiency of highway transportation by changing user fees to bring them more in line with government construction and maintenance costs while ignoring external costs of pollution, accidents, and congestion (not accounted for in conventional highway cost allocation studies). It is possible that user fees calculated considering government infrastructure costs alone would encourage changes in highway use that were undesirable when considered from the standpoint of all social costs.

The answer to this question depends on whether the freight transportation system is severely out of balance as a result of pervasive and large subsidies and external costs. If the benchmark study shows that imbalances are relatively minor, then the government can proceed with the traditional, pragmatic pattern of making periodic incremental adjustments to fees, regulations, and finance to curb problems as they are recognized. The small size of the estimated subsidies in most of the case studies in Chapter 4 suggests that the imbalances may prove minor, although a more comprehensive and detailed study is desirable. If, by contrast, the benchmark study shows that the distortions are severe (for example, if the failure of users to pay their way substantially alters the market shares of the freight modes), then incremental policy making may do more harm than good and fundamental reforms are needed. As described in Chapter 1, one motivation for conducting this study was criticism of some past Transportation Research Board policy studies recommending incremental liberalizations of truck size and weight limits on grounds that a broader perspective on costs and freight options was needed.

Refining Current User Fees

Although government user fees are primarily intended to finance highways, waterways, and other public transportation services, these fees do, as a by-product, affect transportation use and efficiency. Trucks pay various federal and state highway user fees, and tow operators pay a fuel tax whose revenues contribute to maintaining the waterways. New toll roads are being developed, and proposals for congestion pricing to manage the use of facilities are receiving more serious attention.

Existing freight transportation user fees and taxes often depart greatly from the ideal of marginal cost pricing. For example, truck fees do not vary with the level of congestion or the condition of pavement on the roads that the truck uses. Nevertheless, these taxes and fees affect the use of the transport system and probably already contribute to more efficient freight transportation, especially compared with the alternative of charging no user fees at all. Refinements within the established user fee scheme might lead to much greater efficiencies.

When reforms to existing user charges are being considered, it would be extremely helpful to supplement the traditional government cost allocation studies with explicit analyses of marginal social costs and potential efficiency gains. As explained in Chapter 2, highway and waterway cost allocation studies typically focus exclusively on government budget costs and ignore pollution, congestion, and accident costs. They typically group users into a few broad classes and attempt to determine whether each class as a whole pays taxes commensurate with the budget costs for which its members are responsible. An equitable allocation of the cost burden is the stated goal, and the studies generally do not consider the implications of alternative tax and financing systems for economic efficiency.

These traditional cost allocation studies have had some effect on federal and state tax policies. Moreover, many of the tax changes that these studies often recommend (e.g., registration fees more steeply graduated with vehicle weight and distance-based taxes that would bring fees more in line with costs) might, on balance, tend to increase incentives to use highway resources more efficiently, improving productivity and yielding economic benefits for the public as a whole.

The decision whether to adopt any of these tax reforms ought to depend in part on how great this economic payoff would be. The debate is usually dominated by arguments about fairness, however, and the question of public economic benefits is often obscured. The public interest would be clearer if the effects of alternative user tax schemes on overall economic efficiency in the freight industries were analyzed in cost allocation studies. This analysis would entail comparing marginal costs with user fees and projecting how facility users would respond to changes in the fees.

It is important to remember that user charge reforms that are too simplistic or crude may not necessarily improve the situation. For example, one study of external costs of road transportation proposed the imposition of a tax per liter of fuel equal to the average accident cost of highway

travel (Kågeson 1993). The problem with this type of broad-based externality tax is that it provides no targeted incentive to reduce accidents in the special circumstances in which risks are greatest except through the weak mechanism of slightly discouraging all road travel.

As discussed previously, all pricing schemes are to some extent approximate, trading off practicality of administration against the benefits of tailoring prices to costs. However, a poorly targeted tax may discourage more beneficial uses of the transportation system than harmful ones and so reduce economic welfare rather than increase it. Once again, understanding the market response to pricing is necessary to design a successful policy.

Guiding Investments and Subsidies

Government infrastructure investments and direct government subsidies to private carriers are other areas in which estimates of whether freight users pay their marginal costs could reveal opportunities for improved freight transportation efficiency. In the case of waterways, for example, government benefit-cost analyses have concluded that the potential savings from reduced lock congestion or delays is enough to justify substantial investments in increased capacity on the Upper Mississippi waterway system (COE 1992). But because these congestion costs are external, public investment to expand capacity may not be the most economically beneficial response. It is possible that, if waterway users were given the incentive through some form of congestion pricing, they would find ways to reduce delay costs by changes in schedule, equipment, routing, or freight mode, thereby reducing the magnitude of economically justifiable government capital investment. Evaluation of a capacity expansion proposal should assess the feasibility and likely effects of pricing to internalize the external costs of congestion, as an alternative to expansion or to finance expansion.

Developing Cost-Effective Regulations

Although pricing already plays a role in the finance and management of public infrastructure, the public response to external safety and environmental costs has been almost entirely through regulation. Programs to manage these costs through pricing appear unlikely to be implemented any time soon.

Assessments of whether users pay their way can be helpful in designing cost-effective regulations by identifying circumstances or categories of shipments for which environmental or accident costs are unusually high. The case study cost estimates illustrate the great variance of external costs depending on geographical area, route, vehicle characteristics, time of day, and other factors. Safety and environmental regulations targeting circumstances under which these external costs are relatively high would (assuming regulatory compliance costs are uniform) be more cost-effective than indiscriminate regulations. An example of such an analysis for truck emissions regulations would be to compare the effects of controls targeting extreme emitters in selected urban areas with the effects of controls applied more uniformly.

REFERENCES

ABBREVIATIONS

COE U.S. Army Corps of Engineers
FHWA Federal Highway Administration

COE. 1992. *Reconnaissance Report for Upper Mississippi River Navigation Study*. Economic Analysis, Rock Island District, Sept., Appendix B.

FHWA. 1995. Federal Highway Cost Allocation Study. *Federal Register*, Vol. 60, No. 28, Feb. 10, pp. 8109–8111.

Kågeson, P. 1993. *Getting the Prices Right*. European Federation for Transport and Environment, Brussels, Belgium, May, pp. 154–156.

6

RECOMMENDATIONS

The recommendations of the study committee call for research to improve information on the costs of domestic surface freight transportation and for application of this information in public decision making. Better cost information would be valuable for managing public roads and waterways and for directing safety and environmental regulatory programs. The committee did not evaluate specific policies for responding to the problems that may be caused by subsidies.

CRITICAL DATA GAPS

The case study results indicate that the following measurements relating to the impacts of freight transportation are among the most critical needs for producing reliable estimates of the efficiency of the freight industries. The U.S. Department of Transportation (DOT), together with the Environmental Protection Agency, should give high priority in its research programs to technical studies aimed at closing these information gaps.

- Measurement of the external safety cost of increased truck traffic. This will require measuring the relationship between traffic volume and accident rates and measuring average truck accident rates.[1]
- Measurement of the air-quality effects of a change in freight volume on a road, waterway, or rail line, especially the effect on particulate concentration. Understanding air quality effects will require the collection of in-use emissions data for a random sample of vehicles, statistically valid sample measurements of concentrations, refinements to models of the formation of secondary particulates, and information on the relative contributions of fugitive dust and other source categories to observed concentrations.

- Additional studies of the health effects of particulates, especially studies comparing the effects of particulates from different sources. A growing body of data suggests that particulates in general are a serious health risk and that diesel particulates are among the more hazardous because of their size distribution and composition. In the case studies, the estimated health effects of particulates account for most of the costs of air pollution from freight.
- Systematic measurement, for a variety of road environments, of the nonrecurring component of highway congestion delay and of truck passenger-car-equivalence ratings.
- Improved measurement of the marginal highway costs of truck traffic on a site-specific basis. Especially, the relationship of truck traffic to bridge fatigue cost and the relationship of highway agency maintenance and reconstruction practices to road user and agency costs should be determined.

EXPANDED CASE ANALYSIS

DOT should conduct an expanded analysis to estimate subsidies in U.S. surface freight transportation. Such a study would provide a benchmark for assessing whether existing policies affecting freight are, taken together, hindering or helping the efficiency of the freight industries and whether the freight market as a whole is seriously out of balance. By focusing on the effects of transportation policies on economic efficiency, the study would highlight policy options that tend to be overlooked, including pricing policies.

An expanded analysis would also allow the government to respond to the criticism, discussed in Chapter 1, that it is impossible to evaluate proposals for incremental change in regulations or taxes affecting freight without considering the global context of the overall performance of the freight market. It would in this way support analyses of truck size and weight regulation, cost allocation, and other issues that governments will be conducting in the future.

Finally, the expanded analysis would help federal and state transportation agencies interpret and respond to the results of recent studies by others that have attempted to estimate the external costs of transportation and that are influencing the debate over national transportation policy.

The study could be conceived as an extension of the case study estimates performed for this study, but it should include a representative sample of freight shipment cases and use more detailed and careful meth-

ods of estimating cost components. The basis for cost definitions should be those used in the case studies. The study would have three parts:

1. Identify subsidies that cause the prices of freight services to differ from costs and estimate the magnitudes of the price distortions. The case studies in this report addressed this step. The expanded case analysis will need to consider whether categories of possible external costs and subsidies not considered in the present study should be included.
2. Project the ways in which shippers and carriers would respond to potential policy changes to reduce subsidies, including changes in user fees and taxes, public investment, and regulation. Possible market responses include changes in the volume of freight, mode choice, and the technologies used by carriers. Some projection will be needed of how developments in vehicle and infrastructure technology will affect costs. This step can only be approximate, but it will be necessary to estimate the magnitude of the economic gain that would result from reducing subsidies.
3. Estimate distributional effects of reductions in subsidies, identifying categories of shippers, carriers, and the public that would gain or lose.

