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Surface Transport Costs & Charges

GREAT BRITAIN 1998

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SURFACE TRANSPORT COSTS AND CHARGES

Final Report

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PROJECT INFORMATION

Surface Transport Costs and Charges

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Disclaimer

The authors of this report are employed by the University of Leeds and AEA Technology Environment. The work reported herein was carried out under a contract placed on 10 December 2000 by the Secretary of State for the Environment, Transport and the Regions.

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The study findings, however, remain the sole responsibility of the authors.

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Efficiency and cost coverage perspectives on transport pricing

This report provides two sets of information that may be used in a complementary way for transport policy development in relation to charging, taxation and subsidy. The two types of information provide economic efficiency and cost coverage perspectives for the road and rail sectors. Results for 1998 are presented for Great Britain.

The **efficiency perspective** is given by the comparison of **marginal costs and revenues**. If prices are set at the cost of an additional passenger or freight tonne kilometre, journeys for which an individual or firm's benefit exceeds the cost imposed on the rest of society will not be deterred. Conversely, travel when the benefit to the individual or firm is less than the social cost imposed will be discouraged. Setting price equal to marginal cost thus maximises economic welfare for society as a whole.

The **cost coverage perspective** provides a different set of evidence based on the comparison of **fully allocated costs and revenues**. Policymakers have a legitimate interest in the comparison between economic costs and revenues associated with the road and rail sectors. The resource needs of these modes, or the resources that may be generated from them, need to be balanced with the resource requirements of other sectors of the economy. A comparison between the total social costs imposed by road and rail users as a whole on the rest of society and the revenues raised can support such considerations. Although many of the costs of the transport sector are joint costs, i.e. costs that cannot be uniquely attributed to any one vehicle class or train type, the fully allocated cost approach seeks to compare social costs and revenues for each vehicle class or train type.

Thus the marginal cost approach presents an efficiency perspective whilst the fully allocated cost approach provides a social cost coverage perspective. There are two ways in which the marginal cost and fully allocated cost approaches may be combined.

The first approach to combination is a **political approach**. Politicians may choose to set a cost coverage target for the road and rail sectors and then design a pricing system that maximises economic efficiency taking into account this constraint. One example of the outcome of such a system may be the use of two-part tariffs, as currently used for rail track access charges. This involves a variable component that reflects marginal costs for an additional train service and a lump sum payment for each individual train operator that, with the help of Government subsidy, achieves cost recovery for infrastructure provision at a national level.

The second approach to combination is a more comprehensive **economic welfare analysis**. This involves modelling the economy as a whole and the competing resource needs and resource generation potential of each individual sector. Depending upon the characteristics of the transport and other sectors, the outcome will also be a modified form of marginal cost pricing. In contrast to the political approach, however, the cost coverage target will be an output of the assessment process, rather than an input to it. The analysis will balance the resource needs of the road and rail sectors at the same time as it considers the distortionary effects of raising revenues from other parts of the economy, in particular the labour market.

Determining the content of the analysis framework

The economic efficiency and cost coverage perspectives determine the social cost and revenue categories that should appear in the marginal cost and fully allocated cost analyses, and how each category should be defined. The main distinction between the two approaches in identifying the social costs of relevance is the unit of transport that is considered.

For the marginal cost analysis it is the additional cost not directly borne by the user in question that arises with an additional passenger or freight tonne kilometre. The private cost of an additional kilometre, e.g. the user's travel time, is of no interest for pricing.

For the fully allocated cost analysis the cost imposed by a group of users on the rest of society is of interest. The cost imposed by the individual user on users of the same mode, e.g. road congestion, is of no relevance. Such costs are both imposed by and borne by the group of users as a whole.

Based upon these distinctions, Table A shows the cost and revenue categories of relevance to the two approaches.

Table A: Summary of Relevant Cost and Revenue Categories

Categories	Short-run marginal cost analysis		Fully allocated cost analysis	
	Road	Rail	Road	Rail
Cost of capital	-	-	✓	✓
Infrastructure costs	✓	✓	✓	✓
Vehicle operating costs	PSV only	✓	PSV only	✓
Electricity costs	-	✓	-	✓
Congestion	✓	✓	-	-
Scarcity	-	✓	-	-
Mohring effect	PSV only	✓	-	-
Accidents	✓	✓	✓	✓
Air pollution	✓	✓	✓	✓
Noise	✓	✓	✓	✓
Global warming	✓	✓	✓	✓
VAT not paid	PSV only	passenger only	PSV only	passenger only
Fares and freight tariffs	PSV only	✓	PSV only	✓
Fuel duty	✓	-	✓	-
VAT on fuel duty	✓	-	✓	-
Vehicle excise duty	commercial vehicle only	-	✓	-

Key: ✓ = relevant for inclusion, although not necessarily included in the empirical work. PSV – public service vehicle, i.e. local buses and coaches.

Disaggregations included in the framework

Since the purpose of the output produced from the framework is to examine differences between social costs and revenues, it is clearly necessary to incorporate within the framework's disaggregations the main factors underlying variation in costs. These disaggregations relate to location of travel, road or rail infrastructure type, vehicle or train type and the time period of travel.

Issues of the potential to reflect such underlying cost drivers in existing and potential charging instruments and of data availability at a sufficiently detailed level also affect the disaggregations that are incorporated within the framework.

With existing charging instruments there is the possibility for highly differentiated infrastructure use charging in the rail sector but only limited variation in the road sector. Rail track access charges could vary for each individual train path. For road, existing instruments are limited to fuel duty and vehicle excise duty. There is the potential for variation of vehicle excise duty by vehicle class/ engine size/ fuel type but this is of limited use in reflecting social costs in a way that can strongly influence travel behaviour. More accurate reflection of costs would require additional instruments such as tolls or electronic road pricing in high cost locations.

The emphasis of this study is on exploiting pre-existing datasets in order to provide estimates of social costs and revenues for 1998. For this reason, data availability and confidentiality constrains the disaggregations that are embodied in the framework. The most notable constraint relates to cost and revenue information for passenger and freight train operators. This information is commercially confidential, so that analysis relies on the very limited disaggregations contained within published accounts.

The disaggregations for the road framework developed in the study are:

- 11 area types (3 for London, 2 for conurbations, 5 other urban, rural);
- 3 road types (motorway, trunk and principal, other);
- 5 vehicle types (car, light delivery vehicle, rigid heavy goods vehicle, articulated heavy goods vehicle, public service vehicle); and,
- 2 time periods (weekday peak from 0700-1000 and 1600-1900, other times)

For rail, the constraint on train operator data, and the confidentiality surrounding some of Railtrack's data, means that the framework developed is restricted to 3 disaggregations relating to passenger service type and 2 types of freight operation. These 5 disaggregations are:

- InterCity passenger services;
- Regional rail passenger services;
- London commuter catchment-based passenger services;
- Bulk freight; and,
- Other freight.

Issues the framework is designed to address

There are six major issues relating to transport charging that the framework is designed to address. These can be grouped under the marginal cost and fully allocated cost analysis headings:

Marginal cost analysis	Fully allocated cost analysis
• What is the direction of change if charges are to be based on marginal costs? • Does there appear to be a case for the introduction of new pricing instruments in the road sector? • Are current levels of subsidy justified on economic efficiency grounds? • How do weighted short run marginal costs compare to charges for the road and rail sectors as a whole?	• How do total social costs compare to revenues for the road and rail sectors as a whole? • How do fully allocated costs for each vehicle class/ train type compare to revenues?

As with any form of research, to prevent results being misinterpreted it is necessary to state the limitations of the analysis. For this reason, limitations are stated in the following results sections and the more important ones are explicitly addressed in the research priorities section.

Results for the road sector

The overall results for the road analysis for 1998 are shown in Table B. These are shown for a typical vehicle kilometre, derived by weighting disaggregate inputs according to relative vehicle kilometres by area type, road type, vehicle type and time period.

The results from the **marginal cost analysis** suggest that:

- Transport charges would need to rise if charges are to be set on economic efficiency grounds. Since the demand/ cost/ price change interactions that would result from changes in prices are not simulated in this study, the ratios of revenues to marginal costs of 2.0 and 2.6 cannot be directly interpreted as the magnitude of the price change necessary;
- When disaggregate comparisons, shown in this report, are made there appears to be a need for a far higher degree of differentiation in charges than current instruments allow for. Without assessing the implementation costs of new instruments, however, it is not asserted that such mechanisms are justified on cost-benefit grounds; and,
- Based on the analysis of public service vehicles contained in this report, subsidy to the bus industry is not fully justified on a purely economic efficiency basis.

Table B: Comparison of 1998 Road Sector Costs and Revenues

Pence per vehicle km, Great Britain, 1998 prices and values

Cost or revenue category	Fully allocated cost		Marginal cost	
	low	**high**	**low**	**high**
Costs:				
Cost of capital for infrastructure	0.78	1.34	n/a	n/a
Infrastructure operating costs and depreciation	0.75	0.97	0.42	0.54
Vehicle operating costs (PSV)	0.87	0.87	0.87	0.87
Congestion	n/a	n/a	9.71	11.16
Mohring effect (PSV)	n/a	n/a	-0.16	-0.16
External accident costs	0.06	0.78	0.82	1.40
Air pollution	0.34	1.70	0.34	1.70
Noise	0.24	0.78	0.02	0.78
Climate change	0.15	0.62	0.15	0.62
VAT not paid	0.15	0.15	0.15	0.15
Sub-total of costs	**3.34**	**7.20**	**12.32**	**17.05**
Revenues:				
Fares (PSV)	0.84	0.84	0.84	0.84
Vehicle excise duty	1.10	1.10	0.14	0.14
Fuel duty	4.42	4.42	4.42	4.42
VAT on fuel duty	0.77	0.77	0.77	0.77
Sub-total of revenues	**7.14**	**7.14**	**6.17**	**6.17**
Comparison of costs, revenues:				
Difference (cost-revenue)	**-3.79**	**0.07**	**6.15**	**10.88**
Ratio: revenues/costs	**2.13**	**0.99**	**0.50**	**0.36**

Notes: Road sector costs exclude costs attributable to pedestrians, bicycles and motorcycles;
Accident costs are reported net of insurance payments;
Vehicle excise duty in the marginal analysis relates to HGVs and PSVs;
n/a – not applicable.

The **fully allocated cost** analysis suggests that:

- For the road sector as a whole total social costs range between being broadly covered by revenues (high cost estimates) and are more than twice covered by revenues (low cost estimates). Since there is no reason to suppose that the degree of social cost coverage should automatically be one, however, these findings do not imply that charges and taxes are excessive; and,
- For the five main vehicle classes within the road sector, coverage of allocated costs occurs for all classes except public service vehicles with low cost estimates but only for cars with high cost estimates. As many of the costs in the road sector are joint costs and cannot be uniquely attributed to different vehicle classes, however, these findings should be treated with caution.

Results for the rail sector

The main results for the rail sector in 1998 are presented in Table C.

Table C: Comparison of 1998 Rail Sector Costs and Revenues

Cost or revenue category	Fully allocated cost		Marginal cost	
	Passenger	Freight	Passenger	Freight
Costs:				
Infrastructure	5.33	3.41	0.42	1.19
Vehicle operating costs	7.07	9.28	7.07	9.28
Electricity	-	-	0.23	-
Congestion	n/a	n/a	0.18	0.00
Mohring effect	n/a	n/a	-1.05	n/a
Air pollution	0.46	0.68	0.46	0.68
Noise	0.16	0.37	0.16	0.37
Climate change	0.10	0.33	0.10	0.33
VAT not paid	1.32	n/a	1.32	n/a
Sub-total costs	14.44	14.07	8.89	11.85
Revenues	7.52	13.41	7.52	13.41
Comparison of costs, revenues:				
Difference (cost-revenue)	6.92	0.66	1.37	-1.56
Ratio (revenue/cost)	0.52	0.95	0.85	1.13

Notes: n/a - not applicable; where electricity costs are not shown, these are included in infrastructure costs. Midpoint of low and high environmental cost estimates

Pence per train km, Great Britain, 1998 prices and values

The results from the **marginal cost analysis** suggest that:

- Transport charges would need to rise for passenger rail and fall for freight if charges are to be set on economic efficiency grounds;
- The excess of revenues over marginal costs for freight contributes to the case for wider economic benefits from rail freight investment. Having said this, whether or not wider economic benefits arise also depends upon the degree of returns to scale for industries for which transport is a major input; and,
- The case for the 1998 level of subsidy for passenger rail services is not fully justified on a pure economic efficiency basis unless arguments based on the under-charging of road are invoked. The converse, however, applies for rail freight.

The **fully allocated cost** analysis suggests that:

- Rail freight almost covers its social costs, but passenger services only cover around half of social costs. As is the case with the road sector findings, there is no immediate implication from these findings for the level of taxes and charges.

Research priorities

There are five general areas in which the analysis developed in this study could be taken forward. These are:

- Enhancing the content of the existing framework;
- Extension of the framework to cover future years;
- Extension of the framework to enable the magnitude of marginal-cost based prices to be determined;
- Development of a more disaggregate road framework; and,
- Development of a more comprehensive rail framework.

Of these areas, the highest priority for the road framework is to integrate demand responses to price changes, and subsequent feedback to changes in costs. This should be done for existing pricing instruments and for a year in the near future (e.g. 2003).

For the rail framework, the key priority is to elaborate a framework that works with changes in passenger demand, rather than train kilometres. Again, this should be carried out for a year in the near future.

1 Introduction

1.1 The Terms of Reference for this study

The Institute for Transport Studies, University of Leeds, in association with AEA Technology Environment, was appointed by the Department of the Environment, Transport and the Regions in April 2000 to undertake the study of “Surface Transport Costs and Charges”.

As part of the study, Dr Heike Link of the German Institute for Economics Research (DIW) conducted a brief review of the study methodology, prior to its full implementation. This review helped to refine various methodological aspects and was also beneficial in setting the study in the context of worldwide experience.

The terms of reference for the study is attached at Annex A. The main features of the terms of reference for the study were:

- Coverage of road and rail sectors at a national level, for a recent year;
- Estimation of social costs of relevance to charging, taxation and subsidy policy;
- Comparison of these costs with revenues;
- Focus on costs and revenues relating to vehicle or train types, rather than on changes in passenger or freight tonne kilometres; and,
- Reliance on existing datasets and functional relationships.

In addition, two approaches to the analysis were to be developed. These were:

- Short run marginal cost analysis. This examines the impacts of a 1% increase in vehicle or train kilometres on social costs when the level of infrastructure provision is held fixed. The comparison is then made with revenues that vary with transport use; and,
- Fully allocated cost analysis. Here, the social costs that road and rail sectors give rise to are estimated. These total social costs are then allocated to vehicle or train types to enable a comparison with revenues by vehicle class/train type.

As the next section explains, the fully allocated cost approach was used for many years in the road sector in Great Britain while interest in the short run marginal cost approach has been spurred by more recent developments.

1.2 The Policy and Research Context

The **short run marginal cost** component of study has been prompted by both the SACTRA report on transport and the economy, and policy developments at the European level:

- In its 1999 report on “Transport and the economy”, in order to understand the degree to which transport pricing covers external costs, SACTRA called for comparisons of price and marginal social cost to be made for a range of contexts (SACTRA, 1999, recommendation 11.16). This allows for examination of the need to move "towards a more efficient allocation of resources in the economy" (7.21). This study was commissioned by the DETR as a direct response to SACTRA's recommendation; and,

- The European Commission has sought to promote transport infrastructure pricing based on marginal social costs in its green and white papers (CEC, 1995 and 1998). A "High Level Group" on infrastructure charging was established and identified the need for empirical evidence on existing prices and marginal social costs. This has led to a number of countries, including Austria, Finland, Spain and Sweden and the UK, to initiate studies on the social costs of transport use. This study is also the DETR's contribution to that evidence.

The study also comes at a time when there is continued interest in the use of existing price mechanisms (notably fuel duty and vehicle excise duty in the road sector, and track access charges in the rail sector) to achieve policy objectives. Furthermore, the potential for the introduction of new pricing levers is under active consideration. Examples include electronic road pricing in cities and inter-urban road tolling.

The theoretical basis for pricing policy has been extensively explored, for example, as part of the European Commission's 4th Framework Research Programme in projects such as Pricing European Transport Systems (Nash, 2000) and the Concerted Action on transport Pricing Research Integration (Nash et al., 2001). To date there have been few studies, however, that have provided comprehensive empirical evidence on marginal costs. Exceptions to this include a study for all modes in the Netherlands (Dings et al., 1999), the ongoing EC 5th Framework project UNITE (Sansom et al., 2000), an ongoing International Union of Railways study exploring the revenue implications of marginal cost pricing (for France, Germany and the UK; Roy, 2000), and the EC's ongoing ExternE series of environmental cost studies (Friedrich et al., 1998).

In terms of **fully allocated cost** and revenue comparisons at a national level, Great Britain has a long tradition of comparing infrastructure-related costs with revenues for the overall road sector. This was known as the Allocation of Road Track Costs exercise (DoT, 1995). A large number of countries, including the USA (DoT, 1997), follow similar approaches. For Great Britain, this exercise has been extended to cover total social costs on a number of occasions by Newbery (1995, 1998), and more recently the VED rates for HGVs have been examined in relation to relative infrastructure, environmental and accident costs (NERA et al., 1999).

Switzerland has a tradition of comparing total social costs with revenues at national level, as does Germany. For Germany such comparisons have been commissioned by interest groups and not the Ministry of Transport and so do not have any official status. Finland has also embarked recently on such comparisons for the road and rail sectors and the European UNITE project also seeks to elaborate this form of "transport accounts" – for five main modes and 18 countries. An extensive review of international experience is contained within Sansom et al. (2000).

Despite this research and policy context, it is asserted that the Surface Transport Costs and Charges project has a high level of ambition in providing cost and revenue information that is comprehensive in its coverage of Great Britain, and is also highly disaggregate in respect of area / infrastructure / vehicle types and time periods. The next section puts this study in the context of recent studies for Britain.

1.3 Recent Research in this Field

Table 1.1 sets out the features of transport cost studies carried out in the last five years. The features are compared with those of the present study.

Table 1.1: Characteristics of Transport Social Cost Studies

Study	Modal coverage		Geographic coverage		Approach			Comments
	Road	Rail	Britain	Case study	MC	Total cost	FAC	
AA – Newbery (1998)	✓	-	✓		-	✓	-	Main focus on total social costs
Blueprint 5 - Maddison et al. (1996)	✓	-	✓	-	-	✓	-	Overall road sector costs Not by vehicle type.
HGV Study - NERA (1999)	✓	-	✓	-	Partial*	✓	✓	HGV only; Issues highlighted (e.g. external component of accident costs), but not resolved.
ExternE Transport – Bickel et al. (1998)	✓	✓	-	✓	✓	-	-	Case studies only. Also, focusing only on environmental costs.
PETS – Sansom et al. (1999)	✓	✓	-	✓	✓	-	-	Case studies only – difficult to generalise to national level. Modelling of optimal prices.
Peirson & Vickerman (1997)	✓	✓	-	✓	✓	-	-	Case studies only. Modelling of optimal prices.
TRENEN II STRAN – Proost & Van Dender (1999)	✓	✓	-	✓	✓	-	-	Case studies only. Modelling of optimal prices.
UIC Study – Roy (2000)	✓	✓	-	✓	✓	-	-	Case studies only. Modelling of optimal prices.
THIS STUDY	✓	✓	✓	**-**	✓	✓	✓	**Highly disaggregate calculations & outputs**

Note: * "partial" means that MC information is contained in the study, but comprehensive marginal cost analysis was not the focus of the work.

The first three of the studies listed in Table 1.1 sought to develop total social cost estimates for Great Britain as a whole. Of these Maddison et al. (1996) relies on relatively coarse calculations, as does Newbery (1998), although to a lesser extent.

The NERA et al. (1999) study lies closest to this in terms of a high level of disaggregation for calculations. The focus of the NERA study, however, was on the relative costs of different classes and vintages of heavy goods vehicles and on a fully allocated cost basis.

In contrast to the road sector focus of the first three studies, the remaining five studies in Table 1.1 cover both road and rail. These five studies provide case study evidence that necessarily limits the conclusions that can be drawn at a national level. Furthermore, there is an emphasis on marginal cost analysis.

Four of the five case study-based analyses, however, incorporate an important feature. This is the inclusion of demand reactions to changes in prices with subsequent feedback into revised estimates of marginal costs. An iterative modelling procedure allows the magnitude of changes in prices that are needed to achieve optimal prices to be assessed.

In comparison to the studies listed in Table 1.1, the main features of this study are that it is comprehensive in its inclusion of road and rail, coverage of Great Britain as a whole and analysis on the basis of both marginal cost and fully allocated cost analyses. The use of highly disaggregate information sources in the estimation of costs also distinguishes the study from most other recent ones for Great Britain.

Reliance on pre-existing data, as opposed to the development of integrated price-demand-cost estimation models, does, however, impose a number of limitations that need to be made explicit and could be dealt with using the complementary tools identified in Section 4.5.

1.4 Structure of this Report

The implications of economic efficiency and cost coverage perspectives are set out in Chapter 2. Combined with discussion of pricing instruments and data availability constraints in Chapter 3, these perspectives lay the groundwork for the specification of the analysis framework in Chapter 4. This specification identifies the cost and revenue categories that are relevant for inclusion and the level of disaggregation at which outputs are to be reported.

Chapters 5 and 6 provide a summary of the methodologies used in the estimation of the cost and revenue categories identified in Chapter 4, for road and then rail.

The results of implementing the framework for road and rail are given in Chapters 7 and 8. Chapter 9 highlights the value of the framework's results in addressing issues including those related to pricing, taxation and subsidy.

The report conclusions (Chapter 10) identify the achievements of the study. Opportunities for further development of the framework are also identified.

2 The Basis for Charging Policy

2.1 Introduction

This chapter sets out a basis for charging policy that shows how the two approaches developed in this study, marginal and fully allocated cost analyses, may be used in combination. This basis is an important determinant of the design of the study's analytical framework.

Economic efficiency and cost coverage perspectives on pricing are set out in the following sections. Subsequently, alternative approaches to reconciling these two perspectives are discussed. Against this background, the traditional way of assessing road taxation levels for Great Britain (Road Track Costs; MoT, 1968) and the outcome of the Rail Regulator's decision on restructuring Railtrack's track access charges (ORR, 2000) are contrasted.

In this study the approaches discussed are elaborated in terms of costs and charges per vehicle or train kilometre. It must be noted, however, that the charges of interest are ultimately those faced by the passenger or freight customer, per passenger or tonne kilometre.

2.2 The economic efficiency perspective

The economic efficiency perspective derives from the simple proposition that society's economic welfare will be maximised when each transport user pays the marginal external cost of each trip. If an individual or firm's benefit from a trip is less than marginal external cost, society as a whole will be better off if the trip is not made. Conversely, if the benefit exceeds marginal external costs, there is a net gain to society from the trip being made.

Two variants to the efficiency (or "marginal cost") perspective exist:

- Short run marginal cost. This is defined as the social cost of an additional trip at the current level of infrastructure provision. This changes over time as the level of infrastructure provision changes; and,
- Long run marginal cost. This is defined as the cost of an additional trip allowing for infrastructure provision to be optimally adjusted to the level of demand. It includes the same categories as short run marginal cost (but with different values as the categories are estimated allowing for the offsetting effect on some of them, especially congestion, of the increase in capacity) and in addition the cost of additional infrastructure provision for an additional unit of traffic.

With the exception of the category of long run marginal cost related to the additional capacity charge, the cost categories for both approaches are identical[1]. In the presence of indivisibilities the additional capital charge is usually approximated by the average incremental cost of capacity. The capacity charge relates to the costs of expansion from optimal capacity to the next level of provision, divided by the

[1] As noted in the above paragraph, however, the values of estimates for the different categories can be very different.

increase in traffic that would justify the next level of provision. To give a simple example from the road sector, the current capacity of a motorway may be dual 2 lane with social cost-benefit analysis suggesting that the optimal level would be dual 3. The next level of expansion may be further widening to dual 4. The capacity charge would be calculated as the incremental cost of expansion from dual 3 (from the optimal level, not today's level) to dual 4. This would be divided by the incremental traffic increase needed to justify this further expansion.

Both approaches have potential advantages and disadvantages, but there are two situations where a choice between the two need not be made:

- Firstly, when infrastructure provision happens to be optimal short run and long run marginal costs will be identical; and,
- Secondly, in circumstances where infrastructure can be assumed to be fixed for the foreseeable future, including urban roads and non-primary rural roads, capacity expansion is highly unlikely so that only the short run marginal cost is of relevance.

For the inter-urban strategic road network and much of the rail network, the competing claims of short and long run approaches require consideration.

Adjustment to the optimal level of capacity can involve major time lags and indivisibilities requiring a minimum level of additional provision. In addition adjustment may be subject to politically determined investment priorities. In such circumstances short run marginal cost pricing achieves optimal use of the existing infrastructure, irrespective of whether capacity provision is optimal or not.[2]

In contrast, pricing based on long run marginal cost offers a different advantage. Many long-term decisions such as location choice and the choice of whether or not to own a car depend on signals about future prices. If infrastructure capacity is currently non optimal but will become so there is a danger that current prices serve as a poor guide to future prices. This could lead to individuals being locked into situations that are inefficient over the longer term (e.g. it is costly to relocate for households and businesses).

An alternative approach to overcoming this issue for the short run marginal cost approach would be to smooth costs over time if additional infrastructure is planned. This would avoid excessive fluctuation once new infrastructure is provided if such provision is intended.

Even if short run marginal costs are used as the basis for pricing, long run marginal costs continue to provide a useful indicator when assessed in conjunction with short run information. If short run marginal cost is substantially in excess of long run marginal cost for a prolonged period of time, this provides a strong indication that capacity expansion would be beneficial at the location in question, and vice versa.

This trade-off between prices that optimise the use of capacity at any given time and prices that provide a sound basis for decisions with long-term implications is

[2] Short run marginal cost will change as infrastructure adapts over time. In a future year it will take account of whatever level of infrastructure provision exists.

amenable to empirical analysis. In this study, however, only the short run marginal cost approach is elaborated.

Neither short nor long run marginal cost approaches guarantee that infrastructure cost recovery will be achieved. This is the concern of the cost recovery perspective.

2.3 The cost coverage perspective

The transport sector has to compete for government resources with other sectors of the economy, so that an alternative perspective is that cost coverage should be achieved. This may be at the level of the road and rail sectors, or for the transport sector as a whole.

A number of arguments for setting a cost recovery target can be identified (e.g. SACT, 1999). Firstly, given that users push for charge moderation, setting a cost recovery target may encourage productive efficiency amongst transport providers. Secondly, it may mean that users will not lobby for excessive infrastructure or service provision, as users will face the costs of expansion. Thirdly, it allows for a range of institutional situations to be established in that the necessary financial returns for private sector provision can be achieved.

The authors of this report do not agree with these arguments. There are other ways of keeping costs down and involving the private sector - e.g. competitive tendering. Even in the presence of cost recovery targets, those users who gain most will still campaign for infrastructure expansion and others (e.g. even users in different parts of the country, given existing price systems) will pay the cost.

Resource allocation decisions should take account of economic costs expressed in non-money terms (e.g. environmental costs) as well as those that are already in money terms (e.g. infrastructure costs, operating costs). For this reason, the cost coverage concept is extended from financial to social cost coverage in this study.

A further extension to examining cost coverage at the modal level (road, rail) is to attempt to allocate costs to the sub-modal level (e.g. to road vehicle types, passenger or freight rail services). Due to the high proportion of joint costs in the transport sector, which by definition are not specific to a particular vehicle class, there is no unique way of allocating costs. A degree of arbitrary allocation is necessarily involved and the comparison of fully allocated costs and revenues is only robust at the level of the road or rail sector.

In general this study consciously avoids attaching the labels of “fairness” or “equity” to the fully allocated cost approach. This is because other interpretations of fairness and equity exist, so that it would be misleading to make such an association. One example of a definition of fairness is that a user pays the costs associated with each individual trip, i.e. marginal costs are covered. A common equity definition examines the relationship between charges and income, so that examining cost coverage for car users as a group would offer negligible insight into equity by income group. Some people, however, may argue for the view that it is 'fair' for the users of each mode to cover its costs, and for them the fully allocated approach will obviously be useful.

The main detraction of a pure cost recovery perspective on transport charging is the absence of any meaningful link to efficiency objectives. It would encourage trips that result in a net welfare loss to society and discourage trips that would yield an increase in welfare.

2.4 Can economic efficiency and cost coverage perspectives be reconciled?

The two approaches elaborated in this study, marginal cost and fully allocated cost analyses, contribute to the efficiency and cost coverage perspectives, but can the two be reconciled?

The European research project UNITE (Sansom et al., 2000) has identified two alternative ways in which a balance may be struck between efficiency and cost coverage viewpoints.

The first alternative is to view the degree to which a particular level of cost coverage is seen as fair or not as a matter for political decision. The politically-determined target for cost coverage may then be taken as a constraint in the maximisation of economic efficiency.

This first alternative reflects the eloquent words of Turvey (1975) in that "…the case for internalizing external expenses is one of fairness, a matter of *political judgement*, which the case of internalizing external economic costs is one of economic efficiency, a matter for *objective analysis*". (emphasis added)

Thus, fully allocated cost analysis provides ratios of revenues to costs that politicians may judge to be too high, about right, or too low when taken into consideration with other budgetary requirements. Then charges can be developed based on marginal costs taking into account cost coverage targets.

The second alternative is to develop a more comprehensive welfare analysis framework that takes account of the inter-relationship of the transport sector and the other parts of the economy and for different modes. Such an approach is set out in Mayeres et al. (2001). The distortionary impact of the need to raise taxes in other parts of the economy if there is a net deficit from the transport sector is identified. Conversely, if a net surplus arises from the transport sector this may be used productively in other sectors or in reducing, for example, the burden of labour taxes.

This second approach seeks to take into account the reasons why achieving cost recovery, under-recovery or over-recovery may be desirable in different sectors of the economy. In contrast to the political approach, however, the cost recovery ratio for each mode of transport is an output from, rather than an input into, the determination of charge levels and structures.

Both political and welfare economics alternatives will result in constrained marginal cost pricing of one form or another. Examples of constrained marginal cost pricing include:

- Two-part tariffs. This consist of a variable component approximately to marginal costs so that an additional trip is priced at marginal cost, plus a fixed part designed to achieve a target level of cost recovery. In the road sector an example of two-part tariff with fixed components (vehicle excise duties, allowing use of the network) and variable components (fuel duties) exists. This retains incentives to maximise economic efficiency as additional trips are priced at marginal cost, but may lead to some customers inefficiently leaving the market altogether; and,

- Mark-ups over marginal costs based on relative price elasticities, often referred to as Ramsey pricing (Ramsey, 1927). Examples are common in the rail industry, where price elastic market segments (e.g. leisure travellers) may pay very different fares for use of the same service relative to less elastic segments (e.g. business). Cost coverage targets may be achieved whilst the distortion in demand relative to unconstrained marginal cost pricing limits the loss of economic efficiency.

The degree of constraint clearly depends on where a balance is struck on the spectrum between the pure efficiency and pure cost coverage perspectives.

Both marginal costs and fully allocated costs are important inputs into the political and welfare economics approaches to reconciling economic efficiency and cost coverage perspectives.

The next two sections set out the traditional approach to cost analysis in the road sector, which was abandoned in the mid-1990s, and the constrained marginal cost approach to rail track access charging, re-affirmed recently in negotiation between the Rail Regulator and Railtrack.

2.5 The traditional approach to road cost analysis in Great Britain

The approach to the analysis of highway costs that prevailed for almost three decades in Britain was established by “Road track costs” (MOT, 1968). The starting point for this was that neither the public income and expenditure account nor the social income and expenditure account provided an appropriate basis for determination of charges. In particular, the incentive mechanisms for encouraging economic efficiency were completely absent.

The view expressed in MOT (1968) was that short run marginal cost-based pricing encouraged the “… economically efficient use of the road system” but that “the available charging and taxing mechanisms, fuel tax, excise duties, tolls, are insufficiently flexible.”

Despite the fact that accurate long run marginal cost pricing also requires pricing instruments that can differentiate between aspects such as location and time of day, MOT (1968) suggests that a long run marginal cost approach can be adopted. In fact, with either approach, a high degree of averaging is required with existing pricing instruments.

The report makes other assumptions that mean that what is calculated is not even really an “average” long run marginal cost. These include substituting the capital charge with “capital expenditure … in the year it is spent” (as it is stated that estimation of the capital charge component of long run marginal cost is too problematic), omitting congestion (on the grounds that road users as a group impose and “pay” this), omitting environmental costs and the non-material component of accident costs (in both cases due to estimation difficulties).

Despite these concessions, it is maintained that the approach proposed constitutes “long run marginal cost for roads as a whole.”

The current study does not seek to maintain the impression that an approach of allocating total social costs to vehicle classes or train types in any way acts as an adequate proxy for long run marginal costs. The comparison of total social costs and revenues is of legitimate policy interest, however, and this study has chosen to term this the “fully allocated cost” approach.

The issue of the constraints imposed by policy instruments is taken up in Chapter 3. In 2001 the instruments that are in use are no different from those in 1968. It is noted here, however, that the limited instruments relating to use that do exist, namely petrol and diesel duties, can still be used in the constrained optimisation of economic efficiency.

As a postscript, the road track cost method was applied up until 1995 (DoT, 1995). Due to controversy about the methodology used, in particular the approach to the estimation of capital charges and the omission of environmental and full accident costs, the annual “Allocation of road track costs” exercise was then abandoned.

2.6 The approach for rail track access charging

The recent periodic review of rail track access charges in Great Britain (ORR, 2000) has resulted in the Rail Regulator’s decision to modify the system of constrained marginal cost pricing in April 2001. The system remains one that consists of a variable component plus a fixed element, but the variable component will be adjusted to approximate more closely to marginal cost.

The way in which the marginal cost component is measured has been adapted, resulting in a higher variable component. Part of the purpose of modification was to ensure that track access fees fully reflect the additional costs incurred when usage varies over time.

The variable component includes infrastructure wear and tear costs, electricity for traction (where applicable) and a component relating to congestion. Due to the omission of scarcity and environmental costs, and the Regulator’s decision to moderate and simplify some charge components, the system approximates to marginal cost pricing for running additional services.

The fixed part of train operators’ track access charges serves to ensure that Railtrack’s overall costs can be covered[3]. For some operators, part - or even all - of the fixed cost is essentially covered by public subsidy through the franchising system. The approach to track access charging demonstrates the use of a “political approach” to setting a cost coverage target (net public subsidy to the rail industry) combined with

[3] Net subsidy from Government to the train operators as a whole enables overall cost coverage to be achieved. An “RPI – X” mechanism for reducing track access charges over time provides incentives for productive efficiency.

the use of marginal costs as the basis for marginal cost pricing. This proposal for a two-part tariff constitutes a form of constrained marginal cost pricing. It maintains economic efficiency incentive properties for additions or reductions in train services, whilst requiring operators to recover more than marginal costs from the final customer (typically through price discrimination).

2.7 Summary of charging issues

This chapter has set out the economic efficiency and cost coverage perspectives on transport charging. It is contended that marginal cost pricing subject to a budget constraint balances these perspectives and illustrates the role for both marginal cost and fully allocated cost information in charge determination.

Other important issues, namely the constraints imposed by existing and potential pricing instruments and by data availability, are discussed in the next chapter.

3 Implications of Charging Instruments and Data Availability for the analytical framework

3.1 Introduction

Chapter 2 has identified efficiency and cost coverage issues relevant to charging, taxation and subsidy policy. Two other key factors are:

- The way in which outputs can be made use of with charging instruments. The differentiations that may be implemented within charging systems present a real constraint on the level of disaggregation of outputs that is useful; and,
- Data availability at a sufficiently disaggregate level. This study relies on pre-existing datasets for calculations, placing limits on the level of disaggregation.

These two issues are discussed in turn.

3.2 Implications of Charging Instruments for the level of disaggregation

Theory is helpful in determining relevant cost and revenue categories for the framework, but at what level of disaggregation should the overall cost and revenue outputs be produced at? One of the main determinants of the level of disaggregation is the level of detail at which outputs can be used in practice by means of charging instruments.

Both existing and potential charging instruments are of relevance to the framework's disaggregations. Existing charging instruments in use in the UK at present are highly constrained in the road sector but offer the opportunity for more differentiation in the rail sector. Existing charging instruments are:

- Vehicle excise duty for road vehicles. Differentiation is possible by engine size, engine standard (pre-Euro, Euro I etc.), vehicle category and vintage (year of registration);
- Fuel duty for road vehicles. Differentiation is possible by fuel type and to a limited extent by vehicle type (e.g. coloured diesel for agricultural vehicles); and,
- Track access charges for rail. Differentiation is possible by train type, location and time period.

Potential charging instruments, either in use elsewhere in the world at present or likely to be capable of implementation in the next decade, offer more potential for differentiation. These include:

- Electronic road pricing for urban areas. Differentiation is possible by vehicle/engine classification (as noted above for VED), location and time period. Cordon pricing shares many of these capabilities;
- Electronic road pricing for inter-urban roads. Differentiation is possible for the same categories as for urban areas. Conventional tolling systems for inter-urban roads also offer many of these possibilities; and,
- Smartcards for public transport passengers. Differentiation is possible by time period, location etc.

Drawing together the capabilities for differentiation from existing and potential charging instruments, the maximum level of disaggregation that could be usefully reflected in the design of a framework is by:

- Location – every link of the national road network and every section of the rail network;
- Road type or rail infrastructure type – the design standard in terms of maximum speed, quality specification;
- Vehicle or train type – by each permutation of vehicle/train class, engine and fuel type, vehicle age; and,
- Time period – by half hour time period for different days over the course of an average week.

Clearly, if all permutations of these disaggregations were specified the result would be a large and probably unworkable framework. For road, it would be more sensible to develop two inter-related frameworks. The first would be for "areas for priority innovation" (cordon charging in selected large cities, electronic tachographs for HGVs, inter-urban tolling on the trunk road network). The second would be for "all other situations" for which existing, aggregate pricing instruments could be optimised. The two frameworks could be used in a joint optimal charge setting exercise.

For rail, a more realistic starting point could be the level of disaggregation that the Rail Regulator has allowed in the periodic review of Railtrack's track access charges (ORR, 2000). This is less detailed than Railtrack's initial proposition.

Disaggregation in charging systems is only economically justified where the benefits of additional disaggregation exceed the additional costs of a more detailed system (e.g. Turvey, 1971). Although such analysis is outside the scope of this study, providing a framework that maximises the level of disaggregation clearly offers the flexibility to gross up to different levels of aggregation. Given the strong non-linearities in some of the relationships in question, it also provides greater accuracy even at a higher level of aggregation.

Thus, the goal of the framework set out in Chapter 4 is to maximise the level of disaggregation, subject to data availability constraints discussed in Section 3.3 and the resources of this study.

3.3 Constraints on disaggregation due to Data Availability

In addition to considering what level of disaggregation is desirable (Section 3.2), the study's emphasis on use of existing datasets poses some constraints on the level of disaggregation that is feasible within this study and future studies.

The characteristics of existing datasets are discussed in more detail in the cost estimation section of this report (Chapters 5 and 6). Here the most important constraint facing the road and rail frameworks is discussed.

This constraint is the lack of availability of cost and revenue data for train operating companies at a greater level of disaggregation than that in the published accounts. This limits any analysis of revenues or operating costs by geographic location (e.g.

route), track type, train type or time period. The Strategic Rail Authority or Association of Train Operating Companies can only release such data with the consent of each individual Train Operating Company. Even with such consent, due to its stock market sensitivity, this data is protected by the terms of the Financial Services Act (1986).

3.4 Summary of factors affecting the study framework

Chapters 2 and 3 have drawn together the implications of economic theory, cost coverage constraints, charging instruments and availability of existing datasets for the design of the study's framework. The link between the short run marginal cost approach and theory is set out, while the origin of the fully allocated approach is shown to have come from the traditional form of analysis that was first proposed by the Ministry of Transport in 1968. The substantial potential for highly differentiated charging mechanisms to be supported by a framework with a high degree of disaggregation is highlighted. The constraints due to reliance on existing datasets, however, are shown to be particularly problematic for any information relating to train operating companies.

These influencing factors are re-visited in the next chapter, where the key features of the framework proposed in this study are specified.

4 Specification of the Framework

4.1 Overview

This chapter draws on the issues raised in previous chapters in determining:

- The relevant cost and revenue categories. These correspond to the alternative approaches of short run marginal cost and fully allocated cost;
- The level of disaggregation at which outputs from the framework are produced. This is affected by charging instruments, data availability and the resources available to the study;
- The policy questions that the proposed framework is able to answer. Here the charging, taxation and subsidy issues that the framework is able to address are set out; and,
- Other policy questions requiring complementary analysis tools. Inevitably, some questions require additional tools that are not developed as part of this study.

To provide a relatively concise chapter focussing on the framework, the details of the calculation methods for individual cost and revenue categories are confined to Chapter 5 for road and Chapter 6 for rail.

4.2 Defining the Relevant Cost and Revenue Categories

As Chapter 2 has illustrated, the marginal cost and fully allocated cost approaches are very different and consequently different cost and revenue categories are relevant. The definitions of these categories also varies. Thus the marginal cost components are set out first and then the contrast is drawn with the fully allocated cost approach.

For the costs of infrastructure use imposed by an additional vehicle or train kilometre, the relevant **marginal cost categories** are those imposed on:

- The infrastructure provider. Categories include wear and tear that results in maintenance costs and a proportion of operating costs;
- Existing infrastructure users. Categories include congestion, accidents and scarcity[4]; and,
- Those outside the transport sector. Environmental costs namely air pollution, noise and global warming.

Additional costs apply when scheduled transport services are involved. In this study, the marginal costs relating to bus and rail services that are relevant are:

- Costs of service provision. Since vehicle and rolling stock can be adjusted over a relatively short timescale it is reasonable to allow the stock and timetable to vary, and to include associated costs in the costs of service provision; and,

[4] This mainly relates to the provision of train paths when infrastructure is used to capacity. When the allocation of one train path precludes another service operating, there is an opportunity cost attached to the path.

- Costs imposed on other users of the service. These can be negative, i.e. benefits, if additional traffic results in better service provision. This phenomenon is known as the Mohring effect (Mohring, 1972).

These marginal costs are compared to existing revenues that may be considered marginal. The relevant revenue categories that vary with changes in vehicle of train kilometres are:

- Indirect taxes that are specific to the transport sector. These comprise fuel duties and the VAT levied on fuel duties[5]. VAT that is levied at lower than the standard rate is also relevant. This is identified as VAT not paid; and,
- Vehicle excise duty on heavy goods vehicles and public service vehicles. It is assumed that HGVs and PSVs are fully utilised at present, so that an increase in demand will result in a direct increase in the vehicle stock and thus in VED[6].

From the **fully allocated cost** perspective, the cost categories of interest are those imposed by the road or rail sector on the rest of society. The relevant revenue categories are defined in relation to these costs.

The distinctions between the definition of the marginal cost and fully allocated cost components are highlighted in Table 4.1.

[5] Note that VAT on the producers price is no different from VAT on other commodities and thus is excluded.
[6] This argument does not apply to cars or to light delivery vehicles.

Table 4.1: Comparison of Marginal Cost and Fully Allocated Cost and Revenue Definitions

Category	**Marginal cost basis**	**Difference under a Fully allocated cost basis**
Cost of capital	Not relevant.	Opportunity cost of capital (interest forgone on the net asset value).
Infrastructure costs	Mainly wear & tear costs that can be related to increased vehicle km.	Expanded to include all costs associated with upkeep of existing infrastructure – operations, maintenance and depreciation.
Vehicle operating costs (public transport)	Cost of an additional vehicle km.	Expanded to include all costs associated with providing services –operating, maintenance, depreciation costs plus cost of capital for vehicles.
Congestion	Costs imposed by one user on all other users of the transport system.	Not relevant. These costs are both imposed and borne by the infrastructure users – and effectively cancel out (see text below this table).
Scarcity	Opportunity cost of providing a service that precludes other services being run.	
Mohring effect	Benefits of increased service frequencies due to additional vehicle km.	
Accidents	External costs of an additional vehicle km, including the increase/decrease in accident risk due to increased traffic.	Overall external costs, attributed to user groups on the basis of responsibility.
Environmental costs	Costs of an additional vehicle km	Costs of all vehicle kilometres.
Fuel duties	Revenue associated with an additional vehicle km	Total revenue from fuel duties
Vehicle excise duty	Revenue relating to an additional vehicle km – only for those vehicles where an increase in vkm would result in an expansion of the vehicle fleet (e.g. HGVs, PSVs, but not cars, LDVs).	All VEDs
Value added tax	On fuel duties.	On fuel duties.
Fares, freight tariffs	Associated with an additional vehicle km	All fares, tariffs.

Two important notes need to be made on the fully allocated cost categories contained in Table 4.1:

- Capital costs relating to future capacity increases are excluded. This is because if in future years' depreciation is to be set against user revenues, then to also include infrastructure expansion costs in the present year's costs would result in double counting. The asset would be charged both prior to its use, when the expenditure occurs and when it is being consumed in use;

- Costs internal to the transport system, such as congestion, are excluded from the fully allocated cost analysis. Transport users both impose and bear these categories of costs. It could be argued that the costs imposed may not entirely net out with the costs borne. For example, the costs imposed by car users on HGVs may not cancel with the costs imposed by HGVs on car users. In theory, the net impositions from one group of users on another would be amenable to empirical analysis. Such analysis could involve examining, for example, the cost of congestion on motorways if all HGVs are removed. Such comparisons tend to strain credulity, however, as it is difficult to envisage removing all HGV traffic from road networks. For these reasons, the net imposition of one group of users on another group has not been examined in the fully allocated cost analysis in this study.

A summary of the cost and revenue categories of relevance to the two approaches is given in Table 4.2.

Table 4.2: Summary of Relevant Cost and Revenue Categories

Categories	**Short-run marginal cost analysis**		**Fully allocated cost analysis**	
	Road	**Rail**	**Road**	**Rail**
Cost of capital	-	-	✓	✓
Infrastructure costs	✓	✓	✓	✓
Vehicle operating costs	PSV only	✓	PSV only	✓
Electricity costs	-	✓	-	✓
Congestion	✓	✓	-	-
Scarcity	-	✓	-	-
Mohring effect	PSV only	✓	-	-
Accidents	✓	✓	✓	✓
Air pollution	✓	✓	✓	✓
Noise	✓	✓	✓	✓
Global warming	✓	✓	✓	✓
VAT not paid	PSV only	passenger only	PSV only	passenger only
Fares and freight tariffs	PSV only	✓	PSV only	✓
Fuel duty	✓	-	✓	-
VAT on fuel duty	✓	-	✓	-
Vehicle excise duty	commercial vehicle only	-	✓	-

Key: ✓ = relevant for inclusion, although not necessarily included in the empirical work. PSV – public service vehicle, i.e. local buses and coaches.

There are many other cost categories that are of potential relevance to transport charging, but which are not readily amenable to monetary valuation are thus not discussed in depth. These include: environmental damage associated with infrastructure provision; the social costs of subsidised parking provision; the barrier effect of transport infrastructure and traffic movement on community activity; upstream and downstream environmental effects relating to fuel and vehicle/train production; and water pollution.

4.3 The Level of Disaggregation of Outputs

Output disaggregations are determined by the level of detail that can be usefully integrated within a charging system and also by the characteristics of existing datasets.

The key disaggregations are for:

- Area type. Urban, rural etc. locations have an important influence on congestion, accidents, air pollution and noise;
- Road or rail infrastructure type. Infrastructure, congestion and accident costs are sensitive to the type of infrastructure, for example, whether or not the infrastructure is designed for high traffic volumes or high speed trains;
- Vehicle or train type. Each cost and revenue category varies strongly by vehicle or train type; and,
- Time period. Congestion and, via vehicle speeds, environmental costs are closely related to traffic volumes and thus to time periods.

For the **road analysis**, disaggregation has been possible for all four of these key variables. The number of levels is shown in Table 4.3.

Table 4.3 Disaggregation of Road Outputs

Variable	Number of Levels
Area type	11 levels • 3 London • 2 conurbation • 5 urban • rural
Road type	3 levels • motorway • trunk & principal • other
Vehicle type	5 levels • Car • Light Delivery Vehicle • Heavy Goods Vehicle – rigid • Heavy Goods Vehicle – articulated • Public Service Vehicle
Time period	2 levels • weekday peak (0700-1000, 1600-1900); • all other time periods in the week

Each choice of the level of disaggregation for each variable is discussed in turn. A more detailed alternative is also set out for each variable.

The format of the road traffic database for congestion cost calculations and the structure of the study's environmental models determined the use of 11 area types. An alternative approach would have been to use more detailed location information.

This could have included a representation of the trunk road network that could be tolled and the large cities for which urban road pricing would be a realistic policy tool.

Due to the specification of the infrastructure cost database (NERA, 1999) and the traffic cost database, 3 road types were chosen. Although the infrastructure cost database separates A roads into trunk roads and local authority roads, the traffic database did not make this distinction, so that these two categories of roads were merged. An alternative disaggregation would break down infrastructure costs into more road types.

Since the traffic database for congestion was limited to 5 vehicle classes while the databases for infrastructure costs, accident and environmental costs contain more detailed breakdowns, 5 vehicle class disaggregations were used. Another option would be to have many more vehicle types, perhaps approaching the number of vehicle excise duty bands (i.e. over forty types). This would allow infrastructure and environmental costs to be identified with vehicle types to a greater degree.

The last disaggregation, of 2 time periods, was chosen to enable the environmental calculations to be performed at a manageable level. Infrastructure costs vary little with time period, and accident costs could be estimated according to time period. For these reasons the 19 time periods in the traffic database could be used as a future basis for disaggregation.

The disaggregations that are discussed in Section 3.2 but which are not shown in the road outputs are for engine type, fuel type and vehicle vintage. To maximise the accuracy of the environmental costs the most important distinctions for these classifications have been incorporated in the environmental analysis in the representation of the 1998 vehicle fleet (see Section 5.6). To ensure the manageability of this study's framework, however, these disaggregations were not used to structure the outputs from the road framework.

Depending on the Department's priorities the alternatives described above could be readily taken forward.

For the **rail analysis**, the level of disaggregation has effectively been limited to five types of service. This is due to the limitations on train operating company data (Section 3.3). The five service types were defined as:

- InterCity passenger services;
- Regional rail passenger services;
- London commuter catchment area services;
- Bulk freight, freight for which trainloads comprise one commodity; and,
- Other freight.

The limitations on operating company data contrast sharply with data available relating to Railtrack costs. This is partly a function of the timing of the periodic review (ORR, 2000), which overlapped with the timescale for this study. Highly disaggregate information exists on infrastructure wear and tear costs, electricity consumption and congestion.

Unfortunately, the Strategic Rail Authority does not have the right to make available the detailed operator data that is collected for monitoring purposes, without the consent of each individual passenger and freight train operator. The Association of Train Operating Companies is in a similar position for passenger data. Given these circumstances, negotiation with individual train operators would be necessary if a more disaggregate framework were to be created. A further constraint is that market sensitive data is protected from release under the terms of the Financial Services Act (1986).

A further alternative would be to focus entirely on the track access charges levied on train operators and neglect charging issues relating to the final passenger or freight customer. This would require augmentation of existing data sources with environmental cost data and information on scarcity costs.

The potential for enhancing the capabilities of the road and rail frameworks is returned to in the final chapter of this report.

4.4 Policy Questions that the Proposed Framework is able to Answer

Having determined the key features of the road and rail framework it is important to be explicit about the capabilities of the framework (this section) and also the policy questions that require complementary tools (Section 4.5).