The expanded analysis does not have to be organized as a single effort conducted all at one time. Once the framework and objective are established, the effort can begin with a series of independent studies addressing specific cost questions such as those recommended in the preceding section, development of a case study data base, and development of methods to project shipper and carrier responses to changes in freight costs and user fees. When the components are available, they can be built into the full analysis.

CONSIDERING ECONOMIC EFFICIENCY IN PLANNING

When DOT, the state transportation departments, and the U.S. Army Corps of Engineers conduct cost allocation studies, studies of alternative user fee systems, and evaluations of investment proposals, they should routinely consider the effects of the structure of road and waterway user fees on freight transportation efficiency and consumer welfare and search for user fee schedules that improve economic efficiency. In considering changes in fee schedules, the government must recognize that penalizing beneficial uses of roads and waterways can cause as much economic harm as subsidizing nonbeneficial ones.

Cost allocation studies, undertaken by transportation agencies to advise legislatures on user fees, generally have not considered the implications of alternative tax and financing systems for economic efficiency.[2] The studies apply other criteria, often legislatively mandated, to evaluate alternative user fee schemes, primarily revenue adequacy and equitable treatment of the various classes of users. Considering the efficiency impacts of user fees is not precluded by these constraints; fee schemes can be compromises among competing requirements. The interests of the public as a whole would be made more clear if evaluation of user fee alternatives considered overall economic efficiency in the freight industries.

This analysis would entail comparing marginal social costs with user fees, projecting the responses of facility users to changes in the fees, and forecasting the effects of user responses on the benefits derived from freight transportation. Despite the uncertainties in such estimates that have been described in this study, enough is known about the costs of freight transportation that a consideration of efficiency can immediately begin to play a part in government decisions that affect freight efficiency.

Public transportation agencies should also consider whether user fees are encouraging the efficient use of facilities when they evaluate capacity expansion proposals. For example, the Corps of Engineers, in its planning for waterway system investment, should consider congestion pricing as an alternative or complement to capacity expansion and as a financing mechanism.

To incorporate the consideration of efficiency in the analysis of public infrastructure finance questions, a new perspective will be necessary. The responsible agency must first specify the objectives that it intends to accomplish through user fees. These objectives probably will include raising a required level of revenues, developing a fee structure that is perceived as fair by users and the public, ensuring that enforcement and administration are feasible, and promoting economic efficiency (for example, discouraging wasteful congestion delay or highway pavement wear). Second, the agency must specify alternative user fee schemes (for example, the current scheme, or schemes incorporating some use of new features such as tolls, congestion charges, or weight-distance charges). Finally, the agency must compare the options according to the criteria and pick the best compromise.

The committee does not endorse any particular policy to impose new charges on freight operators in an effort to capture external costs. This study did not evaluate the costs and benefits of possible alternative user fees and taxes. Simplistic approaches to attempting to recover external

costs by increasing freight carriers' fuel taxes or registration fees so as to generate revenue equal to an estimate of external costs almost certainly would harm efficiency. For example, charging congestion tolls reflecting immediate traffic conditions to vehicles at the actual time that they enter a congested highway might, in the future, as toll collection technology evolves, be an efficient way of managing congestion in the best interests of the public. However, estimating what an appropriate congestion fee would be on average, and then collecting equivalent revenues through a broad-based tax such as the fuel tax, would have virtually no effect on congestion but would harm efficiency by discouraging many worthwhile trips on uncongested roads for which the travelers were willing to pay the full cost.

Other barriers stand in the way of using taxes or user fees to reduce the inefficiency caused by external costs. First, the magnitudes of many costs are poorly known. Second, any new fee system, especially a complex one, could entail substantial administrative costs, and these costs would have to be shown not to outweigh the economic benefits of the more efficient use of transportation that would be the goal of the fees. Finally, it may often be ineffective or even counterproductive to impose a fee on one source of an external cost while ignoring other sources. Charging trucks but not cars for road congestion, for example, would be unjustifiable; charging transportation sources for air pollution without at the same time charging other sources and reforming the existing system of emissions controls would have unknown consequences for economic efficiency and public welfare.

However, the acknowledgment that pricing solutions would be difficult does not constitute an argument for not knowing the costs of freight. The economic losses caused by external costs and subsidies are real. Knowledge of the magnitudes of external costs and subsidies is essential for determining whether these losses are likely to be relatively great or small and whether practical government policies aimed at reducing such losses would have payoffs justifying their costs.

The important practical constraints on user fee policies—revenue requirements and considerations of administrative and political feasibility—do not preclude promoting efficiency through user fees. Considering the effect of user fees on economic efficiency does not demand an all-or-nothing policy choice: developing sophisticated, complex schemes versus ignoring efficiency altogether. For any two fee options under comparison, one will always be more efficient than the other—one will encourage economically beneficial use of the facility more than the other. These differences ought to be weighed carefully in decisions on tax policy.

NOTES

1. The problems of measuring average truck accident rates were addressed by another TRB study committee (TRB 1990).
2. The Federal Highway Administration's 1982 highway cost allocation study presents results of a macroeconomic model simulation of impacts of proposed changes in user charges (FHWA 1982, VI-83–VI-84). Such models predict the multiplier effects of changes in government or consumer spending but have no capability to predict the benefits of more efficient use of resources that could be encouraged by improved pricing. An appendix to the federal study (FHWA 1982, E-58–E-64) does present a simple estimate of the gain from more efficient resource utilization.

REFERENCES

ABBREVIATIONS

FHWA Federal Highway Administration
TRB Transportation Research Board

FHWA. 1982. *Final Report on the Federal Highway Cost Allocation Study*. U.S. Department of Transportation

TRB. 1990. *Special Report 228: Data Requirements for Monitoring Truck Safety*. National Research Council, Washington, D.C.

APPENDIX A

SHORT-RUN MARGINAL COST VERSUS MARGINAL COST WITH FACILITY EXPANSION

Marginal costs can be measured in the short run or in the long run. The short run is the period in which some inputs are fixed, usually the capital plant; the long run is the period in which all inputs can be adjusted optimally.

The distinction can be understood by considering the example of a highway. The short run is the period in which the basic capacity of the highway cannot be modified by adding lanes or other improvements. Thus the short-run marginal cost does not include the costs of acquiring right-of-way, grading, or constructing the road surface or structures (since such costs are fixed or sunk in the short run). The major components of short-run marginal cost of highway use are thus

1. The damage to the pavement caused by the passage of an additional vehicle,[1]
2. The traffic delays or congestion that an additional vehicle imposes on other highway users, and
3. The air and noise pollution and accident costs imposed on others by the additional vehicle.

In the long run the highway authority can accommodate more traffic by investing in increased physical durability or capacity. The major components of long-run marginal cost, therefore, are

1. The cost of increasing the durability of the pavement to withstand an additional vehicle without deteriorating (e.g., by increasing pavement thickness),
2. The cost of increasing highway capacity so that an additional vehicle does not slow highway speeds and add to congestion (e.g., by adding another lane), and

3. The air and noise pollution and accident costs that the additional vehicle creates for others. (Actually, the highway authority can also invest so as to avoid at least some of these cost increases as well with increasing traffic, for example, by building noise barriers or widening shoulders.)

If the investment in highway durability and capacity is optimal, short-run marginal cost equals long-run marginal cost and there is no conflict between the two concepts. In essence, the highway planner has two ways of accommodating more traffic: by tolerating additional pavement roughness and congestion or by investing in the facility to reduce the amount by which the extra traffic causes pavement deterioration or slows down other traffic. If short-run marginal cost exceeds long-run marginal cost, the road investment is too small because it would be cheaper to accommodate additional traffic by investing in greater roadway durability and capacity than by tolerating increased pavement roughness and congestion. Similarly, if long-run marginal cost exceeds short-run marginal cost, the road investment is too large because it would be cheaper to accommodate the extra traffic by tolerating more congestion and pavement damage than by increasing the level of investment. When long-run and short-run marginal costs are equal, the levels of pavement roughness, congestion, and investment on the road are just right.

Another way of stating this conclusion is that when the capacity of the transportation system is optimal, short-run marginal cost pricing will neither generate a profit nor necessitate a subsidy, because revenues collected from peak-period congestion tolls will equal the cost of providing capacity. An exception to this rule can arise because some transportation facilities can only be practically constructed to a minimum scale. For example, a road bridge must have at least one lane, and a river lock must be at least large enough to accommodate one vessel of the size used on the river. Because of this indivisibility, it is possible that a capacity expansion would be justified on a benefit-cost basis but would never be congested. Revenues from the optimum toll on such a facility would never cover its construction costs.

Most road investment in the United States today takes the form of incremental additions to a dense and heavily traveled network on which capacity can be regarded as continuously adjustable for all practical purposes. Expansion can be achieved by adding a new route paralleling several existing ones or, more typically, by alleviating bottlenecks at multiple points in the network by local widening, alignment adjustments, intersection redesign, signalization, or other incremental techniques. In this

setting, the indivisibility problem (the fact that certain kinds of highway facilities have some minimum practical size) does not stand as a significant obstacle to the expectation that short-run marginal cost pricing would exactly cover the cost of the optimum-scale network.

In some other cases, for example, a sparse rural road network or a waterway lock, the problem of indivisibility might sometimes justify subsidizing a minimum-capacity facility or, if a subsidy is impractical, charging fees greater than marginal cost.

NOTE

1. This can be measured either as the increase in operating and other costs imposed on subsequent motorists because of increased pavement roughness or the cost of earlier resurfacing required because the pavement is deteriorating more rapidly.

APPENDIX B

COST RECOVERY AND MARGINAL COST

Charges based on marginal social costs suffice to recover governmental infrastructure investment, maintenance, and operating costs if

1. Investment levels are approximately optimal (so that short-run marginal cost equals long-run marginal cost),
2. There are few economies or diseconomies of scale in investment (so that long-run marginal cost equals long-run average costs), and
3. Pollution external costs are modest (or just enough to offset any economies of scale in investment).