Five questions may be addressed by the short run marginal cost analysis. These are:

- **What should the direction of change in prices be if existing charges are set to maximise economic welfare?** Existing charges include fuel duties and vehicle excise duty for road and charges to rail passenger and freight customers;
- **In broad terms, does there appear to be a need for the introduction of new pricing instruments in the road sector?** These include urban and inter-urban pricing systems (both low technology and more sophisticated solutions) and electronic tachographs for HGVs;
- **Are current levels of subsidy justified on economic efficiency grounds?** If marginal costs are lower than (or equal to) existing charges this implies that to maximise economic welfare the current level of subsidy is appropriate (or is insufficiently high); and,
- **How do weighted short run marginal costs compare to charges for the road and rail sectors at the national level?** Weighting by overall vehicle or train kilometres yields a broad measure of the overall direction of change in charges. If there is clear under- or over-pricing of a given mode this measure provides a useful indicator.

Two questions arise from the fully allocated cost perspective:

- **How do total costs calculated on a fully allocated cost basis compare to overall charges for the road and rail sectors at the national level?** this comparison provides what some would view as a test of the fairness of current charging levels; and,

- **If overall costs are allocated to different vehicle or train types, how do these compare to revenues?** Since many costs are joint within a sector, there is no robust way of fully allocating costs to vehicles or train types. Despite this, again some view this as a test of "fairness".[7]

The following section seeks to clarify where additional tools are necessary to go beyond these policy questions. In part this helps to define the limitations of the framework and also identify future priorities for extending the framework.

4.5 Policy Questions Requiring Complementary Tools

Some of the issues that may not be addressed by the framework produced in this study are:

- What the magnitude of change in prices should be. If a transport demand model were added this would enable iterations between prices, demand and costs to be made. This approach would allow for equilibrium charges to be calculated[8];
- What level of infrastructure provision is appropriate. The framework would need to be augmented with an estimate of the incremental costs of capital and a method for estimating user benefits if it were to be used as a tool for exploring whether or not the current level of infrastructure expansion is satisfactory, excessive or inadequate;
- Which pricing instruments should be introduced. Additional information on capital and operating costs would be needed in order to make a robust case for new and more differentiated pricing systems; and,
- Whether current levels of safety and environmental regulation are at an appropriate level. The framework would need to be augmented with cost information on different levels of regulation in order to determine whether current regulations are excessively lax, about right or overly stringent.

These limitations are reiterated in the subsequent results chapters in order to avoid any misinterpretation of the findings of the research.

[7] As noted in Section 2.2, since the fully allocated costs approach has no real basis in economic theory this would only be accepted as a test of fairness or equity by a small minority of economists.

[8] This is an extremely important complement as the case studies in Proost and Van Dender (1999) and Nash (2000) show that equilibrium prices in some situations may be one third to one half of the marginal costs estimated in the base demand situation.

5 Estimation of Cost and Revenue Categories for the Road Framework

5.1 Cost of capital for infrastructure

As noted in Section 4.2, this is only relevant for the fully allocated cost analysis. The steps involved in calculating the cost of capital are to:

- Estimate the net value of road infrastructure assets;
- Apply the public sector discount rate (6%), representing the interest foregone; and,
- Allocate to vehicle types on the basis of PCU-km (85% of total allocation) and gross maximum vehicle weight-km (15%), following the 'road track costs' methodology (DoT, 1995).

The DIW et al. (1998) study of HGV costs applies an accountancy approach (the perpetual inventory method) to estimate the value of the current asset stock. The estimate obtained, of £57.4 billion for 1994/5 in 1994 prices, is reported in NERA (1999).

Newbery (1998) reports a value for the capital stock of £120 billion in 1998 prices. This was determined by adding the gross value of investment in roads each year to the last figure for the capital value of the road system published (for the year 1981).

On the basis of these figures, low and high ranges of asset values of £60 and £120 billion were adopted for use in the analysis, yielding a cost of capital of £3.6 and £7.2 billion. When the proportion allocated to motorcycles is excluded these allocated costs amount to £3.4 and £6.8 billion p.a.

The difficulty of estimating asset values, and thus the cost of capital is a particular constraint on the use of results from a fully allocated cost approach. Alternatives include historic cost, replacement cost or modern equivalent asset valuation. These difficulties are more pronounced due to the unique nature of the transport networks involved.

5.2 Infrastructure operating, maintenance and depreciation costs

The full range of infrastructure costs is relevant to the fully allocated cost analysis. Only a subset of infrastructure costs can be related to traffic volume and thus included in the marginal cost analysis. The database used in this analysis is from NERA (1999), an update of the Allocation of Road Track Costs analysis. The same procedure is followed for both the marginal and fully allocated cost analyses:

- Costs for 15 expenditure categories and 4 road types are estimated for 1998;
- For each of the 15 expenditure categories, the relationship with cost drivers is determined (the cost drivers being PCU-km, average gross vehicle weight-km, maximum gross vehicle weight km, and standard axle-km). Again, the allocations used in the road track costs exercise are assumed to apply. These relationships are shown in Table 5.1 (along with the categories considered to be marginal);

- The cost drivers for 37 vehicle categories (most of which relate to heavy goods vehicles, but also including cars, PSVs) are estimated for the 4 road types;
- Costs are then allocated to the 37 vehicles by 4 road types; and,
- The final infrastructure cost outputs, for the 5 vehicle types and 3 road types are then created by weighting the disaggregate vehicle/road types according to relative vehicle km.

Table 5.1: Values of Cost Drivers and inclusion in MC Analysis

Description	PCU -km	av.gwt -km	max gwt -km	sa - km	Include in MC?
Long-life pavements				100%	✓
Resurfacing				100%	✓
Overlay				100%	✓
Surface dressing	20%	80%			✓
Patching and minor repairs		20%		80%	✓
Drainage	100%				✓
Bridges and remedial earthworks		100%			-
Footways, cycle tracks & kerbs		100%			-
Fences and barriers	33%	67%			-
Verges, traffic signs and crossings	100%				-
Sweeping and cleaning	100%				-
Road markings	10%	90%			✓
winter maintenance & misc.	100%				-
Street lighting	100%				-
Policing and traffic wardens	100%				-

Note: av.gwt– average gross vehicle weight; max gwt – maximum gross vehicle weight; sa – standard axles (a measure of the relative damage due to axle weights). The costs attributed to pedestrians for roads other than motorways (50% of the categories from Fences and barriers through to Street lighting) are removed prior to allocation to motorised vehicles.

As a proxy for depreciation, renewals expenditure was adopted. Since there is a danger that renewals expenditure has been insufficient to maintain the quality of the overall road network, this figure was used as a lower bound. On the basis of our judgement, an upper bound was estimated by increasing infrastructure costs by 30%.

5.3 Vehicle operating costs (public service vehicles only)

Vehicle operating costs for public service vehicles enter into both the fully allocated cost and marginal cost analyses. Operating costs from Transport Statistics Great Britain (DETR, 2000) for local bus services for London, the English Metropolitan areas and other areas of Great Britain were mapped onto comparable area types. English Metropolitan areas were assumed to be similar to conurbations in general, whilst statistics for other areas of Great Britain were adopted for smaller urban areas and rural areas.

For non-local bus services, for which geographically-based data is not collected, the assumption that operating costs per vehicle kilometre were uniform across Great Britain was adopted.

Operating costs include an element of taxation (including vehicle excise duty, net fuel duty and VAT on fuel duty). Rather than remove these elements from operating costs, the results for PSVs also show the offsetting taxation components that are paid. In this way, the taxation components in costs and revenue cancel out, and the comparison that is left is between social costs in resource terms and fares paid by passengers.

5.4 Congestion

Congestion costs are only relevant to the marginal cost analysis. The main database used in their calculation was the National Road Traffic Forecasts (NRTF) database. This is disaggregated according to 11 area types, 5 urban and 7 rural road types, 19 time periods, 4 vehicle types, and for car, by 6 categories of journey purpose. Calculations were carried out at this disaggregate level.

In most circumstances when an additional vehicle enters the road system it will cause delays to the existing vehicles on the network. It is this additional cost to other vehicles that is known as the marginal external cost of congestion. As it is the external cost that is of interest, the marginal external cost of congestion does not include the additional vehicle's private travel time.

The marginal external cost of congestion (MECC) is thus derived by differentiating total time cost (TTC) by traffic volume (Q), and subtracting the average time cost (the value of time, VOT, multiplied by the average time, AT). The average time cost is subtracted in order to remove the additional vehicle's private travel time cost.

Total time cost for a 1 kilometre stretch of road on which traffic travels at speed S is given by:

$$TTC = VOT.Q.AT = VOT.Q.\frac{1}{S}$$

So that differentiating this and then subtracting the average time cost gives:

$$MECC = \frac{\partial TTC}{\partial Q} - VOT.AT = VOT.Q.\frac{-1}{S^2}\frac{\partial S}{\partial Q}$$

A linear speed-flow curve (constant term α, slope -β) gives speed as:

$$S = \alpha - \beta.Q$$

Thus the marginal external congestion cost is given by the following equation:

$$MECC = \frac{\beta.VOT.Q}{S^2}$$

Where, to reiterate, β is the slope of the speed-flow function, VOT is the value of in-vehicle time, Q is the traffic volume and S is the traffic speed.

The steps followed in operationalising this equation for the marginal external cost of congestion were:

- Factor up 1996 traffic figures to 1998 - using Transport Statistics GB (DETR, 2000) figures for growth in vehicle km for car, LDV, HGV-rigid, HGV-artic and PSV;
- Factor down 1996 speeds to give 1998 speeds – assuming a linear speed-flow curve, this was done on the basis of growth in relative PCU-km;
- Estimate the composite value of time for each disaggregation – weighting standard resource values of time per vehicle (the 1994 values contained in Highways Economics Note 2, DETR 1997, uprated to 1998 prices and values using the nominal average earnings index) according to journey purpose/ vehicle type;
- Associate a speed-flow curve with each road type – the NRTF speed flow curves that define traffic speed at any given flow were taken from NRTF Working Note 4 (DETR, 1999a);
- Estimate the flow per hour per lane – through use of the speed-flow curve and the 1998 speed;
- Calculate the marginal external cost of congestion per PCU – using the above equation;
- Weight these disaggregate outputs by relative PCU-km in order to give the cost per PCU for the 11 area, 3 road, 5 vehicle types and 2 time periods specified for the road framework; and,
- Apply PCU factors to convert to marginal costs per vehicle km (1 for car, LDV; 1.68 for rigids, 2.46 for artics, 1.5 for PSVs).

The NRTF model team within the DETR has examined this methodology, and has also developed a parallel method making direct use of the NRTF model. This loads a very small additional proportion (less than 0.01%) of traffic onto an individual link. The next step was then to use the model to estimate the increase in generalised time caused by this incremental increase in traffic. The NRTF team has confirmed that the initial results from this analysis concur with those of this study.

A worked example is given in Table 5.2 for the following disaggregation from the traffic database:

- Direction – busy (i.e. in direction of peak flow);
- Area – Inner London;
- Road type – motorway; and,
- Time period – Saturday, 0900-1400.

Table 5.2: Example of the calculation of marginal external costs of congestion
Results shown in 1998 prices and values, per PCU km

Step	Component	Output	Units
1. **Calculate ratio of 1996 to 1998 PCU km**	PCU, 1996 (from NRTF database)	4.03 x 10^6	annual PCU km
	PCU, 1998	4.18 x 10^6	annual PCU km
	Ratio (1996/ 1998)	96.4%	no units
2. **Estimate 1998 speed** (assuming that for a small change in speed, the speed-flow curve is linear)	Light vehicle speed, 1996 (from NRTF database)	78.61	kph
	Speed, 1998 estimate	78.61 x 96.4% **= 75.6**	kph
3. **Estimate value of time** (use of HEN2 values not shown here)	Value of time	**796**	pence/hour/average PCU, 1998 prices, values
4. **Identify the appropriate speed-flow curve** *	1st point on S-F curve	1000 97	PCU/lane/hour kph
	2nd point on S-F curve	1200 80	PCU/lane/hour kph
	Slope	(97-80)/ (1000-1200) **= -0.085**	kph per (PCU/lane/hour)
5. **Infer flow**, from speed-flow curve (extrapolate beyond 2nd point on S-F curve)	Flow	1200 + 0.085*(80-75.6) **= 1250**	PCU/lane/hour
6. **Calculate marginal external congestion cost**	Slope × Value of time × Flow × 1/(Speed^2)	0.085 × 796 × 1250 × 1/(75.6^2)	
	= MECC	**= 14.8**	pence/ PCU km

*Note: looking at a speed-flow curve (speed = y-axis; flow = x-axis), the first linear S-F curve is shallow and the second is steeper; since speeds is <97 kph, this second linear portion is selected for these calculations.

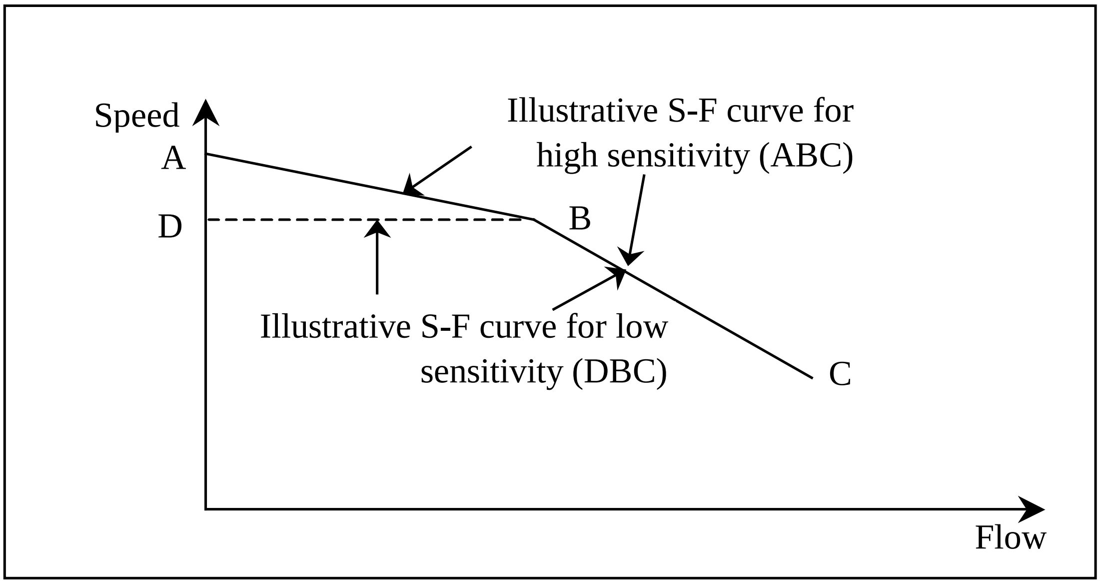
It was not possible to carry out many tests of the sensitivity of the estimates of congestion costs to assumptions about the speed-flow curves within this study's resources. For many of the environmental values used in this study the range of uncertainty regarding economic values that has been accepted in other studies has been adopted. Speed-flow curves used for highway appraisal and design purposes, however, are expressed in terms of single estimates rather than ranges and uncertainty is taken account of at a different stage of the decision process. Since this study has been concerned with developing estimates of transport costs and charges from existing data and methods, it has not been possible to test in any detail the sensitivity of the congestion costs estimates to alternative sets of speed-flow curves.

When the importance of congestion costs in the overall analysis became apparent, however, comparison was made between the speed-flow curves in use in UK appraisal (COBA10, DMRB) and those specified in the USA High Capacity Manual (TRB, 2000). The UK curves are defined by segments that reflect a small decrease in speed with additional traffic, followed by a more dramatic decrease as the road approaches capacity.

In contrast, those in the US Highway Capacity Manual[9] are characterised by the absence of an impact on vehicle speeds of increased traffic until traffic reaches between two-thirds (high capacity road) and one third (low capacity road) of capacity (Gartner et al.,1996). This implies a zero marginal external congestion charge until over half of capacity is used. As with most speed-flow formulations, the curve is undefined once traffic exceeds road capacity. Gartner et al. (1996) also provides a critique of the UK speed-flow curves contained in COBA9, suggesting the empirical evidence to support a downward sloping curve at low traffic flows is weak.

As a broad indication of the difference between the US and the UK curves, as sensitivity was carried out assuming that the first portion of the UK speed-flow curve had a zero gradient. This yields a zero marginal external cost of congestion for all road types, time periods etc. when traffic volumes are low in relation to capacity. Figure 5.1 provides an illustration of the variants of speed-flow curves used in the low and high cost estimate sensitivities.

Figure 5.1: Speed-flow curves used in congestion sensitivities



Although the detailed results are confined to Chapter 7, in this section some of the overall congestion results are reported. Table 5.3 shows the marginal external costs of congestion for low and high cost estimates for different combinations of road type, area type and time period.

[9] In the 1994 and 2000 versions, previous versions had a smooth curve that has approximately the same shape as the COBA piecewise linear speed-flow function.

Table 5.3: Estimates of the Marginal External Costs of Congestion

Pence per vehicle kilometre, 1998 prices and values

Category	Proportion of vehicle km	Low	High
Motorway	17%	12.80	12.80
Major urban central peak	1%	85.76	85.87
Major urban central off-peak	3%	46.61	47.15
Major urban non-central peak	4%	22.89	24.26
Major urban non-central off-peak	8%	11.09	13.67
Other urban peak	7%	4.58	8.38
Other urban off-peak	15%	0.65	4.89
Rural trunk & principal	30%	9.11	9.21
Rural other	16%	1.32	2.92
Overall	100%	9.71	11.16

Note: major urban area refers to London and conurbations.

For motorways, rural trunk and principal roads and roads in major urban areas the similarity of low and high cost estimates reflects the limited number of disaggregations that lie on the shallow part of the speed-flow curve (see Figure 5.1).

As the figures in Table 5.3 indicate, the sensitivity test conducted is only a very limited one, with minimal impact. It should be noted that the "low" and "high" labels used do not reflect the full range of low and high values that would have been produced with more comprehensive sensitivity testing.

Table 5.3 also reveals the sensitivity of the estimates to the context. The disaggregations shown in this table were chosen to facilitate comparison with results from Newbery (1990).

The results of Newbery (1990) are shown in Table 5.4. Care should be taken in comparing the results in Tables 5.3 and 5.4, since the figures in Table 5.4 are based on Newbery (1990) and uprated by the increase in average earnings between 1990 and 1998 (as opposed to calculations based on 1998 traffic levels and speeds) and are expressed per PCU kilometre (and not per vehicle kilometre). Furthermore, the Newbery (1990) figures were adapted from the 1985 figures originally presented in Newbery (1985).

Table 5.4: Estimates of the Marginal External Costs of Congestion from Newbery (1990)

Pence per vehicle kilometre, 1990 figures factored by increase in average earnings (1998/1990)

Category	Proportion of vehicle km	MCC
Motorway	17%	0.39
Urban central peak	1%	55.12
Urban central off-peak	3%	44.30
Non-central peak	3%	24.04
Non-central off-peak	10%	13.25
Small town peak	3%	10.45
Small town off-peak	7%	6.37
Other urban	14%	0.12
Rural dual carriageway	12%	0.11
Other trunk and principal	18%	0.29
Other rural	11%	0.07
Overall	100%	5.15

Note: PCU figures converted to vehicle figures by multiplying by a factor of 1.067.

Taking into account the different years, the larger values shown in Table 5.4 exhibit the same pattern as those in Table 5.3 and in many cases are broadly of the same order of magnitude. The main difference appears to be for the categories at the low end of the spectrum in Table 5.4, for which there are major differences.

The marginal external congestion costs developed in this study may also be compared with the decongestion benefits per car kilometre used in the appraisal of public transport initiatives such as light rail schemes. It should again be noted that the estimates in this study are at the current level of demand, whilst the estimates used in appraisal are obtained from transport models in which new demand equilibria have been reached.

A range of 12.7 to 50.8 pence per PCU km in 1998 prices and values is identified for assessing the decongestion benefits of "major rail-based urban public transport" (DoT, 1994, uprated using the average earnings index).

5.5 Mohring effect (public service vehicles only)

The Mohring effect is only relevant for the marginal cost analysis. It is a form of user economy of scale in public transport services. As traffic on a particular route increases, so public transport operators tend to improve the frequency of service, and to provide other benefits to passengers. Other benefits may include services to a wider range of places and a mix of express and stopping services. If it is assumed that any increase in passengers on public transport is met with a proportionate increase in services, there are clearly benefits to existing users from increases in traffic.

In practice, it may be that operators would not increase services, or would not increase them proportionately. In such circumstances, if the result is simply increased load factors, then there is no Mohring effect and the marginal cost to operators is close to zero (although there may be a disbenefit to passengers from increased crowding to take into account). If operators maintain load factors by operating larger vehicles then there is no disbenefit to passengers but there is a significant marginal operating cost, which, however, is typically well below average cost.

In this study the assumption has been made that operators increase service frequencies in direct proportion to increases in patronage. Indicative service frequencies for different area types were used.

A basic approach to estimating the Mohring effect is set out in Sansom et al. (1999). The steps in the calculation begin by estimating the marginal external benefit of increased passengers as the number of existing passengers (Q) multiplied by the change in their average cost (AC) with a change in passengers:

$$Q.\frac{\partial AC_{user}}{\partial Q}$$

An increase in frequency allows the user to choose a more favourable departure time. The value placed on departure time can be taken as half the headway (h), multiplied by the value of time for departure time shifts (VOT_{dep_time}). The above equation then becomes:

$$Q.\frac{\partial}{\partial Q}[0.5.h.VOT_{dep\_time}]$$

Furthermore, if occupancy (O) is fixed and Q is expressed in terms of passengers per hour, the headway equals O/Q and the equation becomes:

$$-0.5.\frac{O}{Q}.VOT_{dep\_time} = -0.5.h.VOT_{dep\_time}$$

The negative sign indicates that this is a marginal external benefit rather than a cost.

The results of Wardman (1998) suggest that the mean value of departure time shift may be taken as 0.72 of the value of in-vehicle time. If service frequency is equal to or less than every 10 minutes, however, passengers are likely to turn up at random so that the departure time shift becomes wait time and, again according to Wardman (1998) this should be valued at a multiple of 1.6 of the value of in-vehicle time.

Standard appraisal values of in-vehicle time (Highways Economics Note 2, uprated to 1998 prices and values using the nominal average earnings index) were combined with service frequencies and the average journey length to convert to per vehicle kilometre figures from the Bus Industry Monitor (TAS, 2000a). A 10-minute service frequency was used for built-up areas (London and other conurbations), a 20-minute service interval for other urban areas, and an hourly service for rural areas.

5.6 External accident costs

Two very different approaches were followed for the fully allocated cost and marginal cost approaches. These differ because:

- The fully allocated cost approach does not take account of the way in which accident rates vary with additional traffic. It simply takes into consideration the total social cost of accidents. In contrast, in the marginal cost analysis additional vehicle kilometres may raise the accident rate; and,
- The component of accident values relating to individual drivers' willingness to pay to avoid accidents is assumed to be an internal cost, similar to congestion, which is not relevant in the comparison of fully allocated costs and charges. The same applies for marginal costs, except for circumstances where additional traffic raises the accident rate. In this case the full accident value applies.

The fully allocated cost and marginal cost approaches are set out in turn.

For the **fully allocated cost** approach, the starting point is the calculation of accident rates per vehicle kilometre based on Road Accident Statistics, Great Britain (DETR, 1999c). The steps involved in accident rate calculation were:

- Use of statistics on absolute numbers of casualties by type of accident by road/area – e.g. car-pedestrian in built-up areas;
- Classification into accidents involving 1 road vehicle, 2 or more vehicles, 1 vehicle and a vulnerable road user (pedestrian, cyclist) etc.; and,
- Conversion to casualty rates per vehicle km for car, light vehicle, HGV (rigids and artics combined) and PSVs.

Standard evaluation values per casualty were used in order to derive monetary values (Highways Economics Note 1; DETR, 1999d). Following the empirical values cited in Christensen et al. (1998) some important changes were made to these, namely:

- Reducing material damages by 40% to reflect the fact that a proportion of these will be reflected in insurance payments; and,
- Adding an additional component, 40% of the individual's willingness to pay for risk reduction, as an estimate of the value that friends and family place on reduced risks. This component is not included in the standard UK appraisal values, and it is conventional to use this in a high sensitivity because there are mixed views on whether friends and family are indifferent or not between individual's risk reduction and money payments.

For the **average accident costs**, the external component of the unit value comprises these net material costs plus the values held by friends and family.

In the absence of robust empirical evidence, an assumption that responsibility is shared equally between the parties involved (e.g. 50:50 for a car-HGV conflict) was adopted for accidents in which vulnerable road users (i.e. pedestrians, cyclists) were not involved. Where vulnerable road users were involved, the external costs were shared equally between the motorised parties involved – with no allocation of costs to the vulnerable road users.

In the case of **marginal cost analysis**, when an additional road user raises the accident rate per vehicle km for all existing transport users, the full value per accident is relevant because this additional risk is external to the additional road user. The full value is also applicable when the costs are imposed on vulnerable road users.

In the marginal cost analysis, the impact of additional traffic on accident risk rates is known as the risk elasticity. Non-zero risk elasticities were only applied in the case of the high cost estimates. For these, the elasticities applied in the analysis, sourced from the European PETS project (Jansson and Lindberg, 1998), were:

- For cars, light vehicles — 0.25 in urban areas, zero for inter-urban contexts; and,
- For HGVs, PSVs — 0.25 in urban areas, 0.5 for inter-urban contexts.

The use of risk elasticities, as opposed to the commonplace assumption of constant risk rates, strongly influences the marginal cost estimates. The risk elasticities were multiplied by unit values and risk rates to yield the marginal external cost by vehicle type and by motorway/other road in built-up area/other road in non-built-up area. These were then linked to the road and area types contained in the framework.

In addition to the elasticity sensitivity (discussed above) for the marginal cost of accidents, for both approaches a low sensitivity was constructed by omitting the value held by friends and relatives.

5.7 Air pollution

The framework quantifies the health and non-health (environmental) effects of atmospheric emissions. Annex B contains a more detailed explanation of the method followed in estimating these environmental costs.

The study has quantified and valued the impacts of emissions using a step by step approach, based on the impact pathway or dose-response methodology (EC, 1995). This is:

- Assess the atmospheric emissions of all pollutants from vehicles. Emissions of carbon dioxide, carbon monoxide, SO_2, NO_x, PM_{10}, hydrocarbons, benzene and 1,3-butadiene have been compiled for each individual vehicle type. Emissions of benzo-[a]-pyrene have also been considered as an indicator of potential impacts from PAHs;
- Assess the effect of these emissions on local and regional air concentrations (including secondary pollutants formed);
- Quantify the health and environmental impacts of pollution concentrations using dose-response functions and data on the population or stock exposed at both the local and regional level; and,
- Value these health and environmental impacts in monetary terms.

Data on emissions from individual road vehicles were taken from the National Atmospheric Emissions Inventory (Salway et al, 1999). Emission factors were collated for the following vehicles.

Table 5.5: Vehicle Types for Air Pollution Cost Estimation

Passenger car	**Light delivery vehicles**	**Heavy goods vehicles**		**Public service vehicles**
		Rigid	**Artic**	
• Petrol	• Petrol	• 3.5 to 7.5 tonne	• up to 33 tonne	• Bus
• Diesel	• Diesel	• 7.5 to 17 tonne	• 33 to 38 tonne	• Coach
		• 17 to 26 tonne	• over 38 tonne	
		• 26 to 32 tonne		

In each case, separate emissions factors were collated by:

- Vehicle technology standard – for pre-Euro, Euro I, and Euro II vehicles; and,
- Speed - with factors for each of 9 speed band categories: <= 10 mph, 11 - 15 mph, 16 - 20 mph, 21 - 25 mph, 26 - 30 mph, 31 - 40 mph, 41 - 50 mph, 51 - 60 mph, > 61mph.

These data were used to compile 1998 emissions, by speed band, for each of the vehicle classes in Table 5.5. These were combined with information in the NRTF to estimate the speed-adjusted emissions for the framework matrix, i.e. for different vehicles on each of the area and road types, for both weekday peak and other time period travel.

The modelling of air pollution concentrations and estimation of health and non-health impacts were calculated using the ExternE computer tool (EC, 1999b). This tool is based around a geographical information system (GIS) and has a series of databases and models to allow the integrated quantification and valuation of environmental costs. It includes local and regional dispersion models as well as databases on the distribution of people, buildings and crops. The model was run in a number of different areas to take account of the effects of population density - air pollution impacts are higher in urban areas because the population weighted exposure is higher. The areas were set to match the eleven geographical categories in the NRTF, which range from 'Central London' to 'rural'. In each area, the model was used to quantify the receptor-weighted pollution increases from transport emissions. These were linked with dose-response functions and valuation endpoint estimates to calculate external costs.

The dose-response functions used for health evaluation were based on two major studies: COMEAP and ExternE. The UK Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP, 1998) reviewed the relationships between air pollution and health. It provided relationships for use in quantification of these health effects for the UK. Only those effects which the Committee felt could be applied to the UK with reasonable confidence were included. The EC's ExternE Project (EC, 1999: 2000) also reviewed and provided relationships between air pollution and health, drawing on UK, European and International studies. As well as the functions included in COMEAP, ExternE recommended the quantification of additional health effects where good evidence existed, even if quantification was more uncertain, such as with chronic mortality effects[10].

To acknowledge the different uncertainty in the use of COMEAP and ExternE recommendations, the health impacts from the two were calculated separately, though in the summary tables the values are combined to a single air pollution value. Further analysis of the health effects was also undertaken, separating health endpoints into four uncertainty bands to reflect the level of confidence in the effects (i.e. the consensus on the impacts being real) as well as the confidence in the quantification method. Further details of this uncertainty analysis are presented in Annex B.

The valuation of the health endpoints recommended by COMEAP was based on the recommended values from the Ad-Hoc group on the Economic Appraisal of the Health Effects of Air Pollution (EAHEAP, 1999). The group recommended a number of alternative values for air pollution mortality. A maximum value (£1.4 million) based on an adjusted value of statistical life (VSL) and a range of values (from £2,600 – £110,000) based on adjusting the VSL to take account of life expectancy (years of life lost) and quality of life. The reported results use the values from the years of life lost approach for the low and central estimate (low £2,600 – central £110,000), with the high value based on the full VSL of £1.4 million[11]. The values for additional health endpoints as recommended by ExternE were taken from the latest ExternE report (EC, 2000). These include the assessment of chronic mortality, based on a years of life lost approach. Details and the results of the additional sensitivity analysis by uncertainty band are presented in Annex B.

The analysis of non-health impacts also followed a dose-response approach using the ExternE computer tool. Quantification and valuation followed the approach of ExternE (EC, 1999: 2000) and is consistent with the recent economic assessment of the National Air Quality Strategy (DETR, 1998). Impacts considered included building soiling, material corrosion and crop damage. There are a number of non-health impacts for which valuation is currently not possible, including acidification, eutrophication and fertilisation effects on forests and ecosystems (terrestial and aquatic). They are also potential non-health effects on visibility. The values for non-health impacts should therefore be considered as a sub-total.

The analysis of both health and non-health impacts used linear functions, which are implemented without a threshold of effect (i.e. down to zero pollution levels). This is consistent with previous UK studies, including the COMEAP and EAHEAP analysis. Marginal and average costs are therefore reported as being equal. For the marginal costs reported in this study, i.e. the costs of one additional vehicle, this assumption is valid. The application of these values to look at greater marginal changes would need

[10] It should be noted that since the analysis in this study, COMEAP has recommended and produced values for the quantification of chronic mortality effects (COMEAP, 2001). The approach used in the two studies are similar, and the functions used here fall within the range recommended by the COMEAP paper.

[11] Note, the use of the full VSL for acute mortality is likely to be a significant overestimate given the evidence on the amount of life lost from air pollution related mortality. Also, whilst the use of the 'value of life years' derived from VoSL is a reasonable approach for valuing deaths brought forward, new evidence is expected shortly from DETR which will provide direct WTP for these health endpoints.

some adjustment because larger marginal changes would alter traffic speeds and so emissions. This analysis is complicated because of the U shaped relationship between speeds and emissions. It is likely that in congested areas, where vehicle speeds are low, additional vehicles will lead to overall speed reductions and will increase emissions (because emissions are higher at very low speeds). In contrast, on high-speed roads, reductions in speeds will decrease emissions (as emissions are higher at very high speeds). Inclusion of speed effects would lead to higher marginal costs for urban traffic, but lower marginal costs for motorway traffic. Further investigation of these marginal issues especially for urban areas are highlighted as a research priority. Additional assumptions and issues with marginal valuation are presented in Annex B.

5.8 Noise

The framework quantifies the amenity effects of noise, and has investigated both fully allocated and marginal costs. Annex B contains a detailed explanation of the method in estimating costs.

Detailed dis-aggregated studies of road noise and valuation are not available at a national level and so a series of case studies were undertaken looking at the noise levels and costs for a number of road types (motorway, trunk, and other), assuming typical speeds and 'annual average' daily traffic flow.

Transport noise was quantified using the established relationships in the DoT publication "Calculation of Road Traffic Noise" (DoT, 1988). For implementation, a threshold of 55 dB(A) was used, below which no noise impacts were assumed to occur.

The fully allocated costs were calculated by estimating noise levels for each of the road types, and attributing noise levels according to vehicle numbers. The study also assessed marginal noise costs by looking at the noise change from a 10% increase for each of the road types. Noise levels were combined with average population density data to derive the population weighted noise levels above the 55 dB(A) threshold. This analysis was repeated for each of the population densities in the NRTF (11 area types).

For valuation, relationships between average noise levels and property prices (Noise Depreciation Sensitivity Index) were used. The low, central and high values reported use NDSI values of 0.2, 0.44, and 0.67 % per decibel, based on figures recommended by the DETR for use in this study.

The case studies were then used to populate the framework, with values extrapolated to provide the detailed dis-aggregation. This was necessary in the absence of national level data, though this increases the uncertainty in the reported results. For these reasons, the individual noise values for the more dis-aggregated categories (and relative noise values between categories) need to be treated with some caution. These problems are magnified for the marginal analysis, as marginal noise costs are very sensitive to the existing traffic flows on a route. There is a logarithmic relationship between traffic volume and noise, so that halving or doubling the amount of traffic will change the noise level by 3dB. On routes with high levels of existing traffic, even large numbers of extra vehicles will only produce small increases in dB levels and will therefore have low marginal costs. Conversely, small increases in the absolute numbers of vehicles on routes with low levels of traffic may lead to significant marginal costs (provided the threshold of effect is exceeded). These effects were seen in the marginal case studies. A fuller discussion of these issues is presented in Annex B.

These uncertainties are reflected in the values presented in the result tables. The high value is based on the fully allocated approach, and the low value based on a marginal analysis based on roads with high traffic volumes.

There are a few other issues concerning the marginal analysis. This analysis has assessed a 10% increase in traffic volumes. However, different marginal increases will give different marginal costs (e.g. a 10% increase in vehicle numbers will give a different marginal cost to a 20% increase in vehicle numbers). As with air quality effects, the values presented for noise assume that marginal increases do not lead to changes in overall vehicle speeds. The effects of including speed effects would be to lower marginal noise costs, as lower speeds reduce the rolling noise (the noise from contact between the surface and vehicle).

We stress that further improvement of the marginal and fully allocated noise costs is a priority for future research.

Finally, there are a number of additional issues with noise that were not fully captured in the analysis. The most important of these relate to potential night-time disturbance, the effects of vibration, the intermittent nature of some transport sources, perception (including the greater levels of annoyance attributed to road vehicles), and the potential health impacts from noise exposure. Further investigation of these issues is also highlighted as warranting further research.

5.9 Climate change

Emissions data from road vehicles were taken from the National Atmospheric Emissions Inventory (Salway et al, 1999), using the same categorisation as Table 5.5. Emission factors were derived for each vehicle, accounting for Euro standard and speed, and then aggregated for the 1998 fleet mix.

Emissions were valued using damage cost estimates for climate change. The low, central and high values were £7.3/tonne of CO_2, £14.6/tonne of CO_2, and £29/tonne tonne of CO_2, based on figures recommended by the DETR for use in this study, with the central value taken from the ExternE Project (EC, 1999c). It is stressed that the uncertainty associated with climate change is very large and these values should only be considered as illustrative of possible costs. Further details of the assumptions, discount rates and scenarios assumed in these values are presented in Annex B.

5.10 Value added tax not paid (public service vehicles only)

VAT not paid is relevant to both fully allocated cost and marginal cost analyses. For the bus and coach industry this was considered as a cost as such services do not pay any value added tax. This category was taken as 17.5% of the fare per vehicle km (next section).

5.11 Fares (public service vehicles only)

For local bus services fares per vehicle kilometre were estimated from Transport Statistics Great Britain (DETR, 2000), for the same area classifications discussed under vehicle operating costs (Section 5.4). Concessionary fare rebates, paid by local authorities to operators, were removed in order to calculate fares paid by passengers. For non-local services, the revenue yield was assumed to be equal to the vehicle operating cost.

5.12 Fuel duties and the value added tax on fuel duties

For both fully allocated cost and marginal cost analyses these were taken from Transport Statistics GB (DETR, 2000) for 1998/99. Vehicle kilometres were used, in conjunction with the relative fuel efficiency of rigids/ artics for HGVs, to allocate revenues to vehicle classes. Since value added tax is applied to fuel duties, this was treated as a tax specific to the transport sector, and included in the analysis[12].

Local bus services receive a fuel duty rebate of approximately 80%. Consequently the figures for PSVs were factored down using this figure, and on the basis that 63% of fuel consumption by PSVs was by local bus services (on the basis of the relative vehicle kilometres of local and non-local services; DETR, 1999b).

5.13 Vehicle excise duties

These were taken from the same source as fuel duties. All vehicle excise duties are relevant for inclusion in the fully allocated cost analysis. For the marginal cost analysis, however, vehicle excise duty was only included for those vehicle classes for which an increase in transport demand is likely to require an expansion of the vehicle fleet. These are HGVs and PSVs.

[12] In contrast, the value added tax applied to the price the producer receives is no different from the standard rate, and therefore is not included.

5.14 Summary of sensitivity tests

The sensitivities incorporated within the road analysis relate to:

a) Variation in the asset base used in estimating the cost of capital;

b) Variation in infrastructure cost estimates to take into consideration the possibility that recent renewal expenditure estimates may be an inadequate proxy for depreciation;

c) Use of a flat speed-flow curve for low traffic volumes (i.e. a zero external congestion cost) to create a low cost sensitivity;

d) Inclusion and exclusion of the value of safety held by friends and family of those exposed to the risk of accidents;

e) For the marginal external cost of accidents, use of zero risk elasticities for the low cost estimates, and non-zero risk elasticities for the high cost estimates; and,

f) Use of low, best estimates and high unit values in the air quality, noise and climate change cost estimates.

In principle, all cost and revenue categories should be subject to sensitivity testing. Therefore, where a single value is used in the subsequent analysis, there is no implication that the cost category in question is more robustly estimated than another cost category with a low and high range.

6 Estimation of Cost and Revenue Categories for the Rail Framework

6.1 Cost of capital

This is relevant for the fully allocated cost analysis, and is included in the estimate of infrastructure costs (discussed further in the next sub-section). Total charges paid by train operators to Railtrack in 1998/99 were taken to represent the full infrastructure cost (including the cost of capital), although the Regulator has since accepted the need for an increase in Railtrack's revenue requirement (excluding infrastructure enhancement) approaching 30% (ORR, 2000).

Although Railtrack's cost of capital is marginally higher than the 6% public sector rate used in the road analysis, no adjustment was made for this. It should also be noted that no information on the value of land take associated with alignments is available, so that the cost of capital relating to land asset values for tracks has not been estimated.

6.2 Infrastructure costs

Infrastructure costs are relevant for the fully allocated cost analysis, with a subset of relevance for the marginal cost analysis.

For the marginal cost analysis, estimates of infrastructure wear and tear were provided by Railtrack at a highly disaggregate level (by train service group). These were aggregated to the 5 train types proposed in the framework according to relative train km. The grouping of Train Operating Companies was as follows:

- InterCity - includes the following TOCs - Anglia, GNER, Great Western Trains, Midland Main Line, Virgin Cross Country and Virgin West Coast Main Line;
- Regional - Cardiff Railway, Central Trains, Mersey Rail, North West Trains, Northern Spirit, Scotrail and Wales and West; and,
- London - Chiltern, Connex South Central, Connex South Eastern, Gatwick, Great Eastern, LT&S, Silverlink, South West Trains, Thames Trains, Thameslink and WAGN.

For freight, the three major rail freight groups (English, Welsh and Scottish Railways Holdings Ltd; Freightliner Ltd; and, Direct Rail Services Ltd) are reconstituted into two categories:

- Bulk freight – coal; iron ore, petroleum and chemicals; and,
- Other - domestic auto, Euro auto, Euro conventional, Euro intermodal, other international, domestic intermodal, waste; enterprise, general merchandise, IM, steel, mail, and engineering.

It was assumed that the freight usage costs provided by Railtrack also include electricity for traction.

For the fully allocated cost analysis, it was assumed that the combined variable and fixed access charges paid to Railtrack in 1998/99 represent total infrastructure costs, including operating, maintenance and depreciation costs, and an allowance for the cost of capital. Furthermore, in preference to allocating costs to train operators on the basis of relative gross tonne km, the apportionment of track access charges by operator has been taken as an appropriate means of distributing overall costs to train operators. The estimates used were taken from the Rail Industry Monitor (TAS, 2000b), and are for 1998/99 and in the prices of that year.

6.3 Vehicle operating costs

Due to data constraints (Section 3.3), the marginal and average vehicle operating costs have been assumed to be equal. Evidence from econometric studies suggests that this is not an unreasonable assumption, provided that variables such as train length are held constant. In practice, this may be a reasonable assumption except in the Regional sector, where there is a lot of scope for increasing capacity at lower cost by running longer trains. This is certainly an area, however, where more detailed analysis would be valuable. The data source was the Rail Industry Monitor (TAS, 2000b), from which track access payments were removed. This leaves the following main cost components:

- Wages and overheads;
- Depreciation;
- Interest paid;
- Auditor's remuneration;
- Rolling stock charges; and,
- Other costs.

6.4 Electricity for traction costs

This category was separately identified from other Railtrack-related costs in the marginal cost analysis (in the fully allocated cost analysis, it was included in the overall track access fees). Data was provided by Railtrack by train operator and train service group.

6.5 Congestion

Congestion costs relate to the likely delays to other train operators as a result of an additional service being added to the network. These costs are only relevant for the marginal cost analysis. Congestion costs were provided by Railtrack from their simulation model. Although this information is in the appropriate price base (1998/99 prices and values), it relates to estimates for the 2000/01 service pattern, and so should be considered as an over-estimate of congestion costs for 1998.

Advice from Railtrack for freight services is that both because they tend to run off-peak and because of the higher degree of flexibility in timings, congestion costs imposed by freight trains are low, and have been excluded in this analysis.

6.6 The Mohring Effect

The Mohring effect is only relevant for the marginal cost analysis. The methodology for its calculation is set out in Section 5.4.

The main assumptions that were adopted for the different types of passenger service were as follows:

- InterCity – hourly service, average journey length 300 km;
- Regional – half-hourly service, average journey length 60 km; and,
- London – service every 15 minutes, average journey length 40 km.

6.7 Air pollution

The assessment of air pollution impacts from rail transport used a similar method to road transport (Section 5.7).

For diesel trains, emissions data were taken from the National Atmospheric Emissions Inventory, NAEI (Salway et al, 1999). Separate emissions were collated for passenger trains (based on factors for pacer, sprinter, and turbo diesel multiple units, InterCity 125s, and class 47 locomotives) and for freight trains (based on class 37, 47, 56, 58, and 60 locomotives). Data on emissions from electricity generation were also taken from the NAEI. Information on electric and diesel train km was provided by Railtrack. These data were combined to compile 1998 fleet emissions, for different train categories (InterCity, PTE, Rural, Cross-country, and London suburban). Calculation of environmental impacts and costs was undertaken using the ExternE computer tool.

6.8 Noise

The assessment of rail noise used a similar method to road noise (Section 5.8) using case studies in the absence of dis-aggregated studies of rail noise costs.

Noise emissions and dispersion was calculated based on the methods recommended in "Calculation of Rail Noise" (DoT, 1995). Predictions were made at a variety of typical mainline sites using the known levels, types of traffic, numbers of trains and train speeds. Marginal costs were investigated assuming a 10% increase in train numbers. Valuation was consistent with the method for road, based on the link between average noise levels and property price.

As with the road noise values, the individual noise costs at the more dis-aggregated categories (and relative noise values between categories at this level) need to be treated with some caution. Similar issues arose for the marginal analysis. For the rail case studies assessed, the existing noise levels on most routes were high. Marginal increases in train numbers had little effect on noise levels and marginal costs were extremely low. However, on one of the minor routes assessed, with low levels of train activity, it was found that that the marginal costs were very high. To accurately assess the fully allocated and marginal costs, a more detailed study of national rail activity would be needed. This was not possible within the constraints of this study, and so both fully allocated and marginal noise rail costs are reported using one set of values. We stress, however, that on busy routes, the marginal costs of one additional train are likely to be much lower.

Further analysis of the rail network and train activity is highlighted as a priority. As with the analysis of road noise, there are a number of additional aspects that may not be fully captured in the analysis. Importantly, the relative distribution of train km by time of day has not been included, and so no account is taken of the higher proportion of rail freight running at night. Similarly, effects of vibration from rail are not taken into account. Finally, this study has not adjusted values to reflect the potentially lower annoyance levels associated with rail noise compared to road noise (the ‘rail bonus’).

6.9 Climate change

Emissions from trains were taken from the NAEI following the approach for air pollution. The same method as for road transport was applied for valuation.

6.10 Value added tax not paid

Rail passenger services are exempt from value added tax. This component was treated as a cost in both fully allocated cost and marginal cost analyses. It was calculated as 17.5% of the fare (Section 6.11).

6.11 Fares and freight tariffs

Fares and freight tariffs were taken from the Rail Industry Monitor (TAS, 2000b).

6.12 Non-Estimation of Rail Cost and Revenue Categories

Rail accident costs were not estimated, since the external element is believed to be small once the level of liability placed on train operators is taken into consideration. The opportunity costs of scarce timetable availability (“scarcity”) were not estimated, except inasmuch as they are reflected in high delay costs. Although a very low level of fuel duty does apply to diesel, due to its level this element was not estimated.

6.13 Summary of sensitivity tests

The only sensitivity analysis conducted for the rail framework was the use of low and high estimates for local air quality, noise and climate change.

In principle, all cost and revenue categories should be subject to sensitivity testing. Therefore, where a single value is used in the subsequent analysis, there is no implication that the cost category in question is more robustly estimated than another cost category with a low and high range.

7 Results produced using the Road Framework

7.1 Introduction

In order to demonstrate the types of output that may be derived from the framework, Chapters 7 and 8 provide illustrative results. All results presented in this chapter are subject to the caveats about the input data previously discussed. The analysis is presented for the year 1998, in the prices and values of 1998 and in resource costs. Results relate to Great Britain and where aggregated outputs are reported these have been produced by weighting disaggregated estimates by vehicle kilometres.

As highlighted in Section 5.14, low and high sensitivities are carried out for a number of cost categories. These are very restricted tests and do not provide the full range of estimates that would have been produced had more in-depth sensitivity analysis been conducted. Sensitivity test were restricted to: the cost of capital, for which the asset value is based on the range reported in literature; infrastructure operating costs and depreciation, for which a 30% increase from current expenditure is used for the high sensitivity; congestion, for which analysis assuming no congestion at low traffic flows was undertaken for the low sensitivity; accidents, for which the low sensitivity omits any increase in accident risk as a result of increased traffic and also the values held by friends and family; and, environmental costs, for which the sensitivities only take account of low and high economic values, and not any other steps in the impact pathway approach.

The subsequent discussion provides examples of the types of analyses that could be conducted using the framework. It also highlights the limitations, indicating the way in which the framework results should not be used.

7.2 National Level Analysis for the Road Sector

Table 7.1 compares fully allocated costs with revenues, alongside marginal costs and revenues for the average road vehicle in Great Britain. Results for the “average” road vehicle are created by weighting disaggregate unit costs and revenues by relative vehicle kilometres (by area, road type, vehicle type, and time period).

Table 7.1: Comparison of 1998 Road Sector Costs and Revenues

Pence per vehicle km, Great Britain, 1998 prices and values

Cost or revenue category	Fully allocated cost		Marginal cost	
	low	high	low	high
Costs:				
Cost of capital for infrastructure	0.78	1.34	n/a	n/a
Infrastructure operating costs and depreciation	0.75	0.97	0.42	0.54
Vehicle operating costs (PSV)	0.87	0.87	0.87	0.87
Congestion	n/a	n/a	9.71	11.16
Mohring effect (PSV)	n/a	n/a	-0.16	-0.16
External accident costs	0.06	0.78	0.82	1.40
Air pollution	0.34	1.70	0.34	1.70
Noise	0.24	0.78	0.02	0.78
Climate change	0.15	0.62	0.15	0.62
VAT not paid	0.15	0.15	0.15	0.15
Sub-total of costs	**3.34**	**7.20**	**12.32**	**17.05**
Revenues:				
Fares (PSV)	0.84	0.84	0.84	0.84
Vehicle excise duty	1.10	1.10	0.14	0.14
Fuel duty	4.42	4.42	4.42	4.42
VAT on fuel duty	0.77	0.77	0.77	0.77
Sub-total of revenues	**7.14**	**7.14**	**6.17**	**6.17**
Comparison of costs, revenues:				
Difference (cost-revenue)	**-3.79**	**0.07**	**6.15**	**10.88**
Ratio: revenues/costs	**2.13**	**0.99**	**0.50**	**0.36**

Notes: Road sector costs exclude costs attributable to pedestrians, bicycles and motorcycles;
Accident costs are reported net of insurance payments;
Vehicle excise duty in the marginal analysis relates to HGVs and PSVs;
n/a – not applicable.

For the **fully allocated cost analysis**, at both low and high values of cost estimates, costs are covered by taxes specific to the road sector - ranging from a multiple of 1.0 to 2.1. Since the fully allocated cost approach provides a political rather than an economic perspective on the level of existing charges, note that this does not imply that charges should be dramatically reduced in the low cost estimate scenario.

Infrastructure-related costs comprise up to half of overall costs, with environmental costs dominating the remainder for the low costs estimates and also exceeding external accident costs in the high cost scenario.

In relation to the cost of capital, it may be noted that this relates to pure infrastructure costs and not the environmental costs associated with infrastructure provision. Although the counterpart of the cost of capital exists for the environmental damage caused, i.e. a rental amount relating to the environmental asset value lost, estimates of such costs are insufficiently robust to allow incorporation within the cost of capital figures. Furthermore, the environmental costs only include tailpipe emissions. Environmental effects associated with upstream activities are not included. Emissions and environmental costs from certain stages, notably fuel production and vehicle manufacture, are significant when compared against end-use emissions.

The **marginal cost analysis** provides contrasting results, with marginal costs exceeding revenues by a factor of 2.0 or more.

Congestion costs dominate marginal external costs, making up 80% of the low cost estimate, and some two-thirds of the high estimate. Recall that marginal external congestion costs are calculated at the current level of demand and no modelling of demand responses to price changes has been carried out. From recent EC research projects[13] such responses would be expected to result in a dramatic reduction in external costs. Thus, the results may not be interpreted directly as the magnitude of change needed to achieve more economically efficient prices.

In Table 7.1 and the subsequent tables presented in this chapter the marginal costs of congestion dominate all other marginal cost estimates, and almost invariably exceed revenues. This is generally the case regardless of area type, road type, vehicle type or time period.

Both accident costs and environmental costs form a significant component of overall marginal costs. The former is amplified through the use of risk elasticities (in the high cost estimate scenario) that incorporate higher accident rates per vehicle km when traffic levels increase. Since linear dose-response relationships are incorporated within the air pollution and climate change cost analysis, fully allocated costs and marginal costs are equal. The values do not, however, take account of possible changes in overall traffic speeds from marginal changes. Details of the choice of values for the marginal and fully allocated noise costs are provided in Sections 5.8 and 6.8, with greater detail provided in Annex B.