The first two conditions are often violated. As noted in Chapter 2, both over- and underinvestment are common among freight modes. Moreover, many infrastructure investments appear to be characterized by economies of scale or traffic density (so that long-run marginal costs are less than long-run average costs). This is particularly true of investments in highway pavement durability, since durability increases disproportionately with pavement thickness. Waterway capacity may also be subject to significant economies of density, although the available evidence is not conclusive. Railway and highway capacities appear to benefit from more modest economies of traffic density.

As a practical matter, short-run marginal cost allocation is most likely to fall short of government cost recovery on rural highways and lightly traveled waterways because of excessive current investments or because rural roads that are built to the least expensive practical scale have greater capacity than the traffic requires. Short-run marginal cost allocation is most likely to exceed government costs on urban highways because investments are constrained. Long-run marginal cost allocation may be closer to government cost recovery because the shortfall caused by economies of scale may be partially offset by pollution external costs.

Where cost recovery is desirable, pricing schemes can be designed that preserve the incentives of marginal cost pricing while still recovering budgetary costs. These schemes involve making up the shortfall between the revenues that would be derived from marginal cost-based fees and desired revenues by imposing additional fees selectively on those users whose behavior would be altered the least by the imposition of an added fee (CBO 1992, 5–8).

It is worth noting, however, that the railroads do recover their total firm costs from prices despite the presence of some economies of traffic density and claims by the railroads of excess capacity. This situation implies that railroad prices are, on average, above the short-run marginal cost for their vehicles and infrastructure.

REFERENCE

ABBREVIATION

CBO Congressional Budget Office

CBO. 1992. *Paying for Highways, Airways, and Waterways: How Can Users Be Charged?* Government Printing Office, Washington, D.C., May.

APPENDIX C

CASE STUDY COMPUTATIONS

The computations behind the case study cost estimates presented in Chapter 4 are outlined. The order of topics follows the order of the discussion of the cost categories in Chapter 3.

INFRASTRUCTURE

Highway Pavement

The method of estimating marginal pavement wear cost of truck traffic is similar to the methods used in recent studies of the Transportation Research Board (TRB 1990a; TRB 1990b) and the Brookings Institution (Small et al. 1989, 42). The TRB studies used a model of the relationship between pavement wear and traffic derived from the pavement design method of the American Association of State Highway and Transportation Officials (AASHTO 1986), which is based on data from the American Association of State Highway Officials (AASHO) Road Test, a test of the effect of truck traffic on pavement wear conducted in 1958. This model has two components:

- Relationships that predict—as a function of pavement structure (primarily thickness), weather, and soil condition—the expected number of passages of an axle of a standard weight of 18,000 lb (8165 kg) before the pavement surface deteriorates to a specified degree of roughness (the terminal pavement serviceability index, or PSI), as a result of cracking, rutting, and other forms of wear.
- Relationships for converting axles or axle groups of any weight into an equivalent number of standard axles. In the AASHTO model, the equivalency factor increases approximately as the fourth power of the weight; for example, a 9,000-lb (4082-kg) axle is approximately 1/16 of

an equivalent single-axle load (ESAL). That is, a pavement that could withstand 1 million passages of the 18,000-lb (8165-kg) standard axle before reaching a specified terminal serviceability rating could withstand 16 million passages of a 9,000-lb (4082-kg) axle before reaching the same rating.

The cost estimating method in the TRB studies assumes that when a road reaches terminal serviceability (determined by highway agency practice), it is resurfaced with a pavement overlay designed (according to AASHTO recommended design methods) to last a specified lifetime before reaching terminal serviceability again. The steps in the cost estimate follow:

1. Compute the change in ESALs from the change in traffic.
2. Compute each road's new remaining lifetime until it reaches its terminal serviceability and requires its next resurfacing.
3. Compute the new resurfacing thickness necessary to maintain the specified pavement lifetime under the new loading instead of the previous loading. (This step is necessary if the change in traffic is assumed to be a permanent increase in the rate of loads applied to the pavement rather than a single passage of an additional load.)
4. Compute the cost of the traffic change: the change in present value of the cost of future resurfacings resulting from changing the time until the next resurfacing and changing the cost of each future resurfacing.

As noted in Chapter 3, in this method user cost (i.e., the added time, vehicle maintenance, and fuel costs of traveling on a damaged road) can be ignored because the consequence of the practice of always resurfacing at the same terminal serviceability is that the average user cost over the life of the pavement is unaffected by a change in traffic volume, so marginal user cost is zero.

Also as noted in Chapter 3, the case study estimates do not include the change in the cost of routine, frequently performed maintenance such as minor pavement patching and guardrail and sign repair caused by a change in traffic.

These computations require models relating pavement life (measured in ESALs) to thickness as well as the cost of resurfacing to thickness. In the case studies, it is assumed that the pavement has been designed to carry the current traffic volume (ESALs per year). The cost of a resurfacing depends on the traffic volume on the road, because it is assumed that the highway agency designs the pavement to last the desired lifetime under

the expected traffic. However, empirically it is known that resurfacing cost is insensitive to the small changes in thickness necessary to accommodate widely differing traffic volumes.[1] Therefore, the case studies assume that the resurfacing cost per mile per lane is constant for all roads in each of six classes (urban and rural expressways, other arterials, and other roads).

Under these assumptions, the present value of the cost of all future resurfacings, per mile, is

$$C = c[1/(1 + i)^{Q/(A+E)}]\{1/[(1 + i)^L - 1]\}$$

and the rate of increase in C with decrease in Q is the marginal cost of an added ESAL mile:

$$-dC/dQ \approx iC/(A + E)$$

where

A = annual ESALs,
E = annual rate of pavement wear (measured in ESALs) that is independent of traffic,
Q = remaining life of existing pavement (ESALs),
L = customary interval between resurfacings (years),
c = cost per mile of resurfacing, and
i = real interest rate.

These two relations are used in the case studies to compute marginal pavement cost. The pavement cost computations were carried out in English units. To convert ($/mi) to ($/km), multiply by 0.621.

The parameter E, the non-load-dependent component of pavement deterioration, can be thought of as a weathering effect. It also sets a lower bound on the resurfacing durability that the highway agency will install—no matter how light truck traffic is on a road, the agency will always build and repave the road to withstand a loading of E. Establishing such a minimum design in the pavement cost computation is important for reflecting actual highway agency behavior.

The value of A in the previous formula is estimated from the Federal Highway Administration's (FHWA's) Highway Performance Monitoring System (HPMS) data on design features and traffic conditions on a random sample of roads that are reported by the states to the U.S. Department of Transportation (DOT) (FHWA 1992), for each case study road segment or similar segments (i.e., roads in the same state and road class). The

TABLE C-1 MARGINAL PAVEMENT COST PARAMETERS

	VALUE
Discount factor	1.05
Pavement design life (years)	7
Effect of environment (ESALs/year)	100,000

TABLE C-2 RESURFACING COSTS ($/LANE-MI)

	RURAL	URBAN
Interstate/freeways	105,000	115,000
Other arterials	94,000	103,000
Other roads	77,000	93,000

NOTE: ($/lane-mi) × 0.621 = ($/lane-km).

present remaining life, Q, is assumed to be half the design life. The other parameters are given in Tables C-1 and C-2. The values of *c* are from an FHWA model for predicting highway program expenditures (Jack Faucett Associates 1991a), updated to 1992 prices.

Highway Bridges

Marginal bridge fatigue cost is computed in the case studies as the number of loaded passages of the case study truck over steel bridges along its route multiplied by $0.01 fatigue cost per passage. The numbers of steel bridges on the case study routes are estimated from HPMS (Table C-3). User cost is ignored in the case study estimates.

Waterway Operation and Maintenance

Marginal cost is defined in the case studies as the change in U.S. Army Corps of Engineers operating and maintenance costs that would be caused by one additional shipment of the case study commodity. Although cost function specifications in past studies have usually measured system use in ton miles, Corps of Engineers cost data suggest that the magnitude of operating and maintenance cost appears to be associated mainly with the number of locks or lockage operations on a segment, so cost per lockage rather than per mile might be a more accurate representation of marginal

TABLE C-3 NUMBER OF STEEL BRIDGES PER MILE BY ROAD CATEGORY

	CONNECTICUT	MINNESOTA	OTHER STATES
Urban			
Interstate/freeways	1.269	0.824	0.894
Other arterials	0.152	0.150	0.157
Other roads	0.043	0.027	0.028
Rural			
Interstate/freeways	0.604	0.212	0.444
Other arterials	0.192	0.077	0.172
Other roads	0.066	0.044	0.062

NOTE: (bridges/mi) × 0.621 = (bridges/km).

cost. An estimate from a regression equation using segment operating and maintenance cost and traffic data for 1990 (COE 1992a, Tables 3, 22, and 25) indicates that marginal cost is $0.03/ton/lock passage plus $0.0002/ton-mi [$0.03/(metric ton)/lock passage plus $0.0001/(metric ton–km)]. This is an oversimplified cost model, based on only nine data points (for the nine major administrative divisions of the system), but the results are not implausible.

Note that with this specification, marginal operating and maintenance cost is computed by calculating the number of ton lockages on the loaded, downstream leg of the trip and multiplying by $0.03. The empty backhaul mileage does not explicitly enter the calculation, since the $0.03 implicitly includes the cost of empty backhauls.

One of the case study summary tables in Chapter 4 (Table 4-6) also shows average and allocated waterways costs for comparison with marginal costs. The average waterways expenditures are based on the following Corps of Engineers data (COE 1992a, Tables 24 and 25):

SEGMENT	1990 AVERAGE OPERATING AND MAINTENANCE COSTS ($/TON-MI)
Upper Mississippi	0.0050
Middle Mississippi	0.0014
Lower Mississippi	0.0006

[To convert ($/ton-mi) to ($/metric ton–km), multiply by 0.685.] Average

annual construction expenditures on all Corps of Engineers inland waterways during 1980–1991 were $0.0016/ton-mi [$0.0011/(metric ton–km)].