7.3 Results by Road Vehicle Type

For average vehicles within each of the five vehicle classes, Tables 7.2-7.3 and 7.4-7.5 report the respective fully allocated and marginal cost analyses. Again, these tables are created by weighting disaggregate cost inputs according to vehicle km by area type, road type and time period.

The comparison of **fully allocated costs with revenues** provides results that differ significantly between low and high cost sensitivities. In both, revenues exceed costs for car. This is also the case for LDVs and HGVs in the low cost scenario, but not for PSVs. In the high cost sensitivity, the situation is reversed for LDVs and HGVs, with costs exceeding revenues.

In the case of the **marginal cost and revenue comparisons** (Tables 7.4-7.5), marginal external costs exceed revenues for the typical vehicle in each of the 5 classes. A common factor is that congestion costs alone exceed revenues in almost every case. High external accident costs feature for PSVs, for both low and high cost estimates. This is due to significant base accident rates and, in the high cost scenario, the use of elasticities for accident risk rates (0.25 urban, 0.5 inter-urban). The high environmental costs of PSVs arise because most PSV trips are in urban areas, which

[13] In the PETS project the Lisbon case study (Viegas et al., 1999) and the Cross Channel case study (Sansom et al., 2000); and the case studies in the TRENEN project Proost and Van Dender (1999).

have higher costs per km. It does not mean that the impact of emissions and noise is highest for this vehicle class.

Table 7.2: Fully Allocated Cost and Revenue Analysis – by Vehicle Class (pence/ vkm, low cost estimates)

Categories	Costs									Revenues					Difference
	Cost of capital	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	External accident costs	Air poll-ution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Car	0.70	0.33	-	0.07	0.18	0.16	0.12	-	1.6	-	1.03	3.86	0.68	5.6	-4.0
LDV	0.83	0.38	-	0.04	0.71	0.30	0.18	-	2.4	-	1.03	3.86	0.68	5.6	-3.1
HGV-rigid	1.45	4.61	-	0.04	1.65	0.87	0.44	-	9.1	-	2.25	13.11	2.29	17.6	-8.6
HGV-artic	1.88	8.74	-	0.03	1.41	1.31	0.71	-	14.1	-	2.50	14.47	2.53	19.5	-5.4
PSV	1.67	6.29	79.61	0.18	3.16	1.24	0.56	13.44	106.1	76.77	0.61	5.26	0.92	83.6	22.6

Table 7.3: Fully Allocated Cost and Revenue Analysis – by Vehicle Class (pence/ vkm, high cost estimates)

Categories	Costs									Revenues					Difference
	Cost of capital	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	External accident costs	Air poll-ution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Car	1.21	0.43	-	0.82	0.88	0.52	0.47	-	4.3	-	1.03	3.86	0.68	5.6	-1.2
LDV	1.43	0.49	-	0.46	3.35	1.00	0.72	-	7.5	-	1.03	3.86	0.68	5.6	1.9
HGV-rigid	2.49	6.00	-	0.61	8.26	2.89	1.74	-	22.0	-	2.25	13.11	2.29	17.6	4.3
HGV-artic	3.22	11.36	-	0.50	7.63	4.35	2.86	-	29.9	-	2.50	14.47	2.53	19.5	10.4
PSV	2.87	8.18	79.61	2.33	15.35	4.11	2.24	13.44	128.1	76.77	0.61	5.26	0.92	83.6	44.6

Table 7.4: Marginal Cost and Revenue Analysis – by Vehicle Class (pence/ vkm, low cost estimates)

Categories	Costs										Revenues					Difference
	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	Cong-estion	Mohring effect (PSV)	External accident costs	Air pollution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty (part)	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Car	0.05	-	8.98	-	0.79	0.18	0.01	0.12	-	10.1	-	-	3.86	0.68	4.5	5.6
LDV	0.06	-	9.26	-	0.53	0.71	0.02	0.18	-	10.8	-	-	3.86	0.68	4.5	6.2
HGV-rigid	3.79	-	16.78	-	1.39	1.65	0.06	0.44	-	24.1	-	2.25	13.11	2.29	17.6	6.5
HGV-artic	7.55	-	24.15	-	0.99	1.41	0.08	0.71	-	34.9	-	2.50	14.47	2.53	19.5	15.4
PSV	5.23	79.61	15.22	-14.70	3.74	3.16	0.09	0.56	13.44	106.3	76.77	0.61	5.26	0.92	83.6	22.8

Table 7.5: Marginal Cost and Revenue Analysis – by Vehicle Class (pence/ vkm, high cost estimates)

Categories	Costs										Revenues					Difference
	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	Cong-estion	Mohring effect (PSV)	External accident costs	Air pollution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty (part)	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Car	0.07	-	10.44	-	1.38	0.88	0.52	0.47	-	13.8	-	-	3.86	0.68	4.5	9.2
LDV	0.08	-	10.61	-	0.89	3.35	1.00	0.72	-	16.6	-	-	3.86	0.68	4.5	12.1
HGV-rigid	4.92	-	18.45	-	1.96	8.26	2.89	1.74	-	38.2	-	2.25	13.11	2.29	17.6	20.6
HGV-artic	9.82	-	24.89	-	1.40	7.63	4.35	2.86	-	51.0	-	2.50	14.47	2.53	19.5	31.5
PSV	6.80	79.61	18.19	-14.70	6.58	15.35	4.11	2.24	13.44	131.6	76.77	0.61	5.26	0.92	83.6	48.0

7.4 Results by Class of Road

The analysis of the average vehicle travelling on 3 road classes (motorway, trunk and principal, other) is set out in Tables 7.6-7.7 (fully allocated cost/ revenue) and 7.8-7.9 (marginal cost/ revenue). For these tables, weighting includes area type, time period and vehicle class – so that the results do not relate to the same vehicle type on different types of road, but to the typical vehicle on a given road type.

With the exception of the other road type with high cost estimates, revenues exceed **fully allocated costs** by a substantial margin.

For the **marginal cost analysis**, overall results are similar across road types, with marginal costs substantially in excess of revenues. In part, this will be explained by the relative mix of vehicle classes for the 3 road types. For example, in the case of air pollution, the highest cost per vehicle km in the table is for motorways. This is explained by the relatively high proportion of HGVs using these roads. It does not mean that the impact of emissions from a given vehicle is highest when that vehicle travels on a motorway.

Once again, congestion makes up the greater part of marginal costs.

Table 7.6: Fully Allocated Cost and Revenue Analysis – by Road Type (pence/ vkm, low cost estimates)

Categories	Costs									Revenues					Difference
	Cost of capital	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	External accident costs	Air poll-ution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Motorway	0.41	0.47	0.47	0.01	0.35	0.26	0.19	0.08	2.2	0.45	1.20	5.08	0.89	7.6	-5.4
Trunk & P'pl	0.55	0.58	0.85	0.07	0.34	0.22	0.15	0.14	2.9	0.82	1.11	4.44	0.78	7.1	-4.2
Other	1.24	1.09	1.08	0.08	0.35	0.25	0.14	0.18	4.4	1.04	1.06	4.09	0.72	6.9	-2.5

Table 7.7: Fully Allocated Cost and Revenue Analysis – by Road Type (pence/ vkm, high cost estimates)

Categories	Costs									Revenues					Difference
	Cost of capital	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	External accident costs	Air poll-ution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Motorway	0.71	0.61	0.47	0.21	1.83	0.85	0.78	0.08	5.5	0.45	1.20	5.08	0.89	7.6	-2.1
Trunk & P'pl	0.95	0.75	0.85	0.86	1.66	0.73	0.60	0.14	6.5	0.82	1.11	4.44	0.78	7.1	-0.6
Other	2.13	1.42	1.08	0.95	1.68	0.83	0.56	0.18	8.8	1.04	1.06	4.09	0.72	6.9	1.9

Table 7.8: Marginal Cost and Revenue Analysis – by Road Type (pence/ vkm, low cost estimates)

Categories	Costs										Revenues					Difference
	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	Cong-estion	Mohring effect (PSV)	External accident costs	Air pollution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty (part)	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Motorway	0.31	0.47	12.80	-0.11	0.03	0.35	0.02	0.19	0.08	14.1	0.45	0.29	5.08	0.89	6.7	7.4
Trunk & P'pl	0.34	0.85	11.61	-0.16	0.87	0.34	0.01	0.15	0.14	14.2	0.82	0.14	4.44	0.78	6.2	8.0
Other	0.57	1.08	5.86	-0.18	1.11	0.35	0.02	0.14	0.18	9.1	1.04	0.06	4.09	0.72	5.9	3.2

Categories	Costs										Revenues					Difference
	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	Cong-estion	Mohring effect (PSV)	External accident costs	Air pollution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty (part)	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Motorway	0.41	0.47	12.80	-0.11	0.15	1.83	0.85	0.78	0.08	17.3	0.45	0.29	5.08	0.89	6.7	10.5
Trunk & P'pl	0.44	0.85	12.38	-0.16	1.50	1.66	0.73	0.60	0.14	18.1	0.82	0.14	4.44	0.78	6.2	12.0
Other	0.74	1.08	8.84	-0.18	1.84	1.68	0.83	0.56	0.18	15.6	1.04	0.06	4.09	0.72	5.9	9.6

Table 7.9: Marginal Cost and Revenue Analysis – by Road Type (pence/ vkm, high cost estimates)

7.5 Other Disaggregate Results from the Road Framework

This section reports disaggregate results for the marginal cost vs revenue analyses for the 2 time periods, 28 area type and road type permutations, and the combination of 5 vehicle classes and 2 time periods. Results are only shown for the low cost estimate scenario. The subsequent section shows the further disaggregations that are possible.

Although the full range of permutations could also be displayed for the fully allocated cost analysis, it is necessary to highlight limitations in the cost allocation processes that mean that this would be unwise. The input data on infrastructure and accident costs are not disaggregated by area type or time period. For this reason, these disaggregations should not be used in overall cost/ revenue comparisons.

Table 7.10 provides the weekday peak/ other time period disaggregations (low cost estimates only). The weekday peak is defined as Monday-Friday, 0700-1000 and 1600-1900. As expected, the main difference between the two sets of marginal cost information relates to congestion, the marginal external cost of which in the weekday peak is often almost double that in the other time period. Environmental costs are calculated using speeds within (typically 10 mph) bands, and also the cost differences between adjacent speed bands are small. For this reason there are minimal differences between the weekday peak and off-peak environmental figures.

The variation in marginal costs for a typical vehicle across the 11 area types in the model is shown in Table 7.11 (low cost estimates). Once again, congestion is the dominant marginal cost category and even for the smaller urban areas the marginal costs of congestion alone outstrip revenues. Environmental costs also show a very large variation with area type, with air pollution costs in urban areas many times higher than rural areas.

The 10 permutations given by 5 vehicle classes and 2 time periods are shown in Table 7.12. This suggests that the difference between marginal costs and revenues in the weekday peak period ranges between 50% to 100% greater than in the off-peak period[14]. Although this is partly due to lower environmental costs in the off-peak, the main factor that explains this is the variation in congestion costs between the two periods.

[14] The other time period is defined as all time periods other than the weekday peak. I.e. it includes weekday periods outside the peak (0700-1000, 1600-1900), Saturday and Sunday.

Table 7.10: Marginal Cost and Revenue Analysis – by Time Period (pence/ vkm, low cost estimates)

Categories	Costs										Revenues					Difference
	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	Cong-estion	Mohring effect (PSV)	External accident costs	Air pollution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty (part)	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Weekday peak	0.43	0.98	14.28	-0.18	0.81	0.36	0.02	0.16	0.17	17.0	0.95	0.14	4.41	0.77	6.3	10.8
Off-peak	0.41	0.82	7.58	-0.15	0.82	0.34	0.02	0.15	0.14	10.1	0.79	0.14	4.42	0.77	6.1	4.0

Note: "weekday peak" refers to the hours 0700-1000 and 1600-1900; "other" relates to all other times in the week.

Table 7.11: Marginal Cost and Revenue Analysis – by Area type & Road type (car, pence/ vkm, low cost estimates)

Categories	Costs							Revenues			Difference
	Infrastructure operating cost & depreciation	Cong-estion	External accident costs	Air pollution	Noise	Climate change	Total	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Central London											
Motorway	0.01	53.75	0.01	0.57	0.04	0.11	54.5	3.86	0.68	4.5	49.9
Trunk & Principal	0.04	71.09	1.68	0.77	0.03	0.16	73.8	3.86	0.68	4.5	69.2
Other	0.08	187.79	1.68	0.87	0.04	0.19	190.6	3.86	0.68	4.5	186.1
Inner London											
Motorway	0.01	20.10	0.01	0.42	0.03	0.11	20.7	3.86	0.68	4.5	16.1
Trunk & Principal	0.04	54.13	1.68	0.61	0.04	0.16	56.6	3.86	0.68	4.5	52.1
Other	0.08	94.48	1.68	0.66	0.03	0.17	97.1	3.86	0.68	4.5	92.6
Outer London											
Motorway	0.01	31.09	0.01	0.31	0.02	0.10	31.5	3.86	0.68	4.5	27.0
Trunk & Principal	0.04	28.03	1.68	0.40	0.02	0.14	30.3	3.86	0.68	4.5	25.8
Other	0.08	39.66	1.68	0.45	0.02	0.16	42.0	3.86	0.68	4.5	37.5
Inner Conurbation											
Motorway	0.01	53.90	0.01	0.47	0.02	0.11	54.5	3.86	0.68	4.5	50.0
Trunk & Principal	0.04	33.97	1.68	0.55	0.02	0.14	36.4	3.86	0.68	4.5	31.9
Other	0.08	60.25	1.68	0.66	0.02	0.17	62.9	3.86	0.68	4.5	58.3
Outer Conurbation											
Motorway	0.01	35.23	0.01	0.25	0.02	0.10	35.6	3.86	0.68	4.5	31.1
Trunk & Principal	0.04	12.28	1.68	0.30	0.02	0.12	14.4	3.86	0.68	4.5	9.9
Other	0.08	0.00	1.68	0.32	0.02	0.13	2.2	3.86	0.68	4.5	-2.3
Urban >25 km2											
Trunk & Principal	0.04	10.13	1.68	0.25	0.02	0.12	12.2	3.86	0.68	4.5	7.7
Other	0.08	0.72	1.68	0.26	0.02	0.13	2.9	3.86	0.68	4.5	-1.6
Urban 15-25 km2											
Trunk & Principal	0.04	7.01	1.68	0.25	0.02	0.12	9.1	3.86	0.68	4.5	4.6
Other	0.08	0.00	1.68	0.24	0.02	0.12	2.1	3.86	0.68	4.5	-2.4
Urban 10-15 km2											
Trunk & Principal	0.04	0.00	1.68	0.17	0.02	0.11	2.0	3.86	0.68	4.5	-2.5
Other	0.08	0.00	1.68	0.19	0.02	0.12	2.1	3.86	0.68	4.5	-2.4
Urban 5-10 km2											
Trunk & Principal	0.04	2.94	1.68	0.15	0.02	0.11	4.9	3.86	0.68	4.5	0.4
Other	0.08	0.00	1.68	0.16	0.02	0.12	2.1	3.86	0.68	4.5	-2.5
Urban 0.01-5 km2											
Trunk & Principal	0.04	1.37	1.68	0.13	0.01	0.11	3.3	3.86	0.68	4.5	-1.2
Other	0.08	0.00	1.68	0.14	0.01	0.12	2.0	3.86	0.68	4.5	-2.5
Rural											
Motorway	0.01	4.01	0.01	0.11	0.00	0.13	4.3	3.86	0.68	4.5	-0.3
Trunk & Principal	0.04	8.48	0.30	0.10	0.00	0.11	9.0	3.86	0.68	4.5	4.5
Other	0.08	1.28	0.30	0.10	0.01	0.10	1.9	3.86	0.68	4.5	-2.7

Table 7.12: Marginal Cost/ Revenue Analysis – by Vehicle Class and Time Period (pence/ vkm, low cost estimates)

Categories	Costs										Revenues					Difference
	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	Cong-estion	Mohring effect (PSV)	External accident costs	Air pollution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty (part)	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Car, peak	0.05	-	13.22	-	0.78	0.18	0.01	0.12	-	14.4	-	-	3.86	0.68	4.5	9.8
Car, off-peak	0.05	-	7.01	-	0.80	0.18	0.01	0.12	-	8.2	-	-	3.86	0.68	4.5	3.6
LDV, peak	0.06	-	13.99	-	0.52	0.76	0.02	0.19	-	15.5	-	-	3.86	0.68	4.5	11.0
LDV, off-peak	0.06	-	7.07	-	0.53	0.68	0.02	0.18	-	8.5	-	-	3.86	0.68	4.5	4.0
HGV-Rigid, peak	3.82	-	26.00	-	1.40	1.84	0.06	0.44	-	33.6	-	2.25	13.11	2.29	17.6	15.9
HGV-Rigid, off-peak	3.77	-	12.75	-	1.39	1.57	0.06	0.43	-	20.0	-	2.25	13.11	2.29	17.6	2.3
HGV-Artic, peak	7.57	-	33.45	-	0.99	1.42	0.07	0.72	-	44.2	-	2.50	14.47	2.53	19.5	24.7
HGV-Artic, off-peak	7.55	-	19.81	-	0.99	1.41	0.08	0.71	-	30.5	-	2.50	14.47	2.53	19.5	11.0
PSV, peak	5.74	78.73	20.31	-14.43	3.82	3.17	0.09	0.58	13.33	111.3	76.19	0.61	5.26	0.92	83.0	28.4
PSV, off-peak	4.93	80.10	12.31	-14.86	3.69	3.15	0.09	0.55	13.49	103.5	77.10	0.61	5.26	0.92	83.9	19.6

7.6 Additional potential results from the Road Analysis

In addition to the results reported here, further potential exists to provide detail on the full 280 area type/ road type/ vehicle type/ time period permutations from the road model. A sample of this output, from the marginal cost and revenue calculations for outer conurbations, is shown in Table 7.13 (low cost estimates).

A greater level of disaggregation could be presented for the environmental cost categories, since the input calculations include area type/ time period disaggregation. Other disaggregations of the environmental costs that could be presented include:

- Costs for passenger cars and light duty vehicles separated by fuel type (i.e. petrol, diesel) – this reveals major differences in environmental costs, especially in urban areas; and,
- Differentiation by Euro vehicle emission standard – again very strong differentials exist.

Table 7.13: Illustration of Disaggregate Output from the Road Analysis for the Outer conurbation area type (pence /vkm, low cost estimates)

Categories	Costs										Revenues					Difference
	Infrastructure operating cost & depreciation	Vehicle operating cost (PSV)	Cong-estion	Mohring effect (PSV)	External accident costs	Air pollution	Noise	Climate change	VAT not paid (PSV)	Total	Fares (PSV)	Vehicle excise duty (part)	Fuel duty	Value added tax on fuel duty	Total	Costs - Revenues
Car, peak	0.04	-	23.01	-	1.68	0.32	0.02	0.13	-	25.2	-	-	3.86	0.68	4.5	20.7
Car, off-peak	0.04	-	7.73	-	1.68	0.29	0.02	0.12	-	9.9	-	-	3.86	0.68	4.5	5.3
LDV, peak	0.05	-	23.01	-	0.88	1.45	0.04	0.20	-	25.6	-	-	3.86	0.68	4.5	21.1
LDV, off-peak	0.05	-	7.73	-	0.88	1.30	0.04	0.18	-	10.2	-	-	3.86	0.68	4.5	5.6
Rigid, peak	2.35	-	38.72	-	1.68	3.54	0.14	0.46	-	46.9	-	2.25	13.11	2.29	17.6	29.2
Rigid, off-peak	2.35	-	13.01	-	1.68	3.11	0.14	0.42	-	20.7	-	2.25	13.11	2.29	17.6	3.1
Artic, peak	7.84	-	56.69	-	1.68	4.36	0.27	0.87	-	71.7	-	2.50	14.47	2.53	19.5	52.2
Artic, off-peak	7.84	-	19.05	-	1.68	3.84	0.27	0.78	-	33.5	-	2.50	14.47	2.53	19.5	14.0
PSV, peak	1.57	83.87	34.52	-14.00	4.20	4.98	0.14	0.65	13.48	129.4	77.04	0.61	5.26	0.92	83.8	45.6
PSV, off-peak	1.57	83.87	11.60	-14.00	4.20	4.45	0.14	0.59	13.48	105.9	77.04	0.61	5.26	0.92	83.8	22.1

Note: the PSV operating cost entry includes the taxation components that are also shown under revenues in this table.

8 Results produced using the Rail Framework

8.1 National Level Analysis for the Rail Passenger Sector

Tables 8.1-8.2 and 8.3-8.4 report the results for the fully allocated and marginal cost analyses respectively for rail passenger transport. As with the illustrative results from the road framework, all results are presented for 1998, in 1998 prices and values. In order to obtain the aggregate results that are presented, disaggregate inputs are weighted according to relative train kilometres.

The only sensitivity testing conducted within the rail analysis was for the environmental cost categories. This was restricted to the range of economic values used in the calculations. It did not include any other steps within the impact pathway approach.

Tables 8.1-8.2 suggest that **fully allocated costs** for the rail passenger sector as a whole are approximately double average revenues. Revenues contribute to approximately 60% of InterCity and London-based train operating company costs and some 30% of Regional rail costs.

Within the total cost measure for fully allocated costs, vehicle operating costs and infrastructure costs dominate. Environmental costs, although of significance, represent a relatively small proportion of overall costs – at least at this level of aggregation.

For the **marginal cost and revenue analysis** (Tables 8.3-8.4), overall infrastructure costs are replaced with marginal infrastructure and electricity costs. These marginal costs represent approximately one tenth of the infrastructure costs included in the average cost analysis, although this varies by type of train operator. Congestion costs make a contribution to overall marginal costs that is on a par with the sum of the environmental cost categories.

Despite the lower infrastructure costs, the high contribution of vehicle operating costs means that costs continue to exceed revenues in the marginal cost/revenue analysis, by approximately 10 to 20% for the overall passenger rail sector.

Table 8.1: Fully Allocated Cost and Revenue Analysis for Passenger Rail

£/ train km, low cost estimates

Category	Costs							Revenue	Difference
	Infrastructure	Vehicle operating	Air pollution	Noise	Climate change	VAT not paid	Total		Costs - Revenue
InterCity	7.74	11.79	0.279	0.122	0.067	2.46	22.46	14.07	8.39
Regional	4.29	5.04	0.041	0.042	0.031	0.54	9.99	3.11	6.88
London	5.13	6.68	0.067	0.088	0.037	1.48	13.48	8.47	5.01
Passenger Sector	5.33	7.07	0.098	0.076	0.040	1.32	13.93	7.52	6.41

Note: Low cost estimates apply to environmental categories only.

Table 8.2: Fully Allocated Cost and Revenue Analysis for Passenger Rail

£/ train km, high cost estimates

Category	Costs							Revenue	Difference
	Infrastructure	Vehicle operating	Air pollution	Noise	Climate change	VAT not paid	Total		Costs - Revenue
InterCity	7.74	11.79	1.887	0.406	0.269	2.46	24.55	14.07	10.48
Regional	4.29	5.04	0.360	0.139	0.123	0.54	10.50	3.11	7.39
London	5.13	6.68	0.770	0.291	0.147	1.48	14.50	8.47	6.03
Passenger Sector	5.33	7.07	0.823	0.252	0.161	1.32	14.95	7.52	7.43

Note: High cost estimates apply to environmental categories only.

Table 8.3: Marginal Cost and Revenue Analysis for Passenger Rail

£/ train km, low cost estimates

Category	Costs										Revenue	Difference
	Marginal infrastructure usage	Vehicle operating	Electricity	Congestion	Mohring effect	Air pollution	Noise	Climate change	VAT not paid	Total		Costs - Revenue
InterCity	1.116	11.79	0.483	0.15	-1.55	0.279	0.122	0.067	2.46	14.92	14.07	0.85
Regional	0.149	5.04	0.068	0.09	-0.67	0.041	0.042	0.031	0.54	5.33	3.11	2.22
London	0.406	6.68	0.371	0.28	-1.19	0.067	0.088	0.037	1.48	8.22	8.47	-0.25
Passenger Sector	0.424	7.07	0.228	0.18	-1.05	0.098	0.076	0.040	1.32	8.38	7.52	0.86

Note: Low cost estimates apply to environmental categories only.

Table 8.4: Marginal Cost and Revenue Analysis for Passenger Rail

£/ train km, high cost estimates

Category	Costs										Revenue	Difference
	Marginal infrastructure usage	Vehicle operating	Electricity	Congestion	Mohring effect	Air pollution	Noise	Climate change	VAT not paid	Total		Costs - Revenue
InterCity	1.116	11.79	0.483	0.15	-1.55	1.887	0.406	0.269	2.46	17.01	14.07	2.94
Regional	0.149	5.04	0.068	0.09	-0.67	0.360	0.139	0.123	0.54	5.84	3.11	2.73
London	0.406	6.68	0.371	0.28	-1.19	0.770	0.291	0.147	1.48	9.24	8.47	0.77
Passenger Sector	0.424	7.07	0.228	0.18	-1.05	0.823	0.252	0.161	1.32	9.40	7.52	1.88

Note: High cost estimates apply to environmental categories only.

8.2 National Level Analysis for the Rail Freight Sector

Tables 8.5-8.6 and 8.7-8.8 report the fully allocated and marginal cost analyses for the rail freight sector and its subdivisions of bulk freight and other. In broad terms, fully allocated costs and revenues are close to being in balance for the freight sector as a whole.

As with passenger transport, infrastructure and vehicle operating costs dominate the fully allocated costs, with environmental costs playing a significant, albeit minor, role.

Table 8.5: Fully Allocated Cost and Revenue Analysis for Rail Freight

£/ train km, low cost estimates

Category	Costs						Revenue	Difference
	Infrastructure	Vehicle operating	Air pollution	Noise	Climate change	Total		Costs - Revenue
Bulk	3.53	8.60	0.166	0.170	0.131	12.60	13.01	-0.41
Other	3.33	9.70	0.166	0.170	0.131	13.50	13.61	-0.11
Freight Sector	3.41	9.28	0.166	0.170	0.131	13.16	13.41	-0.25

Note: low cost estimates apply to environmental categories only.

Table 8.6: Fully Allocated Cost and Revenue Analysis for Rail Freight

£/ train km, high cost estimates

Category	Costs						Revenue	Difference
	Infrastructure	Vehicle operating	Air pollution	Noise	Climate change	Total		Costs - Revenue
Bulk	3.53	8.60	1.201	0.563	0.525	14.42	13.01	1.41
Other	3.33	9.70	1.201	0.563	0.525	15.32	13.61	1.71
Freight Sector	3.41	9.28	1.201	0.563	0.525	14.98	13.41	1.57

Note: high cost estimates apply to environmental categories only.

Since the fully allocated cost analysis balances to a degree with revenues, and marginal infrastructure costs are substantially below total infrastructure costs, revenues are somewhat in excess of marginal costs (low and high cost sensitivities, Tables 8.7, 8.8).

Table 8.7: Marginal Cost and Revenue Analysis for Rail Freight

£/ train km, low cost estimates

Category	Costs						Revenue	Diff-erence
	Marginal infrastructure usage	Vehicle operating cost	Air pollution	Noise	Climate change	Total		Cost - Revenue
Bulk	1.79	8.60	0.166	0.170	0.131	10.86	13.01	-2.15
Other	0.88	9.70	0.166	0.170	0.131	11.05	13.61	-2.56
Freight Sector	1.19	9.28	0.166	0.170	0.131	10.94	13.41	-2.47

Note: low cost estimates apply to environmental categories only.

Table 8.8: Marginal Cost and Revenue Analysis for Rail Freight
£/ train km, high cost estimates

Category	Costs: Marginal infrastructure usage	Vehicle operating cost	Air pollution	Noise	Climate change	Total	Revenue	Difference Cost - Revenue
Bulk	1.79	8.60	1.201	0.563	0.525	12.68	13.01	-0.33
Other	0.88	9.70	1.201	0.563	0.525	12.87	13.61	-0.74
Freight Sector	1.19	9.28	1.201	0.563	0.525	12.76	13.41	-0.65

Note: high cost estimates apply to environmental categories only.

8.3 Additional Potential Results from the Analysis

Further levels of disaggregation from the analysis could potentially be reported. This would be possible for certain inputs that are shown in the tables set out above (e.g. congestion, vehicle operating cost and passenger revenue by train operating company, environmental costs by type of traction).

This would not, however, be possible for all the cost and revenue elements for all disaggregations by train operator and time period. For example, passenger revenues would not be available by time period. This could only be obtained by survey information, rather than ticket sales data, and this is currently not available due to commercial confidentiality constraints.

9 Policy implications that follow from the framework results

9.1 Introduction

In this chapter the results of the analysis presented in Chapters 7 and 8 are interpreted in terms of their implications for charging, taxation, subsidy and related policy areas. Throughout, the framework's capabilities and the limitations on interpretation that should be drawn are highlighted. The main caveats are reiterated in the last section (Section 9.7).

9.2 Pricing Policy Implications

Five of the six key questions to be addressed (Section 4.4) relate to pricing policy. Although the analysis has been conducted for 1998, and is subject to the caveats stated above, the results from using the proposed framework in relation to the five pricing policy questions are considered in turn:

> **"What should the direction of change in prices be if existing charges are set to maximise economic welfare?** Existing charges include fuel duties and vehicle excise duty for road and charges to rail passenger and freight customers."

For road, the results would suggest that a major increase would be necessary in most cases in order to bring prices in line with marginal costs. For rail, some increase would be justified for most passenger services but not for freight; in the case of freight some reduction would be justified.

> **"In broad terms, does there appear to be a need for the introduction of new pricing instruments in the road sector?** These include urban and inter-urban pricing systems (both low technology and more sophisticated solutions) and electronic tachographs for HGVs."

Due to the differentiated nature of the marginal costs of congestion and environmental costs, and the high significance of these categories, the implemented framework demonstrates a clear case for the introduction of more differentiated charging mechanisms in the road sector. In addition to area, road and vehicle type, the underlying environmental analysis confirms the issue of reflecting strong differentials by fuel type (petrol/diesel) and Euro vehicle emissions standard.

Note, however, that the framework does not provide economic validation of the case for a new form of pricing mechanism (e.g. urban road pricing), since neither implementation costs nor travel demand and costs at the optimum charging point feature in the framework.

> **"How do weighted short run marginal costs compare to charges for the road and rail sectors at the national level?** Weighting by overall vehicle or train kilometres yields an overall measure of the overall direction of change in charges."

For the road sector, the marginal costs set out in the framework substantially exceed revenues for the five vehicle classes analysed (car, light delivery, rigids lorries, articulated lorries and public service vehicles). For rail, costs also exceed revenues for the passenger sector but not the freight sector.

"How do total costs on the fully allocated cost basis compare to overall charges for the road and rail sectors at the national level? This comparison provides what some, although not the authors of this report, would view as a test of the fairness of current charging levels."

For the road sector as a whole, the analysis would suggest that revenues are in excess of fully allocated costs by a fairly substantial margin when low cost estimates are used, but that a more ambiguous picture emerges with high cost estimates. For the rail sector, the picture once again differs between passenger and freight. For rail freight, in broad terms overall costs on the fully allocated cost basis are in balance with average revenues. For passenger rail, however, fully allocated costs substantially exceed revenues.

> **"If costs are allocated to different vehicle or train types, how do these compare to revenues?** Since many costs are joint within a sector, there is no robust way of fully allocating costs to vehicles or train types. Despite this, again some view this as a test of "fairness".[15]"

For the five road vehicle classes contained in this report, it is also the case that revenues exceed costs under low cost estimate assumptions, with the exception of PSVs. In the high cost scenario, revenues only exceed costs for cars. The aggregation of vehicle types into five vehicle classes means that major differentiations within a vehicle class (e.g. by weight of HGV) are not presented in this analysis. Such variations may exceed those between vehicle classes. For the 3 passenger train types, the results in terms of deficit per train kilometre do not vary markedly from the overall results for the rail passenger sector as a whole. Obviously per passenger kilometre the subsidy is much higher in the lightly loaded Regional sector. The same result is apparent for rail freight.

9.3 Implications for Taxation

If the results of the marginal cost analysis provided by the framework were to be interpreted directly, the implication from an efficiency perspective would be that fuel duty should be increased in order to reduce the gap between marginal costs and revenues. Price increases would result in demand reductions that would lower the marginal cost of congestion. Thus, it should be reiterated that the ratio of marginal costs to revenues would not be directly used as an indicator of the magnitude of change necessary. The framework would need to be extended to include demand responses in order to provide an iterative means of determining new price levels based on marginal costs.

[15] As noted in Section 2.3, since the fully allocated costs approach has no real basis in economic theory this would only be accepted as a test of fairness or equity by a small minority of economists.

If revenue neutrality or the maintenance of a balance between total costs and total revenues were thought to be desirable, a corresponding decrease in VED could be made. The total cost and revenue side of the framework could be used in order to determine how such a balance could be struck.

The output from the road framework, in particular the estimation of environmental costs by vehicle type/ fuel type, could be used to justify a more highly differentiated system of vehicle excise duties. This could reward cleaner vehicles and potentially encourage a more rapid turnover of older, more polluting vehicles.

The results produced do not provide clear evidence on the efficiency case for rural rebates to fuel duty or to VED on HGVs in comparison with current levels, even if a viable mechanism for rebates were available. This is partly due to the separate definition of area type from road type. For example, a rural area type may contain motorways, trunk and principal roads, and other road types. If fuel tax or VED were increased to match the weighted average marginal cost then some special treatment of rural areas may or may not be justified.

If more differentiated road charging mechanisms were introduced, the case for increasing fuel duties as an, albeit weak, tool for improving economic efficiency would be diluted. This would only be the case, however, in circumstances where widespread introduction of differentiated road charging in both inter-urban and urban situations had taken place. Although this may be a long-term prospect, in the medium term, with only a clutch of road pricing schemes in urban areas likely, fuel duty will continue to make an important contribution in an efficiency role.

9.4 Subsidy Questions

In relation to subsidies, the question posed in Section 4.4 was:

> **"Are current levels of subsidy justified on economic efficiency grounds?"**

For the road sector, this question refers mainly to PSVs. From the results output from the framework marginal costs appear to be substantially in excess of existing revenues, in both the weekday peak and the other time period.

Of course, the rail passenger results arise from the heavy subsidies paid in 1998, although these have since significantly reduced. Having said this, it would appear that subsidies to Regional passenger services may have been excessive in terms of economic efficiency. This is the sector, however, for which marginal operating costs were most likely to be over-estimated. In contrast, the results for rail freight indicate that a greater degree of subsidy than at present would be beneficial on a pure economic efficiency basis.

9.5 Insights into Other Policy Areas

The use of such a framework would provide estimates of the magnitude of costs associated with accidents and with environmental impacts. Since it does not seek to estimate the costs associated with different levels of safety or environmental regulation, however, no conclusions could be drawn on whether existing levels of regulation are satisfactory.

The comparison of prices and marginal costs in the transport sector provides information that could be combined with future analysis of price and marginal cost differences in the transport-using sectors in order to examine issues of wider economic benefits associated with transport projects (SACTRA, 1999; Table 4.2).

Moving outside from the development and results of the framework into the institutional context in which it may apply, it is evident that the institutional framework of the rail industry does not provide a barrier to innovation in pricing. The forthcoming adjustment of the two-part tariff for infrastructure use with a re-emphasis on the variable component reflecting short run marginal costs illustrates the absence of such a barrier. Perhaps a bigger question relates to the way in which train operators, particularly the passenger operators, are able to convey more differentiated infrastructure use charges to the final customer. A large proportion of fares is heavily regulated, with a cap on overall price increases and limitations on potential predatory pricing. Clearly, if the price signal to the final customer is heavily restricted, the effect of innovation in infrastructure use charging may be heavily diluted.

Although the issue of regulation of fares paid by rail passengers is not of direct relevance to the framework, it should be borne in mind that such constraints effect the way in which the outputs may be interpreted.

9.6 Caveats: the Dangers of Directly Interpreting Results from such a Framework

There are three reasons why the results produced by such a framework, even if they were completely accurate, should be interpreted with care:

- **A balance between fully allocated costs and revenues falls squarely within the political domain and should not necessarily be interpreted as an objective**. There is no basis in economic theory for such a balance and estimation requires the use of relatively arbitrary procedures for allocating joint costs. The revenue to fully allocated cost ratio provides important information that must be taken in conjunction with social considerations and fiscal needs of the Government in order to determine whether increases or reductions in this balance are desirable;
- **The ratio of marginal cost to revenue estimates should not be used to determine the price changes necessary to achieve efficiency** – although this ratio indicates the direction of change in prices, both marginal cost and revenue are sensitive to the level of transport demand, which would clearly adjust if prices were to change; and,
- **For public service vehicles and rail passenger services results are not presented per passenger kilometre.** The analysis has been based on changes

in vehicle and train kilometres. This cannot be interpreted per passenger kilometre unless a strong assumption is made. This is that a 1% increase in passenger kilometres is reflected in a 1% increase in bus or train kilometres.

10 Conclusions

10.1 Introduction

In this chapter the main achievements of the analysis framework are highlighted and the policy questions the framework is able to address are summarised. Due to the innovative and exploratory nature of the study, the chapter concludes with a broad and extensive range of possible future directions for the analysis.

10.2 The Analysis Framework

Despite the uncertainties associated with the individual cost and revenue elements, the analysis presented in this report demonstrates that the framework set out in Chapter 4 may be implemented with a reasonable degree of completeness of content.

Although there are specific concerns in relation to all environmental cost categories, and for road congestion and accidents, it is also important to highlight the achievement of creating a reasonably complete framework covering:

- Both road and rail;
- Marginal cost and fully allocated cost analyses; and,
- Being created from inputs and containing outputs at a high level of disaggregation.

The suitability and compatibility of the road databases has been confirmed. The level of detail relating to issues of rail infrastructure use charging has enormous potential but the analysis for the rail sector as a whole is highly constrained by the confidentiality associated with train operator cost and revenue information.

10.3 Examples of Policy Implications from the Analysis

The analysis has demonstrated the types of policy implication that may be drawn. These are as follows:

- What is the *direction* of change in prices if existing charges are to be based on marginal costs?
- Does there *appear* to be a need for the introduction of new pricing instruments in the road sector?
- Are current levels of subsidy justified on *economic efficiency grounds*?
- How do *weighted short run marginal costs compare to charges* for the road and rail sectors at the national level?
- How do *fully allocated costs compare to charges* for the road and rail sectors at the national level?
- If the overall costs are apportioned to different vehicle categories, *how do the allocated costs by vehicle class compare to revenues*?

In order to illustrate the boundaries within which the framework may be used to answer policy questions, the limitations in the use of the framework have also been identified. Some of these limitations generate a range of research possibilities for the future. These are discussed in the following section.

10.4 Future Research Opportunities

Future research opportunities are identified under five headings. These are not in order of priority, nor are they mutually exclusive areas of research. The five areas are:

- Enhancing the content of the existing framework;
- Extension of the framework to cover future years;
- Extension of the framework to enable the magnitude of marginal-cost based prices to be determined;
- Development of a more disaggregate road framework; and,
- Development of a more comprehensive rail framework.

These areas are discussed in detail in Annex C.

Of these areas, the highest priority for the road framework is to integrate demand responses to price changes, and subsequent feedback to changes in costs. This should be done for existing pricing instruments and for a year in the near future (e.g. 2003).

For the rail framework, the key priority is to elaborate a framework that works with changes in passenger demand, rather than train kilometres. Again, this should be carried out for a year in the near future.

Annex A: The DETR Terms of Reference

RESEARCH PROPOSAL: SURFACE TRANSPORT COSTS AND CHARGES (Project reference H025A)

1. The research will provide an assessment of the social costs of road and rail transport and of the coverage of these costs from taxes, charges and other payments in 1999. The attached annex sets out background information about the research issues.

Objective

2. The purpose of this project is to estimate the costs (other than those input by the final user) of each of the main modes of surface transport in the UK. The main components of these costs are track costs, environmental costs, and an element of accident costs. For most rail transport, the cost of maintaining and operating locomotives and rolling stock and depreciation and interest on these vehicles is a further relevant cost to be added to track and environmental costs since these costs are not met directly by the users of rail services.

3. The project will also assess the extent to which these costs, both at a marginal and aggregate level, are covered by payments made by users, other parties and by Government. The intention is to compare at an aggregate level and at various levels of disaggregation the extent to which each mode and vehicle category covers these costs out of payments in the form of taxation, user charges and fares. The information provided will inform policy and project appraisal and decisions about fair and efficient price levels and subsidy. In order to reduce uncertainty caused by forecasting, the study will take costs and prices in the single most recent year for which data are available.

4. The project has been initiated as part of the Government's response to recommendation 11.16 in the recent SACTRA report "Transport and the Economy". The project will build on the work by the EC Expert Groups on Infrastructure Pricing and Costing, Environmental Costs and Safety and the report of the EC High Level Group which reviews the Expert Group's reports published in May of this year. It will also take account of the work currently being undertaken by NERA on Lorry Track and Environmental Costs.

5. The project is intended to provide estimates of the marginal and average costs and charges for different modes improving appraisal techniques and determining fair and efficient prices. But it will not research the specific values or cost/impact relationships. Rather it will take these from published literature or other studies. An important part of the study is to provide a structure or model which allows the user to change the values and relationships used to determine costs so as to assess the robustness of the estimates to other sources of information. The model will also be used to assess the extent to which different modes meet either marginal or total costs under different assumptions about the relevant values and relationships.

Outputs

6. The first output from the study will be a review of recent work on transport costing and charging. The review will focus on the broad principles of costing, valuation and allocation rather than on specific values or cost/damage functions. The values and cost/damage functions to be adopted are to be taken from the NERA work or other readily available information and such values and functions will be capable of being changed by the user of the model. The literature review will serve to inform the consultants and the Department about higher level options for the structure of the model.

7. The outputs from the study will be;

- a literature review of recent work on transport costing and pricing, which examines the broad principles adopted and draws conclusions from these about the methodology proposed in these terms of reference;

- a report explaining the methodology and the input values used, giving information on data sources used to derive these input values, the relationships between these values and costs;

- a matrix which shows, by mode by peak/off-peak, by vehicle/train type, road type and area type the marginal and average cost per vehicle/train kilometre on each or a sample of the assumptions used about the level and allocation of these costs in the report;

- a similar matrix which shows the revenue per vehicle kilometre from charging, taxes and other revenue sources on the same disaggregated basis as the marginal and average cost tables described above;

- a matrix showing the differences between (iii) and (iv) to indicate levels of subsidy or payment in excess of costs for each of the categories/locations/times of day identified in the matrix;

- a matrix which gives the quantities in terms of vehicle km etc needed to provide for the total costs and revenues in each of the entries in the costs and revenues matrices on the assumption that the marginal cost and revenue figures represent the average for each cell in the matrices;

- a spreadsheet based model which allows users to change the values of the costs and/or the relationships between vehicle kms and costs used in the model.

Timetable

8. The contract will commence on 3rd April and be completed by Monday 4th September. The Department will require a draft final report (12 copies) covering all the objectives of the research including an executive summary in Word 97.

Administrative Arrangements

9. Invoices should be sent to Tina Langford, HETA Division, DETR, 3/19, Great Minster House, 76 Marsham St, London SW1P 4DR.

10. The Contractors will need to maintain close liaison with the project officer and be available for regular progress meetings.

Evaluation of the Tenders

11. The tenders will be evaluated according to the following criteria:

- knowledge of the subject areas, including environmental, economic and engineering knowledge.
- participation in similar work for other clients.
- understanding of the requirements.
- the quality of the tender specification.
- meeting the objectives of the research.
- experience at bringing information from a wide number of potentially inconsistent sources and developing a useable framework.
- willingness to work closely and interactively with the client.
- overall value for money

HETA Division **January 2000**

Overall Approach to Costing: Average Costs/Marginal Costs

The aim of this project is to provide information on both average and marginal costs. However, estimates of both average and marginal costs are not always both regularly available. For example, congestion costs are commonly estimated in terms of the costs imposed by the marginal vehicle, as discussed below. In some cases, especially those relating to environmental costs, there is some uncertainty about the form of the relationship between the cost of the damage and the volume of traffic. In particular with health related effects, there is a lack of data on damage costs at low levels of impact. In absence of such data, cost functions are often assumed to be linear. The consultants should note in their report those cases where evidence to support the relationship between average and marginal values is particularly weak.

These terms of reference set out in some detail the structure for such a model that might be used for road transport, the main components of which are the levels of disaggregation by road, area and vehicle type and by time of day etc. However, this structure does not immediately lend itself to an analysis of rail industry costs as these are usually estimated with regard to different types of service. The consultants will need to consider how the costs of the different modes can be set out on a broadly comparable basis and at a level which is sufficiently disaggregated to inform cross modal policy analysis.

Overall Approach to Costing: Estimates of Track Costs - Congestion Pricing or Cost Recovery?

The EU Paper "Fair and Efficient Pricing" recommended the use of short run marginal cost pricing for all transport modes. This approach was followed in the Reports of the 3 Expert Groups and in the summary of these reports by the EU High Level Group. (Final Report on Estimating Transport Costs 26 May 1999). The Group adopted a cost causation approach whereby the short run marginal costs included the congestion costs imposed by the marginal road or rail vehicle on other vehicles.

The EU Groups considered those circumstances in which for policy reasons there is a requirement to recover the costs of past investment from users. It recommended that, in these circumstances, a market pricing approach based on Ramsey principles or Two Part Tariffs should be adopted.

The EU analysis did not address in any depth the relationship between congestion charging and additions to capacity or other means of managing demand. If a costing regime based on marginal short run social costs is efficient, there is an implicit assumption that the level of provision of capacity and/or the level and pattern of demand is optimal. In other words, there is an assumption that there exist no opportunities for cost beneficial enhancements to capacity or from other demand management measures which have the effect of reducing marginal short run social costs. In many cases such an assumption is unrealistic. Moreover, prices based on estimates of the existing level of marginal short run social costs do not reflect even the first round response that would arise from directly charging such costs to road users, resulting in reduced levels of demand and hence lower congestion costs. For these reasons the DETR believes that, despite the theoretical superiority of short run marginal social cost pricing when combined with an optimal investment programme, the difficulty of incorporating these second round effects provides practical grounds for not relying exclusively on such estimates.

Having reviewed the options, DETR have decided that this study should consider two methods for addressing track costs. The first should omit congestion costs and include an allowance for past investment based on resource accounting techniques with engineering based procedures for allocating costs between vehicle types. This approach might follow the DETR road track costs methodology although the method of estimating capital costs would be based on resource accounting practice, as in the NERA report, rather than on the three year average of past capital expenditure as in the DETR Road Track Costs publication. The researchers should review briefly the methods for estimating track costs used in the NERA report and consider whether there are good grounds for changing the methods or relationships. They should review the way in which the various assets, including the land taken by a transport scheme, are treated and the consistency of the methodology with the objectives of the study. Rail track costs should be allocated in line with Railtrack's current practice (see below).

The second approach which the Department wishes to pursue requires estimates of congestion costs as the cost of capacity. Estimates of the marginal social cost of road use attributable to capacity constraints and/or the absence of efficient pricing can be derived from many transport models. Estimates from such models show the benefits to remaining road users from the removal of the marginal vehicle from the network. The Department's NRTF model provides one nationally consistent basis for estimating marginal congestion costs on this basis by time of day and by road and area type. If the consultants wish to use these estimates in preference or as an alternative to others, the Department will make them available.

These two approaches to assessing the costs of the transport network will be developed separately. Estimates based on both approaches to costing are required. It is the Department's view that a single approach following the methods set out below will suffice for most other categories of cost. The approach that the Department suggests should be adopted is set out in the following sections.

Although the two approaches have a different theoretical basis, they should be considered as alternatives for the purpose of this study. Total marginal costs, shown at whatever level of disaggregation is appropriate, should be estimated using first the congestion based measure of marginal infrastructure costs and then taking the estimate of track costs based on partial cost recovery.

Congestion based cost estimates are more difficult to derive for the rail network because such costs tend to be confined to specific locations. Treatment of such costs is discussed at paragraph 37 below.

Infrastructure Costs which vary in part or in whole with use

Many of the costs of providing and maintaining road and railway infrastructure vary in part or entirely with the level of use. These include the costs of repairs, maintenance and operating the networks. For some of these costs a well established relationship between cost and use at the margin exists. For example, the 4th power rule relates damage to the road surface to the axle weight of a road vehicle. Similar cost causation functions exist between expenditure on track maintenance and different levels and types of rail traffic. However, many costs, such as the lighting of roads, winter maintenance, operation of traffic/railway signals, station facilities, administration etc, while related broadly to use, may not vary directly with small changes in traffic levels.

The consultants will be required to develop a method for the treatment of those costs which bear only an indirect relationship to use, which should be discussed as it is developed with DETR. The Department would wish to reach an agreement with the consultants upon the proportion of such costs to be treated as marginal and the method of allocation. As with the estimation of track/congestion costs, alternative approaches might be required, ranging from a narrow definition of costs varying with small changes in traffic levels to a more exhaustive average cost pricing basis.

Environmental Costs: Local Air Quality

The adoption of a short run marginal social cost approach assumes, in effect, that capacity is fixed. Costs such as those associated with the impact of new infrastructure on the landscape are therefore not an issue for this project. The main marginal environmental costs of transport are associated with emissions in terms of air quality at a local, trans-national and global level and noise. Some emissions affect people's health and/or reduce their welfare when on the street, in open countryside, in their homes and in other buildings. Others have a wider impact by increasing global warming. Certain emissions have an adverse visual impact, making buildings dirty and damaging their facades.

It is not the intention of the study to research dose response effects or the welfare costs of each pollutant from road and rail transport. The consultants should take an established set of dose response effects and values of the impacts (and the ranges) such as those used in the NERA report on lorry track and environmental costs. These impacts were estimated using case studies to show the population and buildings at risk from transport related emissions, the notion of those risk and their costs. The consultants should also use established estimates of emission factors, such as those provided to DETR by AEA Technology's NETCEN model.

Environmental Costs: Transboundary Emissions

Certain emissions, in particular those from the generation of electric power used by rail transport, have transboundary effects. The consultants should review the literature on the impacts of costs on such emissions, including the values from the EXTERNE project, and consult DETR about the value or values to be included in the model.

Environmental Costs: Noise

The NERA report derives estimates of HGV related transport noise costs using the approach adopted for estimating the costs of emissions. The case studies quoted above were used to estimate the number of dwellings, banded by the noise levels they suffered and changes in the number of dwellings in each band as a result of a policy initiative. Estimates of the impact of noise on the market price of a dwelling and of the average market price of dwellings affected by noise were used to derive a relationship between changes in noise levels and changes in the value of the stock of dwellings now affected by noise. Either this approach or a similar existing method should be used in this study. The Department is not aware of methods which value noise nuisance suffered by pedestrians and those using other public spaces. The consultants, if they are aware of any such values, should draw these to the Department's attention and discuss how best to use these values in the model.

Environmental Costs: Climate Change

The NERA report included several non-health related effects of transport emissions, including the effects on ozone and climate change. Since the intention of this project is to bring together existing research rather than initiate new studies in valuation and quantification, the approach followed by NERA or a similar approach should be taken in respect of these environmental impacts of transport. Since these environmental costs are related directly to fuel consumption, they can be applied equally to rail transport so long as information on energy sources for electric train traction is available.

External Costs: Accidents

An element of the costs of road accidents is internalised through the process of insurance against claims made by accident victims against drivers at fault. However, not all accident costs are covered by insurance, in particular where those suffering damage or injury are unable to claim off an insurance policy. This may be because the relevant insurance policy does not cover all forms of accident and damage or because the injured party is unable to prove that fault can be attributed to an insured driver.