The allocated costs presented in the case study tables are computed as 77.4 percent of average annual construction expenditures plus 80.2 percent of average annual operating and maintenance costs. The allocation is between commercial navigation and other purposes of Corps of Engineers facilities (recreational boating and flood control) and is consistent with the definition of allocated cost used in Corps of Engineers cost allocation studies. The allocation percentages are taken from cost allocation studies of both the Upper and Lower Mississippi (COE 1980, Tables 9, 10, 12, and 13).

CONGESTION

Highways

In the case studies, marginal external delay cost per vehicle mile on a road segment, assuming free-flow conditions, is calculated from a set of typical speed-volume curves (Figure C-1).[2] The curves come from a simulation model used by FHWA to evaluate the benefits of road improvement programs (Margiotta et al. 1994). They are somewhat steeper than the recent *Highway Capacity Manual* curves discussed previously. Truck passenger car equivalencies (PCEs) are selected from the *Highway Capacity Manual*. Traffic volume estimates for the case study roads are developed from the HPMS data base.

Volume on most roads varies markedly over the course of a day. Hourly volume data are not reported in HPMS. In the case studies, plausible hourly variations (Table C-4) are assumed on the basis of distributions reported in the *Highway Capacity Manual* (TRB 1994). Each case study truck trip is assigned a starting time, and delay cost is computed for each road segment along the trip according to the time the truck arrives at that segment.

In the case studies, it is assumed that nonrecurring delay is 1.5 times recurring delay (computed from the slope of the speed-volume curve) on all roads, so marginal external delay cost per mile of truck travel is computed as 2.5 times marginal external recurring delay. This assumption is speculative, because no data are available concerning nonrecurring delay costs on rural roads or on marginal nonrecurring delay. Computations

TABLE C-4 HOURLY TRAFFIC VOLUME AS A FRACTION OF ANNUAL AVERAGE DAILY TRAFFIC, BY TIME PERIOD

PERIOD	URBAN	RURAL
6:00 a.m.–10:00 p.m.	0.070	0.052
10:00 a.m.–3:00 p.m.	0.061	0.064
3:00 p.m.–7:00 p.m.	0.081	0.073
7:00 p.m.–6:00 a.m.	0.027	0.032

NOTE: The sum of the hourly fractions over 24 hr is greater than 100 percent because traffic on weekdays is heavier than the average traffic on all days.

were carried out in English units. To convert hours per mile to hours per kilometer, multiply by 0.621.

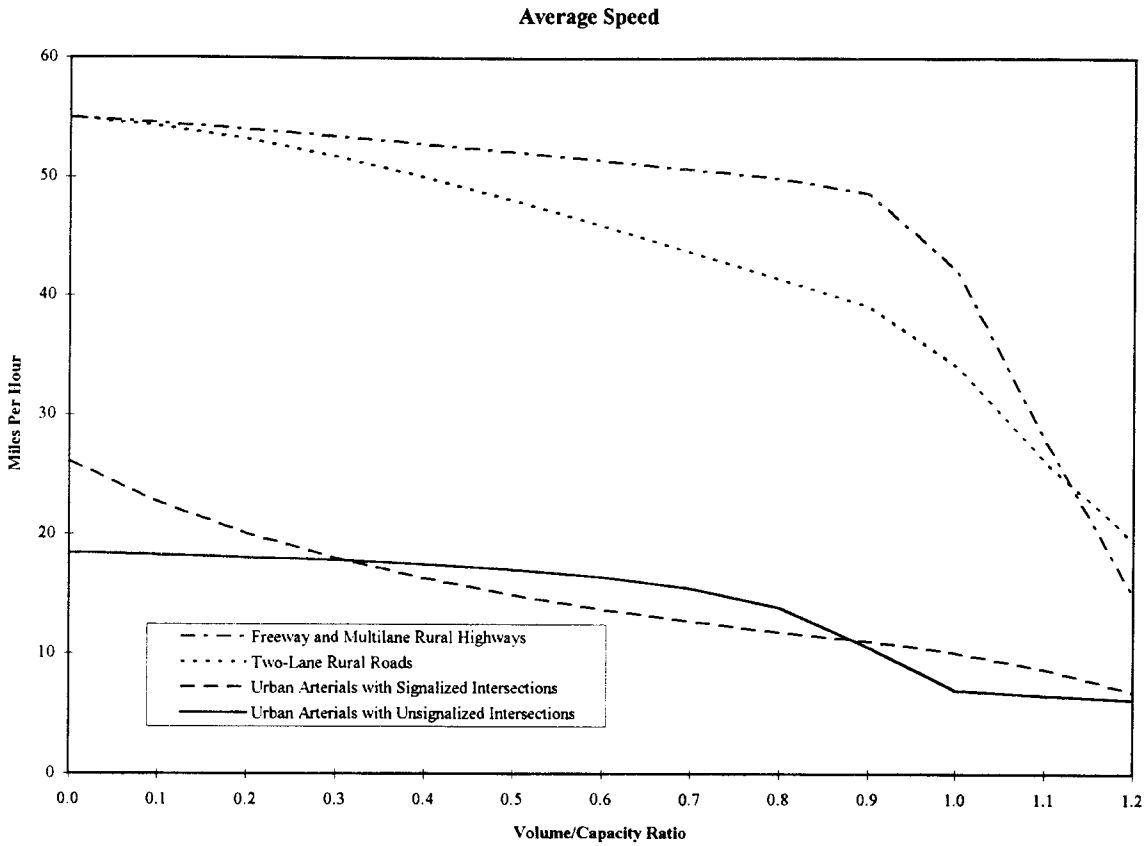
The value of travel time used in the case studies, $12/PCE-hr, is taken from a literature review (Miller 1989).

Waterways

In the waterways case study, an estimate is made of the marginal external delay cost of a barge tow transiting each lock along the case study route (Locks 6 through 26 on the Upper Mississippi). The computation uses a simple queueing model and assumes that processing time through the lock and vessel arrival times are random and independent. Under these assumptions, the marginal external cost per lock transit (in units of time) is $UP/(1 - U)^2$, where P is the processing time in the lock (once the tow's turn comes) and U is the lock utilization rate, the ratio of average time between arrivals to P (COE 1992b, B-23). Values of U and P for each lock are reported by the U.S. Army Corps of Engineers (COE 1992a, Appendix B).

The result of the computation is an estimate of marginal delay of 223.3 hr. That is, adding one extra tow traveling through Locks 6 through 26 results in 223.3 hr of additional travel time for all tows in the system. Of this, 47.7 hr is the time it takes the added barge itself to go through the locks. Therefore, the marginal external delay is 176 hr.

Barge delay is valued at $382/hr per 22,500-ton cargo weight tow, based also on Corps of Engineers data (COE 1992b, Table B-11) (22,500


Average Speed
Miles Per Hour
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Volume/Capacity Ratio
Freeway and Multilane Rural Highways
Two-Lane Rural Roads
Urban Arterials with Signalized Intersections
Urban Arterials with Unsignalized Intersections

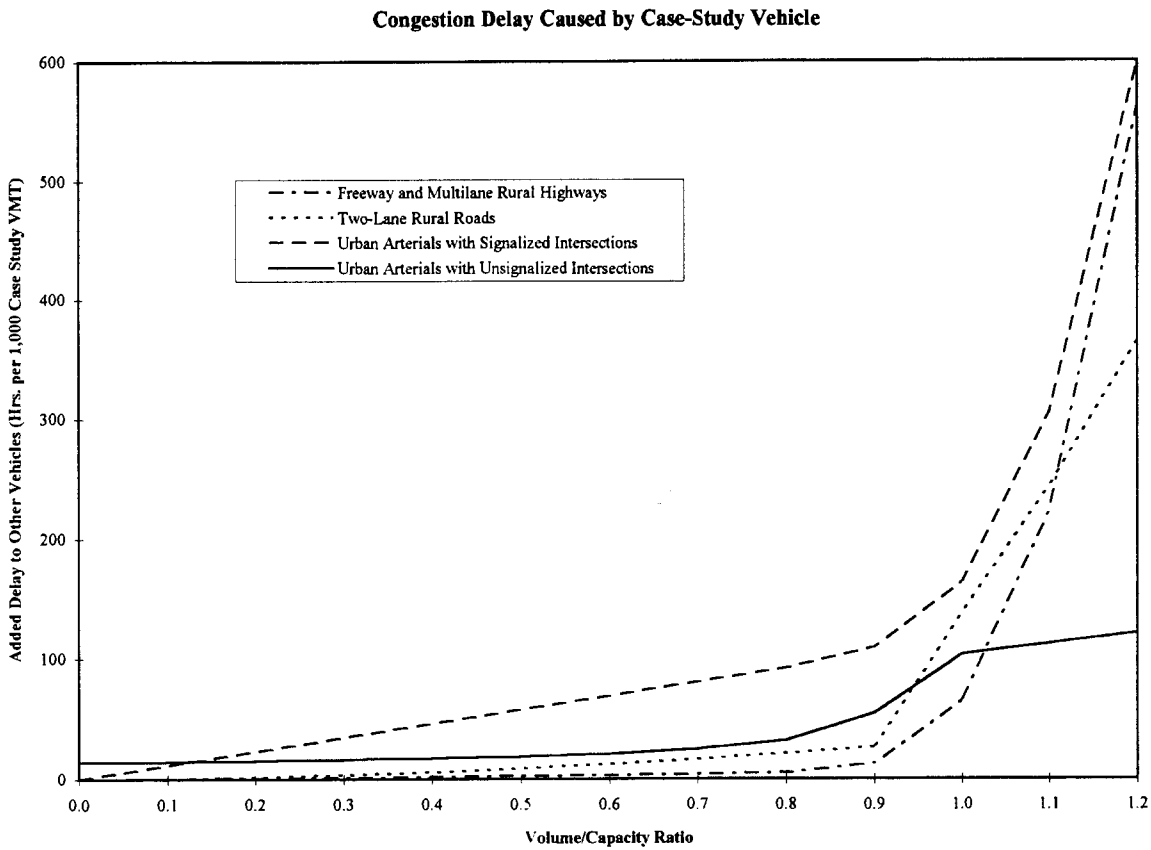


FIGURE C-1 Case study volume-speed (*top*) and volume-delay (*bottom*) relationships. Note: (miles per hour) × 1.61 = (kilometers per hour); (hours per 1,000 case study VMT) × 0.621 = (hours per 1,000 case study vehicle kilometers).

tons = 20 412 metric tons). Allowance is made for recreational boats in the marginal delay cost computation by calculating a weighted average value of delay time depending on the commercial/recreational mix in the queue. The value of delay for a lockage of recreational boats is assumed to be $90/hr. No data were located for the value of recreational boat delay. Recreational boat lockages usually contain several boats; $90/hr corresponds to six boats in a lockage, each of which values its time at $15/hr.

The value of 1 hr of delay for each lock is computed as ($90) × (fraction of lockages that are recreational at the lock) + ($382) × (fraction of lockages that are nonrecreational at the lock).

The computation of the marginal external cost per trip assumes empty backhaul; that is, the cost of delay on the backhaul is attributed to the fronthaul cargo.

ACCIDENTS

Highways

The case study estimates of marginal external accident cost of truck traffic, following the general method outlined in Chapter 3, proceed in the following steps:

1. Estimate the relationship of accident rate to truck volume and car volume on the road for each of the following six accident categories:
   - –Truck involvements in fatal and nonfatal truck-only accidents (including accidents involving one truck and no other vehicle and involvements in truck-truck accidents),
   - –Truck involvements in fatal and nonfatal truck-nontruck accidents (including truck-car, truck-cyclist, and truck-pedestrian), and
   - –Vehicle involvements in fatal and nonfatal accidents not involving a truck.
2. From these six relationships, predict the change in the expected number of each of the six kinds of accident involvements, per added truck trip.
3. Estimate the average dollar cost per occurrence of each of the six categories of accident and compute the marginal cost of an added truck trip as the average cost per occurrence times the net change in the number of occurrences of each of the six kinds of accident involvements.
4. Separate each of the six marginal costs into internal and external components. The internal cost of an accident to the truck operator is the

sum that the operator would have been willing to pay to avoid the accident. It is reasonable to assume that truck operators' marginal (internal) accident costs equal their average accident costs. The marginal external cost is the difference between marginal cost and marginal internal cost.

Accident Involvement Rate Versus Traffic Volume Relationships

Data are not available for estimating the relationships between accident involvement rate and traffic volume that Step 1 calls for. For the purpose of illustrating a marginal cost calculation in the case studies, the following assumptions are made concerning the six required relationships. The assumptions are plausible but speculative. A sensitivity analysis in Chapter 4 illustrates how altering the assumptions affects the estimates of marginal external accident costs.

Truck Involvements in Truck-Only Fatal Accidents

The rate of truck involvements in truck-only fatal accidents (per truck mile) is assumed to be independent of the level of truck traffic volume. This assumption may be justified on two grounds: the average rate is small to begin with compared with other fatal involvement rates, so the absolute size of any change in magnitude of the rate with change in truck volume might be expected to be relatively small also; and any tendency for the rate to increase because of increasing traffic volume might be offset by the tendency for a larger share of accidents to be multivehicle as volume increases.

The implication of this assumption is that there is no marginal external cost of injury or death to truck occupants or damage to trucks or truck cargoes in truck-only accidents. If a truck is added to the traffic on a road, the risk to other trucks does not change, and all the cost of the risk of damage to the added truck or of injury or death to its occupants is internal, that is, borne fully by the operator (the owner) of the added truck.

The rationale for classifying the cost of death or injury to the truck driver as entirely internal from the standpoint of the truck owner is the assumption that the driver is compensated for the risk of his or her occupation through wages and employer-paid benefits (or through business income, if the driver owns the truck).[3] However, if by adding a truck trip to a road, a carrier increases the risk of injury to truck drivers employed

by other carriers, part of this added cost may be external to the carrier adding the truck trip.

If the rate of truck involvements in truck-only accidents is constant and the volume of truck traffic increases, the number of truck-only accident involvements will increase. Any cost of these added involvements that is not paid for by truck operators is a marginal external cost of added truck travel. The most important cost in this category may be delay costs imposed on other road users by an accident. Damage to the roadway or medical services for which the truck operator is not held liable are also in this category.

Truck Involvements in Truck-Nontruck Fatal Accidents

The rate of truck involvements in truck-nontruck fatal accidents (per truck mile) also is assumed to be independent of the level of truck traffic volume. This assumption implies that the rate of car involvements in truck-car accidents per car mile rises with increasing truck volume. It might therefore be regarded as a middle case between two extreme assumptions: no change in car risk as truck traffic increases, or the more rapid increase in car risk that would occur if the rate of truck involvements in truck-nontruck accidents rose with increased truck volume.

Specifically, according to this assumption, the rate of car involvements in car-truck fatal accidents per car mile increases proportionately with truck traffic volume on the road. (That is, the elasticity of this rate with respect to truck volume is 1. The effect of assuming a lower elasticity is illustrated in the sensitivity analyses described in Chapter 4.)

Further, under this assumption, if r_{tcf} is the rate of truck involvements in fatal truck-car accidents per truck mile (assumed constant), and c_{tcf} is the average cost to all parties of a truck-car fatal accident per truck involvement, then $r_{tcf}c_{tcf}$ is the marginal cost per truck mile of truck-car fatal accidents. If a is the average fraction of the total cost of a truck-car accident for which a truck operator is liable, then the marginal external truck-car fatal accident cost is $(1 - a)r_{tcf}c_{tcf}$ per truck mile.

Involvements in Fatal Accidents Not Involving a Truck

The rate of fatal accident involvements per nontruck vehicle mile is assumed to increase linearly with traffic volume, measured in units of PCE per hour. That is, the rate is assumed proportional to $V_c + (\text{PCE})V_t$, where

V_t and V_c are the volumes of trucks and nontrucks, respectively, and PCE is the passenger car equivalency factor of a truck. (For example, if PCE = 2, a typical value, then the effect on the nontruck accident involvement rate of adding a truck to the traffic stream is twice the effect of adding a car.)

In the case studies, the slope of the linear relationship between involvement rate and volume is assumed to be $+r_0/(4C)$, where r_0 is the rate of vehicle involvement in nontruck fatal accidents at very low traffic volume and C is the design capacity of the road. That is, it is assumed that the involvement rate increases by 25 percent between very low volume and volume equal to the capacity of the road. A rate of increase of this magnitude is not inconsistent with the limited empirical findings available.

According to this assumption, as the volume of truck traffic on a road increases, the risk to a car occupant, per mile of car travel, of being involved in a car-car fatal accident increases. The marginal cost of this risk, per mile of truck travel, is $(\text{PCE})(r_0/4)(V/C)c_{ccf}$, where c_{ccf} is the average cost of a fatal accident not involving a truck per vehicle involved. This marginal cost is entirely external from the standpoint of the truck, since a truck would rarely be liable for the cost of an accident in which it was not involved.

Nonfatal Accident Involvements

The rates of truck involvement in truck-only nonfatal accidents per truck mile, truck involvement in truck-nontruck nonfatal accidents per truck mile, and vehicle involvement in nonfatal accidents not involving a truck are assumed to be independent of truck volume. The costs of nonfatal involvements are small relative to the costs of fatal involvements, so the assumption hardly affects the estimate of the magnitude of the marginal accident cost.

Complete Marginal Cost Computation

The preceding string of assumptions is equivalent to asserting that the change in external (from the point of view of the truck operator) accident cost caused by adding a truck to the traffic on a road, per mile of travel of the added truck, is

$$(1 - a_{tc})(r_{tcf}c_{tcf} + r_{tci}c_{tci} + r_{tcp}c_{tcp}) + (\mathrm{PCE})(r_{ccf}/4)(V/C)c_{ccf} + (1 - a_{tt})r_{tt}c_{tt}$$

where

r_{tcf}, r_{tci}, r_{tcp} = rates of truck involvements in truck-nontruck fatal, injury, and property-damage-only accidents on the road;

c_{tcf}, c_{tci}, c_{tcp} = corresponding average costs per truck involvement;

r_{ccf} = prior rate of vehicle involvements in nontruck fatal accidents on road (assumed to be equivalent to the very low volume rate r_0);

c_{ccf} = average cost of a nontruck fatal accident per vehicle involved;

a_{tc} = average fraction of total cost of truck-car accident for which truck operator is liable (assumed to hold constant regardless of severity);

(V/C) = volume/capacity ratio;

r_{tt} = rate of truck involvements in truck-only accidents per truck mile; and

$(1 - a_{tt})c_{tt}$ = average uncompensated cost to the public of a truck-only accident, per truck involved; this cost is assumed, as an approximation, to include only delay costs.

This formula is used in the case studies to compute the marginal external cost of truck travel. Computations were carried out in English units. To convert involvements per mile or $/mi to involvements per kilometer or $/km, respectively, multiply by 0.621.

In the case studies, for computational simplicity, delay caused by accidents is included as a part of the nonrecurring delay component of congestion cost rather than as a part of accident cost; however, for consideration of pricing policies, including it with accident cost might be more appropriate. Average accident delay cost is small compared with other accident costs and is a small component of nonrecurring delay, most of which is attributable to breakdowns and other nonaccident events.