In theory, therefore, the external cost of road accidents is the difference between the total cost of all such accidents and the payment by road users for accident related insurance. In practice this is not a workable option. No information exists on aggregate injury and death related payments by insurance companies to road accident victims or the extent to which these are abated because the victim him/her self is partly at fault. Moreover, the payments made by insurance companies bear no relationship to the Department's HEN1 willingness to pay based values of a statistical life or injury. Such payments are intended to put the accident victim and/or his/her dependants back in the same financial position as before the accident.

For the purpose of this study DETR standard accident values should be used and the consultant should, in absence of better information, allocate the costs using an approach such as that adopted by NERA. However, the Department would be willing to consider other methods which refined the allocation process and avoided the potential double counting through failing to deduct from the estimate an element of insurance costs paid by motorists.

Rail operators are under a strict liability with respect to injuries suffered by rail passengers and so this element of rail accident costs is internalised. No such consideration applies to those who trespass on railway lines but the numbers of trespasses injured are small enough to be ignored for the purposes of this study.

Certain elements of accident costs are met by the public sector or other transport users and are not covered by insurance costs. These include police and ambulance costs, hospital costs etc and delays to other transport users. The Department provides estimates of the costs of road accidents to the police and health service.

Average/Marginal Costs; Disaggregation of Road User Costs by Area and User Type

Optimal pricing requires that users pay the full marginal social costs at the "new" equilibrium level of demand. This level is achieved after users have responded to the new pricing initiative. Past studies have used whatever definition of cost is readily available. Transport modelling techniques make it possible to estimate the marginal cost of delay imposed on other road users by a small increase in traffic levels on a specific part of the road network. However, other costs, such as certain categories of environmental costs, may be less well defined, in respect of small changes, with marginal costs often assumed to be equal to average costs in absence of specific evidence to the contrary. The consultants should identify those relationships where average and marginal costs are assumed to be equal and comment on the validity and implications of this assumption. In many cases disaggregation by area, road and vehicle type and by time of day will allow these average costs to be disaggregated to a level which is closer to the marginal.

Previously published estimates of road track and other external costs have generally disaggregated these costs by vehicle class. The NERA work focuses, in some detail, on different HGV types because it is intended to provide information relevant to decisions on VED. The DETR Road Track Costs Publication disaggregated between all vehicle types, with costs allocated across all classes of road traffic. Analysis of costs by vehicle type can inform decisions on fuel duty and VED.

Road user charging and other area specific measures can provide more efficient signals than measures such as VED and fuel duty, which impact upon all traffic irrespective of the location. One of the innovations in this study will be to provide estimates of the marginal social costs of transport for different area types taking the classification used in NRTF or a variant of it. The model should also be capable of showing such costs by vehicle type, road type and time of day. The disaggregation by area type, road type and time of day should be based on the NRTF database, which gives information on speeds, traffic volumes and road capacities from which the marginal costs of road damage and of congestion can be calculated. Information on speeds and traffic mix can be used to estimate emissions and accident costs.

Because of the diversity of sources of information, the costs that we expect the consultant to provide will be a mixture of average and marginal costs. For instance, congestion and environmental costs are largely based on marginal costing at present levels of demand. Certain other costs, such as those related with routine maintenance, are more likely to be related to average levels of demand. As noted above, the consultant should indicate which costs are marginal in terms of their changing with respect to small changes in traffic levels and those which vary with overall traffic levels but are not directly related to marginal changes.

Public Transport: Bus and Rail

The incorporation of buses in terms of vehicle kilometres into a framework of this form gives rise to no new technical issues. Under one scenario, increases in bus patronage could be equated with increases in vehicle kilometres and all outputs would be in terms of cost per vehicle kilometre for different types of bus, area type, road type etc. For the purposes of this study the marginal unit will be taken to be the vehicle rather than the passenger. (Similar considerations apply to private vehicles, whose occupancy is assumed to remain constant). There would seem to be good grounds for identifying rail costs on a train kilometre basis although other measures (e.g. vehicle km) might provide an alternative basis for analysis.

Disaggregation of costs by area type for rail transport cannot be based on NRTF road and area types. For several area types rail has an insignificant share of the market. Railtrack has developed detailed bottom-up engineering models to estimate track usage costs. In addition, Railtrack argue that further cost elements should be included in usage costs to reflect the effect on underbridges, signals and electrification assets. They have provided top-down estimates for these additional estimates and have estimated marginal costs by track type and train type. Booz, Allan and Hamilton have reviewed Railtrack's model and have recommended that a top-down approach is used for all cost drivers. The Regulator will determine what approach is to be taken in the Spring and the consultants should incorporate this into their analysis. This framework would appear to provide one approach to the disaggregation of rail user costs. As with other parts of the study, the requirement is to build on existing work wherever possible since the timescale and funding does not permit new data collection.

Two agents are responsible for delivering rail services - the network provider (Railtrack) and the relevant train operator. While these are met in total either by the final user or through subsidy, the consultants will need to identify separately the costs met by each agent responsible for providing rail services and, in addition, those costs which are external to the network provider and to the operator. Train operation costs include the maintenance and operating of locomotives and rolling stock, along the depreciation and interest. The allocation of environmental costs between train operations and the network provider is a matter which should be discussed with the Department when the framework for identifying and allocating rail costs has been established.

The NERA report relates road transport emissions to atmospheric concentrations of pollutants, and then to physical damage. The physical damage caused is then evaluated in monetary terms in order to estimate a damage cost function. Data on emissions from different types of train has been compiled by the University of Sheffield. However, this work has only investigated the quantity of rail transport emissions. It has not developed the three further necessary steps. In order for the consultant to use the NERA approach for evaluating health damage costs from rail it will be necessary to reach some views (to be discussed with the Department) about the number of people affected by emissions through living near railway lines, and the average number of people present in stations at any one time.

The consultant should bear in mind that the NERA methodology for estimating health damage cost functions makes the simplification of linearity, thereby assuming a constant rate of change of physical damage as pollution concentration levels increase. The rate of change is estimated using current concentration levels. If the actual relationship is non-linear, especially at lower concentration levels, this approach makes optimal pricing difficult.

A proportion of rail congestion costs are incorporated through the performance payments paid by operators whose trains delay those run by other operating companies. Some allowance must also be made for knock-on delays on other trains run by the operator responsible for causing the delays. Railtrack has conducted modelling work in order to inform their congestion charging proposals. This along with any emerging publications from the Rail Regulator should be taken into account. The consultants should be aware that Railtrack's proposals need to consider delay costs to other timetable services and not the opportunity cost of higher valued services denied access to the network. The consultant should consider options for attributing congestion costs to service types, area types etc. Moreover, consideration should also be given to the treatment of these congestion costs alongside track access charges. For consistency with the approach taken on roads, the two costs should be seen as alternatives rather than as additive.

Prices and Charges

Estimation of most road user charges and taxes is relatively straightforward. Marginal costs are made up of the tax and duty on fuel. The approach to be adopted for providing estimates of vehicle speeds by area and road type will make it possible to derive estimates of fuel consumption by vehicle type. Indeed, these fuel consumption estimates are required in measuring the impact of emissions on local air quality. Estimates of charges paid by road users should also include such information as is available on parking charges and other related payments. In addition, an average cost per vehicle kilometre figure should be provided which includes VED payments.

The relevant table for rail traffic will show separately passenger receipts and subsidy payments. These sources of revenue should be shown at the same level of disaggregation as are the total cost of train operations. Hence information is required on train occupancy to provide estimates of revenue per train kilometre. The Department will advise the consultants on what assumption should be made about rail freight revenues.

Annex B: Environmental Cost Estimation

Paul Watkiss, Chris Dore, Katie King and Tim Murrells.
AEA Technology Environment.

Introduction

This annex sets out the approach used within the framework to assess the environmental costs of road and rail vehicles. It also presents a discussion of the results. The study includes the following environmental costs:

- Effects of atmospheric effects on human health;
- Effects of atmospheric effects on buildings and crops (non-health);
- Effects of noise on amenity; and,
- Effects of greenhouse gas emissions on climate change.

Discussion of the Framework

Air Pollution

The framework includes values for the effects of atmospheric emissions on human health and on the natural and man-made environment (non-health effects). The study has quantified and valued the impacts of emissions using a step by step approach, based on the impact pathway or dose-response methodology (EC, 1995). This is:

- Assess the atmospheric emissions of all pollutants from vehicles.
- Assess the effect of these emissions on local and regional air concentrations (including secondary pollutants formed);
- Quantify the health and environmental impacts of pollution concentrations using dose-response functions and data on the population or stock exposed at both the local and regional level; and,
- Value these health and environmental impacts in monetary terms.

For both road and rail, the following emissions have been considered:

- CO_2;
- CO;
- SO_2;
- NO_x;
- PM_{10};
- Hydrocarbons;
- Benzene; and,
- 1,3-butadiene.

For road vehicles, emissions of benzo-[a]-pyrene have also been considered as an indicator of potential impacts from PAHs.

Data on emissions from road vehicles were taken from the National Atmospheric Emissions Inventory (Salway et al, 1999). Emission factors were collated for the following vehicles.

Table C.1: Vehicle Types Assessed

Car	LDV	Rigid	Artic.	PSV
Petrol passenger car	Petrol LDV	3.5 to 7.5 tonne rigid	up to 33 tonne articulated	Bus
Diesel passenger car	Diesel LDV	7.5 to 17 tonne rigid	33 to 38 tonne articulated	Coach
		17 to 26 tonne rigid	over 38 tonne articulated	
		26 to 32 tonne rigid		

In each case, emissions were derived by:

- Vehicle technology standard – for pre-Euro, Euro I, and Euro II vehicles; and,
- Speed - with factors for each of 9 speed bands. <= 10 mph, 11 - 15 mph, 16 - 20 mph, 21 - 25 mph, 26 - 30 mph, 31 - 40 mph, 41 - 50 mph, 51 - 60 mph, > 61mph.

These data were used to compile 1998 emissions, by speed band, for each of the 14 vehicle classes in the table above. These were combined with information from the NRTF to estimate the speed adjusted emissions for the different vehicles on each of the area types (11 categories) and road types (7 categories for rural areas, 5 for urban), for both peak and off-peak, in busy and non-busy directions (4 categories). In the reported results these were summarised to 3 road types (motorway, trunk and principle, and other) and two flow types (weekday peak and off-peak).

For diesel trains, emissions data were taken from the National Atmospheric Emissions Inventory (NAEI, Salway et al, 1999). Separate emissions were collated for passenger trains (based on factors for pacer, sprinter, and turbo diesel multiple units, InterCity 125s, and class 47 locomotives) and for freight trains (based on class 37, 47, 56, 58, and 60 locomotives). Data on emissions from electricity generation were also taken from the NAEI. Data on electric and diesel train kilometres were provided by Railtrack. These data were combined to compile 1998 fleet emissions, for different train categories (InterCity, PTE, Rural, Cross-country, and London suburban).

The modelling of air pollution concentrations and estimation of health and non-health impacts were calculated using the ExternE computer tool (EC, 1999b). This tool, summarised in the figure below, is based around a geographical information system (GIS) and has a series of databases and models to allow the integrated quantification and valuation of environmental costs from transport.

Local population data and meteorological data are input into the model, along with emissions data. Air pollution concentrations are then calculated at a local and regional level. The pollution concentration at the local scale is modelled using a Gaussian plume dispersion model. Regional dispersion modelling is undertaken using a Lagrangian model (for secondary particles and acidic deposition) and an ozone matrix model (based on the EMEP ozone model output). The European CORINAIR emissions database is incorporated in the model to provide the background emissions of pollutants needed to model secondary species.

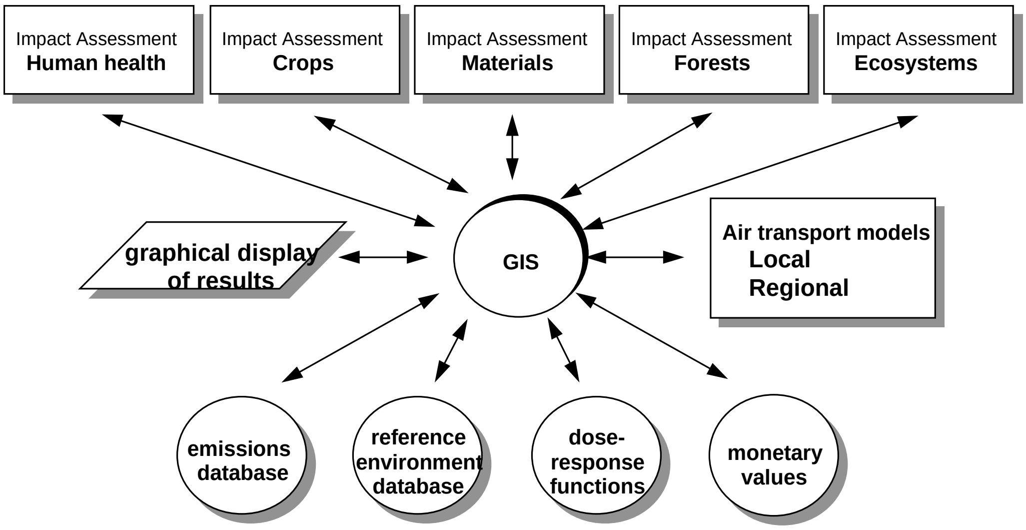


Figure C.1. Structure of the ExternE Transport Computer Tool.

The tool includes geographical databases of population, crops, forests and the stock at risk of building materials for the UK and Europe. The output from the dispersion models is linked to these databases to calculate the receptor-weighted increases that arise from incremental transport emissions. Impacts are quantified using dose-response functions that link pollution concentration to specific endpoints (e.g. cases of asthma). Finally, each endpoint is assigned a monetary value, so that impacts are expressed in economic terms. A higher resolution is used for the local analysis (hence the need for local population data), to ensure local impacts are accurately assessed.

The tool was run in a number of different areas, to examine the differences between emissions in various locations. This is important as the location of emissions has a strong influence on the size of environmental costs. Urban transport emissions are released at ground level in areas of high population density. Such emissions have greater impacts than rural emissions or high-level stack emissions from electricity generation, because they lead to larger pollution-weighted increases.

The areas considered in the tool were set to match the eleven geographical categories in the NRTF. These are:

- Central London
- Inner London
- Outer London
- Central Conurbations
- Outer Conurbations
- Area>25 sq kms
- Area 15-25 sq kms
- Area 10-15 sq kms
- Area 5-10 sq kms
- Area 0.01-5 sq kms
- Rural

By running the tool in a number of representative locations, it was possible to derive unit pollution costs that reflect the NRTF area categories and population densities. Both health and non-health effects were assessed using this approach, using the functions and values described below.

Health Impacts

The impacts of atmospheric emissions on human health are well documented, causing a wide range of impacts from premature mortality (deaths brought forward), through to respiratory hospital admissions, exacerbation of asthma, other respiratory symptoms and loss of lung function.

Dose-response functions were used to quantify health impacts in the analysis. These functions link the changes in air pollution concentrations to additional health events. Each health event is then valued in economic terms, using cost of illness and willingness to pay estimates.

The dose-response functions used in this study derive from two major sources: COMEAP and ExternE. The UK Department of Health's *Committee on the Medical Effects of Air Pollutants* (COMEAP, 1998) reviewed the relationships between air pollution and health. It provided relationships for use in quantification of these health effects for the UK. Only those effects which the Committee felt could be applied to the UK with 'reasonable confidence' were included.

The functions recommended by COMEAP (1998) are based on the results of time-series studies and are shown in Table C.2. These are relationships between daily levels of pollutants and the risk of adverse health effects, on the same or subsequent days, adjusting for weather and other factors.

Table C.2. Dose-Response Functions recommended by COMEAP.

Pollutant	Impact Category	% change in rate per μg/m^3
PM_{10}	Acute mortality	0.075%
SO_2	Acute mortality	0.060%
Ozone	Acute mortality	0.060%
PM_{10}	Respiratory Hospital Admissions	0.080%
SO_2	Respiratory Hospital Admissions	0.050%
Ozone	Respiratory Hospital Admissions	0.070%

Source: COMEAP (1998). Quantification of the Effects of Air Pollution on Health in the UK.

COMEAP provided functions for particles, sulphur dioxide and ozone for two health endpoints - deaths brought forward and respiratory hospital admissions. The group did not quantify health effects from NO_2 due to doubts about the reliability of evidence, though a possible relationship for NO_2 and respiratory hospital admissions was included. The lack of UK studies and uncertainties about the independent effect of CO led COMEAP not to quantify the effects of this pollutant.

The EC's ExternE Project (EC, 1995; 1999; 2000) also reviewed the relationships between air pollution and health and provided functions for quantification. As well as the functions included in COMEAP, ExternE recommended the quantification of additional health effects where good evidence existed, even if quantification was more uncertain. An example is the use of the US literature on chronic mortality[16]. The dose-response functions recommended by ExternE include mortality due to primary particles, nitrates, sulphates, SO_2, ozone, benzene and butadiene. For particles this also includes chronic (long-term) effects, based on US literature. Functions for morbidity were recommended for particles, CO, SO_2 and ozone. The functions recommended by ExternE, in addition to deaths brought forward and respiratory hospital admissions, are shown in Table C.3[17].

Both COMEAP and ExternE form similar judgements on which pollutants are causal. They also agree closely on those functions (e.g. deaths brought forward - acute mortality, respiratory hospital admissions) for which the evidence is strongest. However, because of the additional endpoints considered in ExternE, the two studies provide very different sets of functions (and so very different results). The use of COMEAP functions provides a sub-total of possible health effects, but the confidence associated with this sub-total is high. The ExternE functions include the same sub-total but also quantify other effects for which quantification is more difficult or which necessitates the transfer of dose-response functions from the US. They therefore aim to quantify total effects. However, by including these additional impacts, the uncertainty in the results increases. Note that, even within the approach recommended by ExternE, there may remain unmeasured endpoints.

To acknowledge the different uncertainty in the use of COMEAP and ExternE, the health impacts from the use of the two studies were calculated separately, though in the summary tables and figures the values are combined to a single air pollution value. Further analysis of the health effects was also undertaken, separating health endpoints into four uncertainty bands. These reflect the level of confidence in the effects (i.e. the consensus on the effect being real) as well as the confidence in the quantification method. Such an approach provides valuable information on the relative uncertainty within the health estimates presented.

[16] Recent communication from COMEAP (2001) now also recommends that effects of chronic mortality are quantified. The approach recommended for quantification from COMEAP was not available during the time-frame of this study, though the approach used here is similar.

[17] To ensure consistency with COMEAP (1998), the quantification of particles for 'deaths brought forward' and 'respiratory hospital admissions' uses the PM_{10} size fraction. The exception has been for quantifying chronic mortality, where in keeping with recent communication from COMEAP, we have used $PM_{2.5}$. It should be noted that this assumes different size fractions of the particle mixture have different levels of causality with respect to acute and chronic effects. The alternative is to assume both acute and chronic effects arise from the same particle fraction and so to correct all functions to one metric based on the proportions in the ambient air mixture. This is the method used in ExternE, which adjusts all functions to $PM_{2.5}$ when implementing transport impacts. Note this assumption does lead to higher values for health impacts for transport, because of the high proportion (>90%) of $PM_{2.5}$ from vehicle exhausts.

Table C.3 Exposure-Response Functions recommended by ExternE. The exposure response slope, f_{er} , has units of case events per year per person per µg/m^3 , except for mortality which is expressed as percentage increase per µg/m^3

Receptor	**Impact**	**Reference**	**Pollutant**[1]	f_{er} [1]
ASTHMATICS				
Adults	Bronchodilator Usage	Dusseldorp et al, 1995	PM_{10}	0.163
	Cough	Dusseldorp et al, 1995	PM_{10}	0.168
	Lower respiratory symptoms (wheeze)	Dusseldorp et al, 1995	PM_{10}	0.061
Children	Bronchodilator usage	Roemer et al, 1993	PM_{10}	0.078
	Cough	Pope and Dockery, 1992	PM_{10}	0.133
	Lower respiratory symptoms (wheeze)	Roemer et al, 1993	PM_{10}	0.103
All	Asthma attacks (AA)	Whittemore & Korn, 1980	O_3	4.29 E-03
ELDERLY 65+				
	Congestive heart failure	Schwartz and Morris, 1995	PM_{10}	1.85 E-05
			CO	5.55 E-07
CHILDREN				
	Chronic cough	Dockery et al, 1989	PM_{10}	2.07 E-03
ADULTS				
	Restricted activity days (RAD)[2]	Ostro, 1987	PM_{10}	0.025
	Minor RAD [3]	Ostro and Rothschild, 1989	O_3	9.76 E-03
	Chronic bronchitis	Abbey et al, 1995(after scaling)	PM_{10}	2.45 E-05
ENTIRE POPULATION				
	Chronic Mortality(CM)	Pope et al, 1995(after scaling)	$PM_{2.5}$	0.214%
	Cerebrovascular hospital admissions	Wordley et al, 1997	PM_{10}	5.04 E-06
	Symptom days	Krupnick et al,	O_3	0.033
	Cancer risk estimates	EC, 1997; based on US EPA	Benzene 1,3-butadiene	1.14 E-07 4.29 E-06

[1]Sources: (EC, 1995; 1999; 2000).

[2]Assume that all days in hospital for respiratory admissions (RHA), congestive heart failure (CHF) and cerebrovascular conditions (CVA) are also restricted activity days (RAD). Also assume that the average stay for each is 10, 7 and 45 days respectively. Thus, net RAD = RAD - (RHA*10) - (CHF*7) - (CVA*45).

[3]Assume asthma attacks (AA) are also minor restricted activity days (MRAD), and that 3.5% of the adult population (80% of the total population) are asthmatic. Thus, net MRAD = MRAD - (AA*0.8*0.035).

The uncertainty bands are shown in Table C.4. Those impacts in band 1 have a high certainty and can be quantified using methods recommended by COMEAP. Those in bands 3 and 4 are largely based on transferring data from US studies and so additional issues are raised with respect to quantification as well as with the reliability of the evidence.

Table C.4: Uncertainty Bands used for the Health Assessment.

Uncertainty Band	Impacts
Band 1	Acute mortality (deaths brought forward) and respiratory hospital admissions as recommended by COMEAP
Band 2	Other acute respiratory effects discussed by COMEAP but not used for quantification, using functions presented in ExternE.
Band 3	Chronic mortality (years of life lost) using approach recommended by ExternE.
Band 4	Chronic morbidity and additional US acute respiratory effects using relationships and approach recommended by ExternE.

For valuation of health endpoints in band 1, the framework uses the recommendations of the Ad-Hoc group on the Economic Appraisal of the Health Effects of Air Pollution (EAHEAP, 1999).

The group recommended a number of alternative values for air pollution mortality (deaths brought forward). A maximum value (£1.4 million) based on an adjusted value of statistical life (VSL) and a range of values (from £2,600 – £110,000) based on adjusting the VSL to take account of life expectancy (years of life lost) and quality of life. The reported results use the values from the years of life lost approach for the low and central estimate (low £2,600 – central £110,000). For the high estimate, the full value of £1.4 million has also been undertaken[18]. Current evidence suggest that acute mortality caused by air pollution only shortens death by a small amount of time. For this reason, and because air pollution is only one of the causal elements in causing acute mortality, the use of the full value (£1.4 million) represents a significant overestimate.

For valuation of health effects in bands 2, 3, and 4, values recommended by ExternE (EC, 2000) have been used. The values are shown in Table C.5 below. For the valuation of chronic mortality, a years of life lost approach is also used, though the approach differs to that presented within EAHEAP (EAHEAP did not produce values for chronic mortality). The value of a life year lost for chronic mortality is derived from a full VoSL, adjusting for full life expectancy and discount rate. There is therefore no adjustment for age (i.e. >65) or quality of life as in EAHEAP. This produces a value of 96500 Euro per year of life lost (assuming a 3% discount rate). A range was introduced around this value, based on the central and high 'years of life lost' estimate from EAHEAP.

[18] Whilst the use of the 'value of life years' derived from VoSL is currently a reasonable approach for the valuation of deaths brought forward, new evidence is expected shortly from DETR which will provide direct WTP for these health endpoints.

Box 1. EAHEAP valuation

EAHEAP only valued acute mortality (deaths brought forward), it did not consider chronic effects. Starting with a Value of Statistical Life (VoSL) of £2 million, EAHEAP concluded that the combined effects of age and increasing physical risk aversion might plausibly result in lower VPF/VoSL for those people aged over 65 (ranging from 80% at age>70, to 35% at age>85). Given deaths brought forward from air pollution predominantly occur in such people, a factor of 70% was used, resulting in a value of £1.4 million.

EAHEAP also investigated issues of life expectancy and health state on the VoSL, stating that '*average life expectancy [for over 65s] is about 12 years. Thus for over 65s with a life expectancy as little as one year, WTP would be expected, as a minimum, to be one twelfth of this. For 1 month, a further division by 12 would be needed (i.e. giving a factor around 0.5% of the baseline). The maximum would be the figure of £1.4 million, reflecting advanced age, but not reduced life expectancy*.'

For quality of life, EAHEAP concluded that people would be willing to pay more to reduce risks if they stood a chance of an extra year in good health, rather than just an extra year in bad health. EAHEAP investigated the effects from assuming WTP is proportional to an index of health-related quality of life. Using a quality of life adjustment of 0.4 (the value severe COPD patients rated their quality of life at) and adjusting for general quality of life of older people (0.76 for over 65s), the VPF was adjusted by (0.4/0.76), i.e. by 54%. A range of 0.2 – 0.7 was also considered for quality of life, based on 1 SD.

Table 1. Values recommended in EAHEAP for valuing Deaths Brought Forward.

	Life expectancy adjusted VoSL	
Quality of life adjustment	**1 year (£120000)**	**1 month (£10000)**
Respiratory deaths (0.4)	£63000	£5300
Respiratory deaths (0.2)	£32000	£2600
Respiratory deaths (0.7)	£110000	£9200

The adjusted range of £2,600 – £110,000 was therefore recommended, with the figure adjusted only for age remaining at £1.4 million. These three values are used as the low, central and high estimates for deaths brought forward in this study.

Table C.5. Valuation endpoints used in the study.