Accident Involvement Rate and Cost Data

For the involvement rates needed in the marginal cost formula, the case studies use national average involvement rates by vehicle type and road class derived from U.S. Department of Transportation (DOT) annual data (Tables C-5 and C-6) (NHTSA 1991, Tables 16–19; FHWA 1990, Table

TABLE C-5 COMBINATION TRUCK AVERAGE ACCIDENT INVOLVEMENT RATES (PER 100 MILLION VEHICLE-MI) BY ROAD CATEGORY

	FATAL	INJURY	PROPERTY DAMAGE ONLY
Urban			
Interstate/freeways	2.83	94.10	304.77
Other arterials	3.45	114.54	371.00
Other roads	4.81	159.97	518.15
Rural			
Interstate/freeways	1.82	10.54	27.57
Other arterials	7.12	41.12	107.55
Other roads	5.37	31.04	81.18

NOTE: (involvements per 100 million vehicle-mi) × 0.621 = (involvements per 100 million vehicle-km).

TABLE C-6 PASSENGER CAR AND SINGLE-UNIT TRUCK AVERAGE FATAL ACCIDENT INVOLVEMENT RATES (PER 100 MILLION VEHICLE-MI) BY ROAD CATEGORY

	RATE
Urban	
Interstate/freeways	1.36
Other arterials	1.22
Other roads	1.65
Rural	
Interstate/freeways	1.31
Other arterials	2.79
Other roads	3.42

NOTE: (involvements per 100 million vehicle-mi) × 0.621 = (involvements per 100 million vehicle-km).

VM-1). Average accident involvement rates are known to vary substantially with time of day. It would be desirable in a more thorough case study analysis to incorporate this effect.

A 1991 study by the Urban Institute for FHWA is the source of highway accident cost data for the case studies (Miller et al. 1991). The study

evaluates deaths and injuries on the basis of a review of past studies that estimated individuals' willingness to pay for reductions in their own risk of injury or death—for example, purchases of automotive safety equipment, wage premiums for dangerous jobs, or trade-offs between convenience and risk in using seat belts or choosing driving speed. The study also estimates traffic delay costs of accidents and costs by vehicle type and road class. The study's estimates of the average comprehensive cost of an accident (i.e., the average cost including casualties, property damage, and delay) are as follows:

ACCIDENT TYPE	COST ($ THOUSANDS)
Fatal (per fatality)	2,300
Nonfatal injury (per injury)	46
Truck-involved property damage only (per accident)	11

The fatal accident cost is based on a valuation of one fatality at $2.2 million, and other costs averaging $100,000/fatality in fatal accidents. The averages are intended to reflect the costs of all crashes involving losses, "excluding minor dents and scratches," whether or not reported to police or insurers. On the basis of the DOT accident data, fatalities per fatal involvement were assumed to be 1.1 and injuries per injury involvement, 1.4.

According to Census Bureau data, for-hire trucking and courier services spent $2.3 billion/year during 1989–1991 for public liability and property damage insurance (DOC 1993, Table 5). This expenditure may be compared with the total cost to parties other than the trucking companies of accidents involving their trucks in order to estimate a_{tc}, the ratio of truck operator accident costs to total costs in truck-nontruck accidents. There are several problems in making this comparison:

- It is difficult to separate out accidents for the set of trucks to which the reported insurance cost applies from available accident data.
- The insurance covers liabilities other than those arising from traffic accidents, although for this industry, traffic liability must surely account for nearly all the total. (The $2.3 billion cost reported does not include workers' compensation or insurance for loss of company property or

cargo. For the purpose of the calculation that follows, it is appropriate to exclude these insurance costs.)

- The reported insurance premiums exclude part of the cost of carrier self-insurance (including self-insurance to cover policy deductible amounts).
- An unknown share of these insurance premiums is insurance company overhead (i.e., the difference between premiums and claims). This overhead is a component of the cost of truck accidents.

Using the Urban Institute study estimates of average accident costs, it may be estimated that the total cost of traffic accidents involving for-hire, cargo-carrying trucks in 1989 was as follows:

ACCIDENT TYPE	COST ($ BILLIONS)
Truck occupant injury and death	2.2
Truck and cargo property damage	1.3
Other injury and death	9.3
Other property damage	1.3
Total	14.1

The total of all internal costs in 1989 for which data are available is as follows:

ACCIDENT COSTS	COST ($ BILLIONS)
Truck occupant injury and death	2.2
Truck and cargo property damage	1.3
Liability insurance premiums	2.3
Total	5.8

The ratio of these internal costs to the total is 5.8/14.1 = 41 percent.

Of course, this ratio would not be 100 percent even if the courts evaluated injury and death the same as the Urban Institute study does and victims were always compensated, since the courts apportion liability among all the involved parties so that it sums to 100 percent.

If it is assumed that the 41 percent ratio holds at the margin and is applicable to all types of truck-involved accidents, and the deficiencies in the calculation are ignored, then $a_{tc} = 0.41$ in the expression for marginal external accident cost of truck travel. This value is used in the case studies.

The computation of the 41 percent ratio ignores the unknown costs of insurance company overhead as an additional social cost (although it

might be argued that willingness to pay to avoid risk includes at least some of this cost) and trucking company self-insurance as an additional component of private cost. If half of premiums (i.e., $1.15 billion annually) is assumed to be overhead and self-insurance costs are assumed to be equal to premiums (i.e., $2.3 billion annually), the ratio becomes (5.8 + 2.3)/(14.1 + 1.15) = 53 percent.

Rail and Waterways

To estimate the marginal external accident cost of rail freight traffic, the following assumptions concerning accident rate relationships and costs can be made:

- All costs of damage to railroad property and cargo and of injury to railroad employees are internal. Note that unlike the truck case, this assumption does not depend on the form of the relationship between rail accident rates and rail traffic volume. Instead, it is a consequence of the railroads' responsibility for their own right-of-way.
- The frequency of rail accidents that cause loss to parties other than railroads or railroad employees (e.g., grade-crossing accidents) is proportional to rail ton miles. That is, the marginal cost of such accidents is equal to the average cost.
- Railroads compensate owners for all property damage caused by rail accidents.

Under these assumptions, the marginal external accident cost of rail freight, per ton mile, is

$$(1 - a_r)(r_{rf}c_{rf} + r_{ri}c_{ri})$$

where

r_{rf}, r_{ri} = rates of rail accident-related fatalities and injuries per rail ton mile, respectively;

c_{rf}, c_{ri} = corresponding average costs per fatality and injury, respectively; and

a_r = average fraction of total cost of fatality or injury to nonrailroad employees that is paid for by the railroad.

Computations were carried out in English units. To convert $/ton-mi to $/(metric ton–km), multiply by 0.685.

Rail accident rates come from DOT data on railroad fatalities and injuries by employee/nonemployee status (RSPA 1993, Table 8) and industry ton mile data (AAR 1992, 3, 5) (Table C-7). The estimates assume that the average cost of a railroad fatality or injury is the same as for highways. The parameter a_r is assumed to be the same for rail accidents as for truck accidents, about 78 percent if the cost of a fatality is taken to be $2.2 million.

As a speculative estimate in the case studies, the marginal external cost of barge accidents is set equal to 10 percent of the average cost of barge carrier employee injuries and fatalities per ton mile (DOT 1993).

AIR POLLUTION

As described in Chapter 3, the steps in estimating the change in the cost of air pollutant emissions caused by a change in freight traffic are to predict

1. Change in emissions,
2. Resulting change in ambient air quality,
3. Change in exposure of humans and property,
4. Physical effects of the change in exposure, and
5. Economic value of the effects.

In the case studies, this five-step procedure was followed to estimate the costs of all pollutants except greenhouse gases. Global costs of greenhouse gases emissions were estimated more simply, on the basis of published estimates, as $3.14/ton ($3.46/metric ton) of carbon dioxide (CO_2) emit-

TABLE C-7 RAIL AND BARGE FATALITY AND INJURY RATES

	TON-MILES (MILLIONS) (1991)	TOTAL FATALITIES (1991)	TOTAL INJURIES (1991)	FATALITY RATE (PER MILLION TON-MI)	INJURY RATE (PER MILLION TON-MI)
Rail	1,153,151	1,194	23,460	0.001	0.02
Barge	1,251,000	8	23	0.000006	0.000018

NOTE: (ton-mi) × 1.46 = (metric ton–km); (accidents per million ton-mi) × 0.685 = (accidents per million metric ton–km).

ted (Harrison et al. 1993, Table 63), or, equivalently, $0.035/gal ($0.009/L) of fuel consumed. Burning diesel fuel produces other greenhouse gases, but the predominant contribution is CO_2 emissions.

Methods and sources of data for performing each of these steps for pollutants other than CO_2 in the case studies are described in the following paragraphs.

Emissions

Emissions from a truck depend on engine size and design, vehicle condition, speed, frequency of acceleration and deceleration, and other factors; they can vary greatly among vehicles and operating conditions. The Environmental Protection Agency (EPA) and others have developed emissions models to simulate these variations to predict aggregate emissions under typical conditions. For the case studies, average emissions of a diesel heavy truck were estimated with the EPA MOBILE 5 model as a function of speed (Table C-8). The estimates assume the national average age distribution of trucks projected to prevail in 1994.

Rail emissions are estimated in the case studies by first estimating fuel consumption (see the section to come on energy costs) and then multiplying fuel consumption by a set of average emissions-per-gallon factors for nitrogen oxides (NO_x), hydrocarbons, carbon monoxide (CO), sulfur oxides (SO_x), and particulates (Booz, Allen and Hamilton 1990, Exhibits 4-4 and 5-5) (Table C-9). Barge towboat emissions estimates assume emissions per gallon of fuel consumed are the same as for rail.

TABLE C-8 TRUCK POLLUTANT EMISSION RATES (G/MI)

TRUCK SPEED (MPH)	PM10	NO_x	CO	VOC	SO_x
10	1.43	18.96	22.26	2.36	0.58
20	1.43	14.52	12.13	2.36	0.58
30	1.43	12.81	7.93	2.36	0.58
40	1.43	13.03	6.22	2.36	0.58
50	1.43	15.28	5.85	2.36	0.58
60	1.43	20.64	6.61	2.36	0.58

NOTE: (g/mi) × 0.621 = (g/km); (mph) × 1.61 = (km/hr).

TABLE C-9 RAIL AND BARGE FUEL CONSUMPTION AND POLLUTANT EMISSION RATES

	FUEL CONSUMPTION (GAL/TON-MI)	PM10 EMISSIONS (g/GAL FUEL)	NO_2 EMISSIONS (g/GAL FUEL)	CO EMISSIONS (g/GAL FUEL)	VOC EMISSIONS (g/GAL FUEL)	SO_2 EMISSIONS (g/GAL FUEL)
Rail-container	0.0033	5.1	232.2	30.9	9.9	16.9
Rail-grain	0.0020	5.1	232.2	30.9	9.9	16.9
Barge	0.0020	5.1	232.2	30.9	9.9	16.9

NOTE: (gal/ton-mi) × 2.59 = (L/metric ton–km); (g/gal) × 0.264 = (g/L).

The computation of concentration changes, described later, requires data on the total primary annual emissions of each pollutant by all sources in the region of the case study freight movement. This computation was performed for each rural county and metropolitan area through which each case study freight movement passes. Unpublished county-level data on emissions of particulate matter less than 10 microns in diameter (PM10) were obtained from EPA. For pollutants other than PM10, county-level emissions were estimated as county population times U.S. average emissions per capita for the pollutant (Table C-10).

Concentration

Atmospheric concentration depends on the rates at which pollutants are emitted, the rates at which they are created and destroyed through atmospheric physical and chemical processes, the rates at which they are transported by vertical and horizontal air movements into and out of the location under study, and rates of settling of solid pollutants from the atmosphere. Sophisticated models of the relationship of pollutant concentration to emissions must explicitly account for each of these processes. However, simple estimates of effects of changes in emissions, suitable for purposes such as these case studies, often are made by assuming that concentrations in an air mass are linearly related to the rate of emissions into the air mass—that is, that NO_2 concentration varies linearly with NO_x emissions, CO with CO emissions, and ozone with hydrocarbon or NO_x emissions. These may be reasonable simplifications for NO_2 and

TABLE C-10 TOTAL EMISSIONS FOR UNITED STATES

	ANNUAL EMISSIONS (MILLIONS OF TONS) 1992	EMISSIONS PER CAPITA (TONS)
NO_2	23.15	0.0908
CO	87.18	0.3420
VOC	22.73	0.0892
SO_2	22.73	0.0892

NOTE: (tons) × 0.907 = (metric tons).

CO, but questionable for ozone (Horowitz 1982, Chapter 3; EPA 1993a, 9–20).

The case studies assume that concentrations are proportional to emissions rates. That is, the percentage change in the ambient concentration of a pollutant in a region resulting from a change in emissions of the pollutant (or its precursors) during a year is estimated to be equal to the percentage change in annual emissions. Ozone concentration is assumed proportional to NO_x emissions, a poor assumption. However, in the cases, ozone is a minor contributor to marginal pollution costs.

The case studies apply the proportional formula to compute the change in concentration caused by one added movement of the case study freight. The computation is carried out for each metropolitan area and each rural county through which the shipment passes. Pollutant concentrations for metropolitan areas are reported by EPA (EPA 1993b, Table 5-6). Concentrations in rural areas are assumed to equal the lowest metropolitan area values that EPA reports (Table C-11).

Estimation of the change in the concentration of PM10 caused by a change in motor vehicle traffic must take into account formation of particulates from emissions of gaseous NO_x, SO_x, and volatile organic compounds (VOC) through chemical and physical processes in the atmosphere. The case studies assume that a constant fraction of primary emissions of each of these pollutants is converted to PM10 and that PM10 concentration varies proportionately with the sum of primary PM10 emissions and these secondary emissions.

Exposure

Exposure is measured in units of person-year-$\mu g/m^3$. One person exposed to a concentration of an airborne pollutant of 1 $\mu g/m^3$ for 1 year constitutes 1 person-year-$\mu g/m^3$. Ideally, exposure would be computed by measuring concentration in the vicinity of each person in a population at intervals throughout a year, computing the average of the measured concentrations for each person, and summing over the population (EPA 1993a, Chapter 4). The case study pollution cost estimates assume simply that change in exposure equals residential population times change in average outdoor concentration in the defined region—either a metropolitan area or rural county.

TABLE C-11 METROPOLITAN STATISTICAL AREA AND RURAL AREA MEAN POLLUTANT CONCENTRATIONS

LOCATION	POPULATION 1995	PM10 ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)	OZONE ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)
Amarillo, TX	202,000	27	38	196	89
Baton Rouge, LA	533,000	30	36	49	110
Chicago, IL	6,483,000	42	56	54	24
Davenport, IA	377,000	31	38	45	16
Denver, CO	1,798,000	39	77	41	24
Des Moines, IA	418,000	115	38	33	89
Dubuque, IA	95,000	20	23	177	8
Hartford, CT	1,165,000	25	32	54	18
Iowa City, IA	92,000	20	23	177	79
Kansas City, MO	1,666,000	44	26	41	13
Las Vegas, NV	764,000	33	58	42	110
Lincoln, NE	223,000	25	38	29	89
Los Angeles, CA	9,403,000	49	96	120	16
Memphis, TN	1,049,000	31	49	49	24
New Orleans, LA	1,304,000	29	43	45	13
Omaha, NE	659,000	44	23	37	5
Riverside–San Bernardino, CA	2,608,000	79	75	107	5
Rochester, MN	109,000	27	38	196	5
St. Louis, MO	2,550,000	50	53	54	34
Waterbury, CT	109,000	24	38	196	18
Rural areas		20	23	29	5

Effects and Economic Costs

The costs of air pollution are premature death and the pain, suffering, and economic loss of illness caused by exposure to pollutants; damage to property and crops caused by chemical and physical effects of pollutant exposure; aesthetic harm of reduced visibility; and costs of long-term climate change caused by pollutants.

The case studies assume that all costs are proportional to cumulative exposure; that is, responses to exposure have no thresholds or other nonlinear characteristics. The unit costs of pollutant exposure that were used in the case studies were taken from a recent study of air pollution damages (Table C-12) (Harrison et al 1993). That study assessed the various phys-

TABLE C-12 EXPOSURE COSTS

AMBIENT POLLUTANT	COST [($/PERSON-YEAR)/(μg/m³)]
PM10	19.62
NO_2	0.68
CO	0
VOC	0.15
SO_2	0.31

ical effect and valuation studies, and the results represent the range of contemporary state-of-the-art measures.

As with accident risk, the basis for valuing the added risk of death from exposure to increased pollution is individuals' willingness to pay for reductions in their own risk of injury or death, as revealed in market transactions such as wage premiums for dangerous jobs or purchase of safety equipment. The estimated cost of increased incidence of illness is a synthesis of estimates based on the economic cost to individuals of illness and on surveys that ask individuals to place a value on the period of restricted activity caused by an illness (Harrison et al. 1992, Table 63).

In the study used as the source of the unit cost estimates, the valuation of risks assumes that a person killed in a transportation accident loses 43 years of life on average and that this loss is valued at $2.2 million. The pollution cost valuation assumes that 12 years are lost on average by a person who dies prematurely as a result of air pollution. A discount rate of 5 percent is used (Harrison et al. 1993, 47–50). The combined effect of these assumptions is that the valuation of the expected increase in deaths from increased exposure to pollution that is consistent with the valuation of accident deaths is $1.3 million/death.

Computations

The calculation of the cost per gram of primary PM10 emissions in the cases is as follows: Let

E_X = primary emissions of Pollutant X by all sources in a region, including "fugitive emissions" (g/year);

C_X = annual average concentration of Pollutant X in region (μg-m^{-3});
p_X = exposure cost coefficient for Pollutant X [\$/(μg-m^{-3}-person-year)];
P = population in region; and
$Y_{Z\text{-}X}$ = cost of exposure to ambient Pollutant Z caused by emission of 1 g of primary Pollutant X (\$/g).

First, an effective emission rate for PM10 is computed:

$$E_{PM10eff} = E_{PM10} + 0.0382E_{VOC} + 0.0910E_{NO_x} + 1.13E_{SO_x}$$

The coefficients for each pollutant are based on modeling results for Southern California reported in a recent analysis of motor vehicle pollution costs in Southern California (Small and Kazimi 1995). Since the rates of formation of secondary PM10 were estimated for a single, atypical urban area, their applicability to other regions is unknown.

The cost of PM10 exposure of an added gram of primary PM10 emitted by a source is, then,

$$Y_{PM10\text{-}PM10} = C_{PM10}p_{PM10}P/E_{PM10eff}$$

and the cost of PM10 exposure caused by an added gram of NO_x emitted by a source is

$$Y_{PM10\text{-}NO_x} = 0.0910Y_{PM10\text{-}PM10}$$

The calculation assumes that ozone and NO_2 concentration depend only on NO_x emissions. That is, the costs of NO_2 and ozone exposure caused by a gram of NO_x emitted are

$$Y_{NO_2\text{-}NO_x} = C_{NO_2}p_{NO_2}P/E_{NO_x}$$

$$Y_{ozone\text{-}NO_x} = C_{ozone}p_{ozone}\ P/E_{NO_x}$$

The total cost of a gram of NO_x emissions is

$$Y_{all\text{-}NO_x} = Y_{NO_2\text{-}NO_x} + Y_{ozone\text{-}NO_x} + Y_{PM10\text{-}NO_x}$$

Costs of the other pollutants are calculated analogously. The calculation of SO_2 exposure cost assumes that SO_2 concentrations depend only on

SO_x emissions from all sources. Most SO_x emissions are from sources other than vehicles.

PETROLEUM CONSUMPTION

The marginal external cost of petroleum consumption in the case studies is computed as an average cost per gallon of fuel consumed of $0.04 ($0.01/L), the estimated national security cost. Fuel consumption rates used in the cases are 5.6 vehicle-mi/gal (2.4 vehicle-km/L) for trucks (FHWA 1993, Table VM-1), 0.0033 gal/net ton-mi [0.0085 L/(net metric ton–km)] for rail container trains, 0.0020 gal/net ton-mi [0.0052 L/(net metric ton–km)] for rail bulk (FRA 1991, Exhibit 5-3; AAR 1992, 60), and 0.0020 gal/net ton-mi [0.0052 L/(net metric ton–km)] for barge freight (CBO 1992, 61).

NOISE

The noise cost estimates are produced very simply. For trucks, the cost is computed as vehicle miles (loaded and empty) times an average cost per mile depending on road class: $0.020/mi ($0.012/km) on urban expressways and $0.065/mi ($0.040/km) on other urban roads. Noise cost is assumed to be zero in rural areas. The average costs per mile are those estimated in an appendix of the 1982 Federal Highway Cost Allocation Study (FHWA 1982, E-48–E-52). If inflated to 1994 prices, the unit costs would be 60 percent higher, so the estimates may be conservative. The FHWA estimates were derived by simulating the change in population exposure to noise caused by a change in traffic and using the valuation of noise exposure from the review cited in Chapter 3 (0.4 percent decline in home values per decibel, which FHWA estimated is equivalent to $21/housing unit/year/dB above a prior background level). A recent estimate of traffic noise costs for various cases defined by vehicle type, road class, and land use is not inconsistent with the earlier FHWA estimate (Haling and Cohen 1995).

Rail fronthaul noise costs per truckload equivalent mile are set equal to truck nonfreeway costs per vehicle mile in urban areas [i.e., $0.065/truckload equivalent-mi ($0.040/km)] and zero in rural areas. Rails are also assigned a backhaul noise cost equal to the fronthaul cost times an assumed ratio of empty car miles to loaded car miles generated by the marginal haul (1.0 for the shorthaul grain movements, 0.25 for longhaul

grain, and 0 for containers). No reference was found estimating U.S. average rail noise emissions or population exposure. Barge external noise cost was assumed to be zero everywhere.

HIGHWAY AND WATERWAY USER FEES

Average user fees, conventionally defined, are used as an estimate of marginal user fees. For trucks, all fuel taxes, vehicle registration fees, mileage

TABLE C-13 TAX RATES BY STATE

STATE	STATE REGISTRATION FEE ($/YEAR)	DIESEL FUEL TAX (¢/GAL)	THIRD STRUCTURE TAX (¢/MI)
MN	1,760	20.0	0
CA	1,583	16.0	0
NV	1,360	27.0	0
AZ	971	18.0	8
UT	1,199	19.0	0
CO	2,101	20.5	0
NE	1,281	24.6	0
IA	1,705	22.5	0
IL	2,200	27.4	0
CT	1,555	18.0	0

NOTE: (¢/gal) × 0.264 = (¢/L); (¢/mi) × 0.621 = (¢/km).

TABLE C-14 CASE STUDY TRUCK PRICE AND OPERATING COST CHARACTERISTICS

VEHICLE CLASS	GAS MILEAGE (MPG)	EXPECTED LIFE (MI)	ANNUAL MILES	PURCHASE PRICE ($)
Grain tractor-semi	5.6	900,000	100,000	100,000
Container tractor-semi	5.6	900,000	100,000	100,000
Urban delivery tractor-semi	5.6	408,000	25,500	100,000

NOTE: (mi) × 1.61 = (km); (mpg) × 0.425 = (km/L).

TABLE C-15 FEDERAL TAX RATES

TAX	RATE
Federal heavy vehicle use tax ($/year, 80,000-lb truck)	550
Federal tax on new trucks and trailers (% of price)	12.0
Federal tire tax (¢/vehicle-mile)	0.2
Federal fuel tax (¢/gal)	24.4

NOTE: (lb) × 0.454 = (kg); (¢/vehicle-mi) × 0.621 = (¢/vehicle-km); (¢/gal) × 0.264 = (¢/L).

taxes, and excise taxes on equipment purchases that apply only to transportation equipment are regarded as user fees (FHWA 1992, Table FE-101; AAR 1993). All fuel tax paid on fuel consumed during the trip is included as a component of the marginal user fees. Registration fees and equipment excises are annualized and prorated to trips according to the ratio of trip mileage to average annual mileage for the type of truck (Tables C-13, C-14, and C-15).

On waterways and rail, the marginal user fee is defined in the case studies as the federal fuel tax paid on fuel consumed during the trip, at rates in effect in 1994. Commercial vessels paid $0.19/gal ($0.05/L) dedicated to a waterways trust fund (CBO 1992, Table 16) and $0.043/gal ($0.011/L) to the general fund. The rail rate was $0.068/gal ($0.018/L) (AAR 1995).

The net marginal subsidy is marginal infrastructure cost plus marginal external accident, congestion, noise, pollution, and energy costs, less marginal user fees for the trip, computed as in the preceding.

CARRIER AVERAGE COST

The carrier average costs that appear in some of the case study summary tables are intended to indicate a typical rate that the shipper would pay for the freight movement. The carrier costs do not enter the computations of marginal subsidies. They are presented solely to give a rough sense of scale to the subsidy estimates.

Truck costs are based on various published estimates of average costs per truck mile (Table C-16) (Jack Faucett Associates 1991b; *Owner Operator* 1994). The rail cost is $0.026/ton-mi [$0.018/(metric ton–km)] in Cases 1 and 2. This equals average revenue per freight revenue ton mile

TABLE C-16 SHIPPER AVERAGE COSTS

	COST
Intercity truck—loaded ($/vehicle-mi)	1.08
Intercity truck—empty ($/vehicle-mi)	1.03
Local delivery truck ($/vehicle-mi)	2.23
Rail ($/ton-mi)	0.026
Barge ($/ton-mi)	0.01

NOTE: ($/vehicle-mi) × 0.621 = ($/vehicle-km); ($/ton-mi) × 0.685 = ($/metric ton–km).

for all U.S. Class I railroads in 1991 (AAR 1992, 30). (In reality, rail average cost for a specific movement can differ substantially from average revenue.) In Case 3, rail costs are $0.42/container-mi ($0.26/container-km) plus $150 for drayage. Barge cost, $0.01/ton-mi ($0.007/metric ton–km), is derived from some information on actual barge rates for grain in August 1991 reported by carriers (C. P. Baumel, personal communication, 1994). The rates ranged from $6.35 to $9.09/ton ($7.00 to $10.02/metric ton) for grain from St. Louis to New Orleans, including the cost of transferring from rail to barge. The higher rate presumably would apply in a peak demand period. The midpoint of these rates is about $0.01/ton-mi ($0.007/metric ton–km).

NOTES

1. The cost could be estimated from the following relationships:

$$c(h) = c_0 + c_1 h$$

$$h(n) = h_0 n^{1/7}$$

where

h = thickness of pavement resurfacing (inches for concrete or structural number for asphalt),
$c(h)$ = cost per lane of applying a resurfacing of thickness h ($/m-km), and
n = desired number of ESAL applications before resurfacing reaches a specified terminal serviceability rating.

The seventh-power relationship between thickness and durability is roughly consistent with the AASHTO pavement design method. Because the exponent of n is small, and because c_0, the fixed cost component, is a large portion of the cost of any resurfacing project, c is not very sensitive to traffic volume.

2. Consider a road of length L with traffic volume V vehicles/hr, speed S km/hr, and traffic density $Q = V/S$ vehicles/km. Let $t = 1/S$ be the time for one vehicle to travel 1 km and let the total vehicle hours consumed for all vehicles on the road to travel 1 km be $T = QLt = VL/S^2$. If one vehicle is added on the road, the increase in Q is $\Delta Q = 1/L$ and the increase in the time required for all vehicles on the road to go 1 km is $\Delta T = (dT/dQ)(\Delta Q) = (dT/dQ)(1/L)$. The time required for the added vehicle to go 1 km is $t + (dt/dQ)(1/L)$. Therefore, the marginal external cost of delay per kilometer of travel of the added vehicle is $(MC_{ext}) = \Delta T - [t + (dt/dQ)(1/L)] = (dT/dQ)(1/L) - t - (dt/dQ) \times (1/L)$. (MC_{ext}) is the added time required for all vehicles that were originally on the road to go 1 km, as the result of the addition of one vehicle.

   Since $T = QLt$, $dT/dQ = Lt + QL(dt/dQ)$. Therefore $(MC_{ext}) = (Q - 1/L) \times (dt/dQ)$. When Q is large compared with $1/L$ (i.e., when the road has many vehicles on it), $(MC_{ext}) \approx Q(dt/dQ)$.

   Because $Q = V/S$ and $t = 1/S$, $(dt/dQ) = (dS/dV)/[V(dS/dV) - S]$. Therefore, $(MC_{ext}) \approx (V/S)(dS/dV)/[V(dS/dV) - S]$. (dS/dV) is the slope of the speed-volume curve at the prevailing volume. Therefore, this relationship can be used to compute the marginal external cost from the known quantities S and V and the speed-volume curve.

3. Sometimes, through insurance or tort liability, a carrier or carrier employee may be compensated by another carrier for injury or damage in an accident involving only freight vehicles. If a carrier expects that it will pay out such claims as often as it receives them from other carriers, then these payments do not affect the assumption that all damage to company property and employee injuries are internal costs.

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ABBREVIATIONS

AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
CBO	Congressional Budget Office
COE	U.S. Army Corps of Engineers
DOC	U.S. Department of Commerce
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
NHTSA	National Highway Traffic Safety Administration

RSPA	Research and Special Programs Administration
TRB	Transportation Research Board

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