	Low	Medium	High
Acute mortality	£2600 [1]	£110,000 [1]	£1,400,000 [2]
Respiratory hospital admissions		£2668	£3235
Bronchodilator use		£27	
Cough		£30	
Lower respiratory system		£5	
Cerebro-vascular hospital admission		£11153	
Congestive heart failure		£2173	
Chronic mortality	£31,500 [1]	£65,000 [1]	£110,000 [1]
Chronic cough		£160	
Restricted activity day (RAD)		£73	
Minor RAD		£30	
Chronic bronchitis	£70,000	£112,867	£166,667
Asthma attack		£50	
Symptom days		£30	
Cancer	£1.1 million	£1.6 million	£2.2 million

Source: EAHEAP, 1999. EC, 2000 (adjusted from 2000 Euro to Pounds).

[1] calculated using a Years of Life Lost approach. [2] calculated based on VoSL approach.

Non-health Effects

Air pollution also has adverse impacts on building materials, crops, ecosystems (terrestrial and aquatic) and on visibility.

The analysis of non-health impacts also followed a dose-response approach, using the ExternE computer tool. The quantification and valuation followed the approach recommended in ExternE (EC, 1999: 2000) and is consistent with the economic assessment of the non-health benefits of the National Air Quality Strategy (DETR, 1998). The study has quantified and valued the following effects:

- Effects of SO_2 and acidic deposition on building materials;
- Effects of ozone on materials;
- Effects of particulates on soiling; and,
- Effects of ozone and SO_2 on crops.

The analysis of buildings is based on the functions recommended by the UNECE Integrated Collaborative Programme (ICP). This programme has looked at atmospheric corrosion of materials across Europe using a uniform experimental protocol. The full set of functions after 8 years of exposure, including description of the program is given in the final ICP report (Tidblad *et al*, 1998). The approach is supplemented with UK information on ozone damages from Holland *et al* (1998). Crop damages are quantified and valued using the approach in ExternE (EC, 1999). Only central values were reported for non-health effects.

There are a number of additional non-health impacts for which valuation is not currently possible. These include acidification, eutrophication effects and fertilisation effects on forests and ecosystems (terrestial and aquatic). They also include potential effects on visibility. The values for non-health impacts should therefore be considered as a sub-total of costs.

Climate Change

Greenhouse gas emissions from individual road vehicles were taken from the NAEI (Salway et al, 1999) with dis-aggregation by vehicle (14 types), Euro standards (3 types) and speed (9 bands). These emissions were linked to damage costs for climate change expressed in costs per tonne.

The low, central and high values (£7.3/tonne of CO_2, £14.6/tonne of CO_2, and £29/tonne tonne of CO_2) are based on figures recommended by the DETR for use in this project, with the central value taken from ExternE (EC, 1999c). This value is based on the IPCC IS92a scenario, assuming equity weighting, a time horizon of damages to 2100, and a 3% discount rate. It is stressed that the uncertainty associated with climate change is very large and these values should only be considered as illustrative of possible costs.

Noise

Transport noise affects amenity and numerous surveys have shown it to be a major nuisance. It may also lead to a number of health impacts through a variety of direct and indirect effects, though there is considerable debate on the reliability of the evidence.

Transport noise arises from the vehicle engine itself, from the rolling noise generated by the contact between the wheel and the road surface or rail line, and from other intermittent noise from braking, etc.

The basic measurement index for noise (sound) is the decibel (dB), a logarithmic quantity reflecting the nature of the human ear's response to sound pressure. As well as responding to sound in a logarithmic manner, the ear is also more sensitive at some frequencies than at others. This frequency sensitivity is included by applying an appropriate frequency weighting to measurements and calculations, the most common of these being the "A weighting", hence the use of "dB(A)". Traditionally, noise impact in the vicinity of transport sources has been assessed using methods based around the concept of the Equivalent Continuous Sound Level (L_{eq}). This technique for "energy-averaging" a fluctuating noise environment is defined as the steady noise level over a defined period that contains the same acoustic energy as the fluctuating level over that period.

The L_{eq} metric has been used to quantify noise impacts here, as this is consistent with the economic valuation data (see below). It is stressed that more complex indices are being considered in the EU Draft Noise Directive to account for the possibility of greater annoyance at different times of the day, particularly at night, for example the L_{den} indicator[19]. The use of such metrics would dramatically change the relative noise impacts for certain vehicle types and time periods, e.g. freight movements at night.

Unfortunately, national level data on the current noise burden is not available for road and rail at a dis-aggregated level. This information will be collated in response to the Directive[20]. For this project, a series of case studies were undertaken looking at the noise levels from vehicles travelling on a number of road types (motorway, trunk, and other), assuming typical speeds and 'annual average' daily traffic flow.

Road transport noise was quantified using the established relationships in the Government publication "Calculation of Road Traffic Noise" (DoT, 1988). Additional corrections were included in urban areas to account for barrier effects. In all cases, noise levels were predicted out to a distance of 300 m.

A threshold was included in the analysis, i.e. a level below which the noise effect was considered negligible. In 1980, the WHO set a general environmental health goal for outdoor noise of $55L_{Aeq}$. In 1995 this was changed to a threshold below which few

[19] Here the 24 hour period is divided into a 12 hour day, a 4 hour evening and an 8 hour night. The L_{eq} is calculated for each period in terms of dB(A), but 5 dB(A) is added to the evening value and 10 dB(A) is added to the night value. The three resulting values are then logarithmically added to form a single time-weighted L_{eq}, the L_{den}.

[20] The Government announced in the Rural White Paper (November 2000) its intention to consult on a proposed national ambient noise strategy and to map the main sources and areas of noise. This would include all large agglomerations, plus the major road and rail links. The aim is to complete this mapping by 2004.

people are seriously annoyed, also set at $55L_{Aeq}$ (WHO, 1999). This value was used as the threshold for the framework[21] and is consistent with other noise valuation studies in the literature.

The fully allocated costs were calculated by estimating noise levels for each of the road types, and attributing noise levels according to vehicle numbers. The study also assessed marginal noise costs by looking at the noise change from a 10% increase for each of the road types. For both the fully allocated and marginal analysis, predicted noise levels were combined with average population density data to derive the population weighted noise levels above the 55 dB(A) threshold. This analysis was repeated for each of the population densities in the NRTF (11 area types from 'central London' to 'rural').

A comparable method was used for rail. Noise emissions and dispersion was calculated based on the methods recommended in "Calculation of Rail Noise" (DoT, 1995). Predictions were made at a variety of typical mainline sites using the known levels, types of traffic, numbers of trains and train speeds. In each case, it was assumed that the track was neither in a cutting nor on an embankment. The average speed, sound level and passage time was calculated for InterCity, multiple units and freight trains. Similar assumptions were made with respect to the noise threshold. For marginal noise increases, the case studies looked at 10% increases in activity, based on the numbers of trains of each type running within the period.

These noise impacts were then valued. The majority of noise valuation studies in the literature are based on hedonic pricing, where noise differences reflected in the market value of housing are analysed (taking into account other variables). The information from these hedonic studies can be used to derive relationships linking average noise levels to changes in property prices – known as a Noise Depreciation Sensitivity Index (NDSI) and usually reported as a percentage reduction in property value for a 1dB increase in noise levels. Most estimates in the literature quote a NDSI of between 0.2 and 1.5%, with most studies concentrated between 0.5 - 1%. These studies do not measure directly individual or household WTP to avoid noise exposure per unit time. Other studies, such as Soguel (1994) that focus on monthly rent, do this more explicitly. WTP values derived from the latter study were used in the NERA lorry track and environmental cost report.

More recent work in the UK has indicated a much lower value for the NDSI. To reflect this, the low, central and high NDSI values used were 0.2%, 0.436%, and 0.67% for each 1dB(A) increase in noise levels. These functions were used to quantify both average and marginal costs and were supplied by DETR.

The case studies were then used to populate the framework, with values extrapolated to provide the detailed dis-aggregation. This was necessary in the absence of national level data. The use of a small number of case studies for extrapolation is not ideal, not least because of the site-specific nature of noise. There are also a number of other factors that increase the uncertainty of the current noise analysis, described in the box below.

[21] Although there will be effects below this level, such as disturbance and small physiological and psychological effects, from (for example) intermittent traffic and from night-time driving.

Box 2. Issues with noise analysis and valuation

- *Threshold*. The noise valuation is implemented with a threshold (55dB). In cases of light traffic, the predicted noise will not exceed the threshold and both fully allocated and marginal noise costs are zero. It has not been possible to assess the proportion of such road and rail lines in this study.
- *Background*. A simplified approach has been adopted within the case studies, assuming the noise from the road or rail line is the sole source (consistent with CRTN and CRN). There are questions how applicable these approaches are for actually assessing ambient noise. In reality, other noise levels (e.g. interaction from nearby road or rail lines, aircraft noise, industrial noise) will contribute to the noise levels. Allocation of different noise sources to the current baseline levels would alter the relative contribution of transport noise. This would strongly influence the fully allocated costs.
- *Model and data resolution (Road)*. CRTN predicts the basic noise level from a relationship between hourly, or 18 hourly, flow and L_{10} for a speed of 75 km/h, no heavy vehicles and no gradient. Speed and % heavy vehicle correction is provided as a single function, due to the interdependence of these factors. The effect of gradient is allowed for as an increase in noise, counteracted by a decrease in average speed and there are independent adjustments for the effects of different types of road surface. For the case studies, no adjustments have been made for gradient or road surface. Also typical parameters have been input for speed and % HGVs. Finally, L_{10} has been converted to L_{eq} using approximate relationships between the metrics. It has not been possible to judge how representative the parameters used in the case studies are for the national level.
- *Model and data resolution (Rail).* The approach assumes that trains are running at speeds that are near to the maximum speed for the line or the maximum speed for the train. This means that noise from the locomotive will not be significant in terms of the L_{Aeq}. The overall effect will be to predict levels that are towards the high end of the distributions of speeds. In practice, trains run at speeds where traction noise is significant at only a few locations such as stations. In such areas there will be differences from the type of locomotive and the use of diesel or electric traction (we assume no differences in this analysis). A greater problem was the lack of detailed data on the speeds and flows of trains in use across the network by route. The case studies are based on example speeds and flows and this will introduce uncertainty to the national level results. Finally, the CRN method omits rail corrugation: a large proportion of the rail on most networks is corrugated, i.e. with a periodic wear pattern on the rail head, and this can underestimate actual noise levels by as much as 20 dB.
- *Local conditions*. Noise is a very localised effect, with potential impacts often extending only tens of metres (in urban areas). The actual noise impact along any road or track is therefore subject to large uncertainties, because of potential differences in local conditions, numbers of buildings, etc. This is especially important when looking at the typical distribution of receptors (and distance from) railways and roads. Furthermore the presence of buildings and barriers will reduce noise levels through a screening effect. Other than a simple barrier effect in urban areas, screening effects were not taken into account.
- *Perception*. The response to noise is extremely subjective. In reality, the level of annoyance from individual noise sources depends on a large number of issues: the nature and duration of the noise source, typical background levels, perceptions towards the individual noise source itself, etc. Some information on these issues is available from the 2000 National Noise Incidence Study. There are also issues with relative effects from road and rail and the rail bonus: there is a body of literature that suggests that people find railway noise less annoying than road transport (or air) noise for equivalent sound levels. It should be stressed that the evidence for this bonus (usually a 5 – 10 dB(A) advantage for rail) is controversial, though it is being discussed in EC Working Groups. Such effects have not been taken into account in this analysis.
- *Valuation*. There are a number of issues in the approach used here for valuation. Firstly, the use of daily equivalent noise levels will omit other parameters that are important with respect to annoyance (e.g. time of day effects). Secondly, the linearity of these relationships may introduce extra uncertainty. When implemented, they assume that a 1 dB(A) increase in noise levels just above the threshold of annoyance (e.g. 56dB(A)) leads to an identical economic value as a 1 dB(A) increase at 80 dB(A). There are also concerns that hedonic pricing reveals the value placed on differentials between noise in stable environments, as opposed to evaluating the effects of actual change (e.g. from changes in noise levels from changes to noise sources or levels). There is a significantly greater reaction to changes in noise than might be expected from the steady state relationship. There is evidence of similar reactions in terms of attitudes towards the level of noise for decreases as well as increases in noise. There may also be important differences between urban and rural contexts in terms of expectations about noise climates.

For these reasons, the individual noise values at the more dis-aggregated categories (and relative noise values between categories at this level) need to be treated with some caution. These problems are magnified for the marginal analysis.

The marginal costs are very sensitive to the existing traffic flows on the route. There is a logarithmic relationship between traffic volume and noise. Halving or doubling the amount of traffic will change the noise level by 3dB, irrespective of the existing flow (similarly a 10% increase in traffic or trains will lead to a 0.4 dB increase). This means that doubling the traffic volume from 100 – 200 vehicles per hour will lead to the same dB increase (3dB) as going from 500 – 1000 vehicles per hour (also 3 dB). However, the valuation of increases in noise, through the NDSI, is linear with a constant unit value per dB applied irrespective of the background noise level. This means that the valuation of a 3dB increase for an increase of 100 – 200 vehicles (an increase in 100 cars) is the same as for an increase from 500 – 1000 (an increase in 500 cars). Obviously the marginal costs per additional vehicle will be very much lower at higher traffic flows.

This has some major implications. Clearly, the marginal noise costs is extremely sensitive to the existing traffic flows or railway activity. On road and rail routes with high levels of existing traffic, even large numbers of extra vehicles will only have very small increases in dB levels and will therefore have low marginal costs. Conversely, small increases in the absolute numbers of vehicles on routes with little traffic may lead to significant marginal costs (provided the threshold of effect is exceeded).

These effects were seen in the marginal cost case studies. For the rail case studies assessed, the existing noise levels on most of the routes were high. Therefore marginal increases in train numbers had very little effect on noise levels and marginal costs were extremely low. However, on one of the minor routes assessed, with low levels of train activity, it was found that that the marginal costs were very significant (a similar level as average costs). To accurate assess the fully allocated and marginal costs, a more detailed study of national rail activity would be needed. This was not possible within the constraints of this study, and so both fully allocated and marginal noise rail costs are reported using one set of values. We stress, however, that on busy routes, the marginal costs of one additional train are likely to be much lower.

Further analysis of the rail network and train activity is highlighted as a priority in order to evaluate the fully allocated and marginal costs for rail, and to provide dis-aggregated values, between train types and routes. Such an analysis would be possible through the data currently being collated within the National Rail Model.

A similar effect between fully allocated and marginal noise costs was seen for road traffic. Marginal noise costs were very much lower than fully allocated costs (usually an order of magnitude lower). However, further work is needed to evaluate how representative these values are when extrapolated to the national level– it is likely that for quieter roads, marginal costs will be more significant. For these reasons, a low and high value is reported for marginal costs, with the high value based on the fully allocated approach, and the low value based on a marginal analysis based on roads with high traffic volumes. As with rail, a more detailed analysis is needed to accurately assess the dis-aggregated values and to accurately estimate the national level

There are a few other areas to stress concerning the marginal analysis. This study assessed a 10% increase in traffic volumes. However, due to non-linearities, different marginal increases will give different marginal costs (e.g. starting from the same background flow, a 10% increase in vehicle numbers will give a different marginal cost per vehicle to a 20% increase in vehicle numbers).

As with air quality effects, the values presented here for noise assume that a marginal increase of 10% does not lead to changes in overall vehicle speeds. Including speed effects will reduce marginal noise costs, as any reduction in vehicle speeds will reduce the rolling noise (the noise from contact between the surface and vehicle).

Finally, a number of additional issues exist that were not captured in this analysis. These include:

- Time of day effects (especially potential night-time disturbance from freight);
- Effects of vibration;
- The intermittent nature of some transport sources;
- Perception (including the lower levels of annoyance attributed to rail, known as the ‘rail bonus’); and,
- The potential health impacts from noise exposure[22].

Further investigation of these issues and the improvement of noise assessment more generally are highlighted as a research priority.

Issues associated with marginal vs fully allocated impacts and costs

The differences between the marginal and fully allocated costs of noise are discussed above. Some of these issues (and others) are also relevant for the emissions analysis.

The dose-response approach used within ExternE (and used here) for evaluation of air pollution effects has been developed to quantify marginal costs.

The values reported here in the marginal analysis are for the costs of one additional vehicle. This makes the assumption that one additional vehicle has no effect on overall vehicle speeds on the road. It is stressed that the marginal costs will vary with greater numbers of additional vehicles, because larger marginal changes will alter traffic flows and therefore overall vehicle speeds.

Interestingly, the change in vehicle speeds has different effects on marginal costs for different road types. This occurs because of the U-shaped relationship between emissions and speed. In congested areas, where vehicle speeds are low, additional

[22] The remaining evidence of effects of environmental noise on health are strongest for sleep disturbance, ischaemic heart disease and performance by school children. It is stressed that much of the evidence in support of actual health effects other than annoyance and some indicators of sleep disturbance is quite weak. The data on other possible health consequences, such as low birth-weight and psychiatric disorders, are inconclusive. For a recent review of transport noise and health effects, see Watkiss et al, 2000.

vehicles will reduce speeds further and will significantly increase emissions (because emissions are higher at very low speeds). Marginal environmental costs will therefore increase with greater numbers of vehicles in urban areas.

In contrast, for fast moving traffic, additional vehicles will reduce speeds. This, however, this will lead to emissions reductions (as emissions are greater at very high speeds) and so marginal air pollution costs may fall. Including speed changes in the marginal analysis will therefore increase marginal costs in urban areas, and reduce marginal costs of motorway traffic. Further investigation of these marginal issues especially for urban areas are highlighted as a research priority.

The marginal air pollution costs calculated here have also been used to calculate the fully allocated costs. In terms of quantification of health and non-health effects this is justified as impacts are calculated using linear dose-response functions assuming no threshold of effects (i.e. down to zero pollution levels). This is consistent with similar analysis of health effects within COMEAP and EAHEAP. It should be noted that the use of non-linear functions or the use of a threshold for impacts would produce different marginal and average costs – indeed the use of such assumptions in other studies has led to many results reporting marginal costs as being higher than average costs.

It is also assumed that marginal costs are appropriate for deriving fully allocated costs with respect to valuation. The marginal changes studied here (one additional vehicle) are small and do not affect the prices of goods or services. It is therefore acceptable to derive costs by multiplying the change in the quantity (the impact) by the appropriate revealed, or stated, price. Within this study we have also assumed that this assumption can be used to value fully allocated costs. It is likely that this assumption may not be valid – to illustrate, if policies are put in place which lead to non-marginal impacts or benefits, then it is likely that this may lead in turn to changes in the equilibrium price. Within this study, it has not been possible to address these issues, though other studies (EC, 2000) indicate that even when looking at the entire transport sector, the additional error this may introduce is likely to be small relative to other uncertainties in the analysis.

Discussion of Results

Most studies of the environmental costs of transport in the UK and Europe (see Table 1.1) have used a top-down approach, based around national level data. These studies provide an important starting point for the analysis here. However, there are theoretical and practical issues that are important in the transport sector, which necessitate a different approach.

The first issue is with respect to speed. Transport emissions vary significantly with speed and this variation is non-linear. To accurately assess the marginal and fully allocated costs of transport, it is therefore necessary to take account of the speeds of vehicles on different types of road (motorways, main roads, etc.). The second issue concerns the location of emissions. Local impacts are important for transport as emissions are released at ground level, often in areas of high population density. The implications of this are clear. A much greater level of geographical resolution (below national level) is required to accurately assess transport externalities.

Studies such as the EC's ExternE project (EC, 1995: 1998) have led the development of bottom-up methodologies that take account of these issues. This current study is one of the first to apply this detailed approach to Great Britain to estimate the environmental costs of the road and rail sector. On the road side, it represents one of the most detailed and comprehensive studies of national level damages to date, working with a level of dis-aggregation covering vehicle type, Euro standard, speed and location.

Such an approach allows a more accurate picture to be built of the environmental costs of different vehicles, travelling on different roads, in different locations. It also provides the information to look at the environmental costs of the transport sector at a greater level of detail than previously possible – examining the importance of different technologies and fuels. This level of information is essential in examining fair and efficient transport pricing policies.

This section discusses some of the key findings from the use of the framework. In particular, it presents information on the sorts of questions that this level of detail allows, such as:

- What are the national level damages for road and rail transport in Great Britain?
- How important are speed and location in determining environmental costs?
- What differences exist between different vehicles, fuel types and technologies?
- How do the marginal and average costs per km vary for road and rail?
- Which impacts are most important and what does uncertainty analysis tell us about the confidence in the values?

National Fully Allocated Costs (total and per km) for Road

The framework has been used to estimate the total environmental costs from the road and rail sector in 1998. The estimated environmental costs from the road sector, based on the 1998 vehicle fleet, are shown in Table C.6 and Figure C2. With all categories included, the central value is estimated at ~7 billion pounds/year.

Table C.6. Fully Allocated Environmental Costs (Road, 1998 fleet, central estimate).

	Total fully allocated costs (£ million/year) 1998 vehicle fleet			
	Climate change	Air Pollution	Noise	Total
Cars	886	1,331	1,283	3,499
Lights	178	681	320	1,180
Rigids	116	451	250	817
Artic	175	376	346	896
PSVs	57	331	137	525
Total	1,412	3,170	2,335	6,917

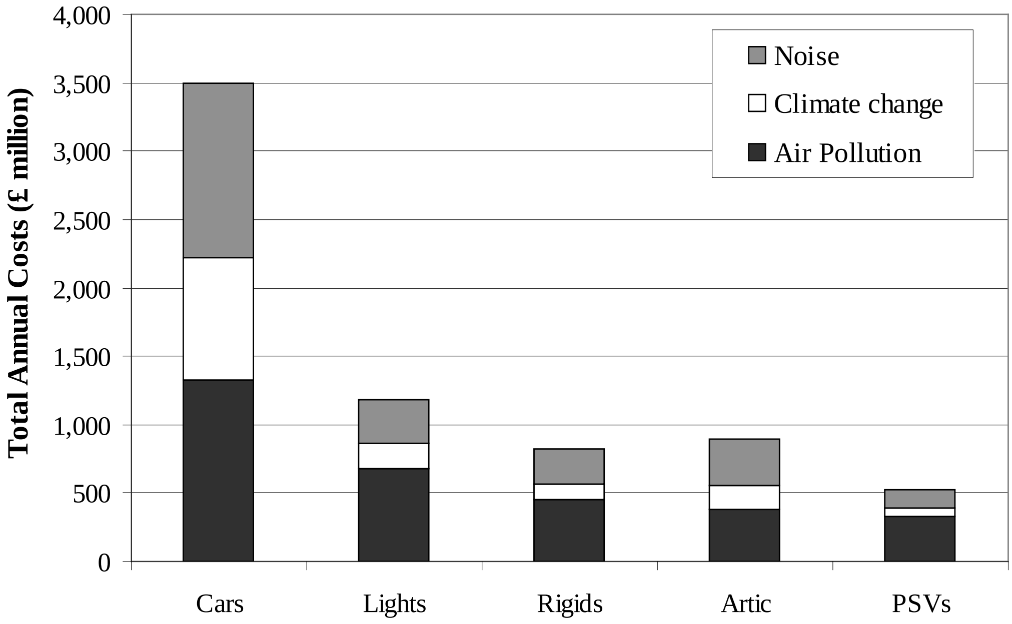


Figure C.2. Total Environmental Costs for the Road Sector (1998) by vehicle type.

Most of the costs can be attributed to passenger car transport. Table C.7 and Figure C3 show the proportion of km and environmental costs by vehicle type.

Table C.7. Allocation of Km and Fully Allocated Environmental Costs (GB Road, 1998 fleet) by Vehicle Type.

	% vehicle km	% damage
Cars	82.5	50.6
Lights	10.8	17.1
Rigids	2.9	11.8
Artic	2.7	13.0
PSVs	1.1	7.6

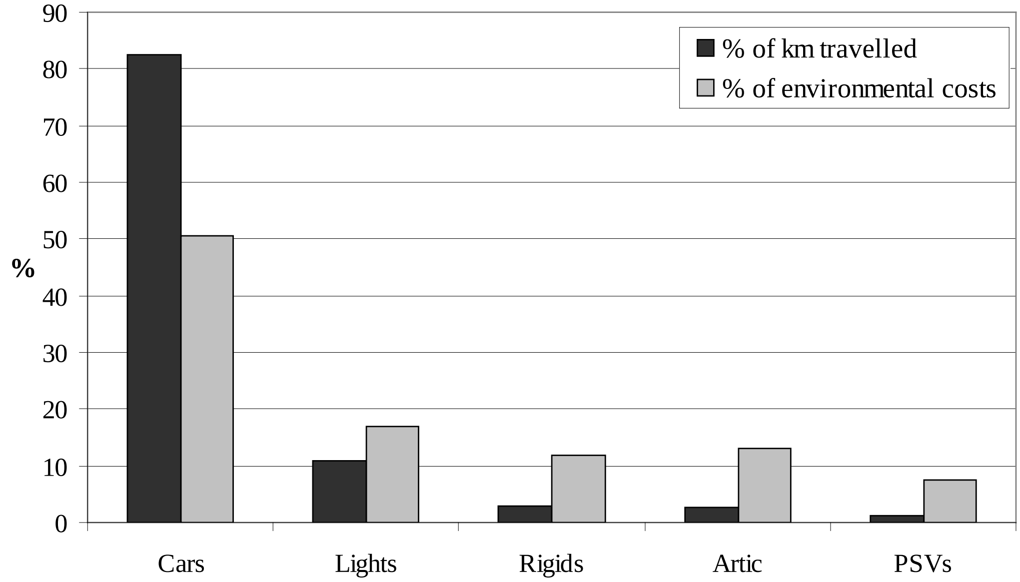


Figure C.3. Proportion of km travelled and environmental Costs by vehicle type.

Although cars are responsible for a very high share of vehicle km driven (>80%) they only account for around 50% of the total road sector environmental damages. In contrast, heavy goods vehicles (rigid and articulated vehicles) have a disproportionately high damage costs despite a relatively low vehicle km share. These traits can be seen when the average costs per km are derived from these national figures, shown in Figure C.4.

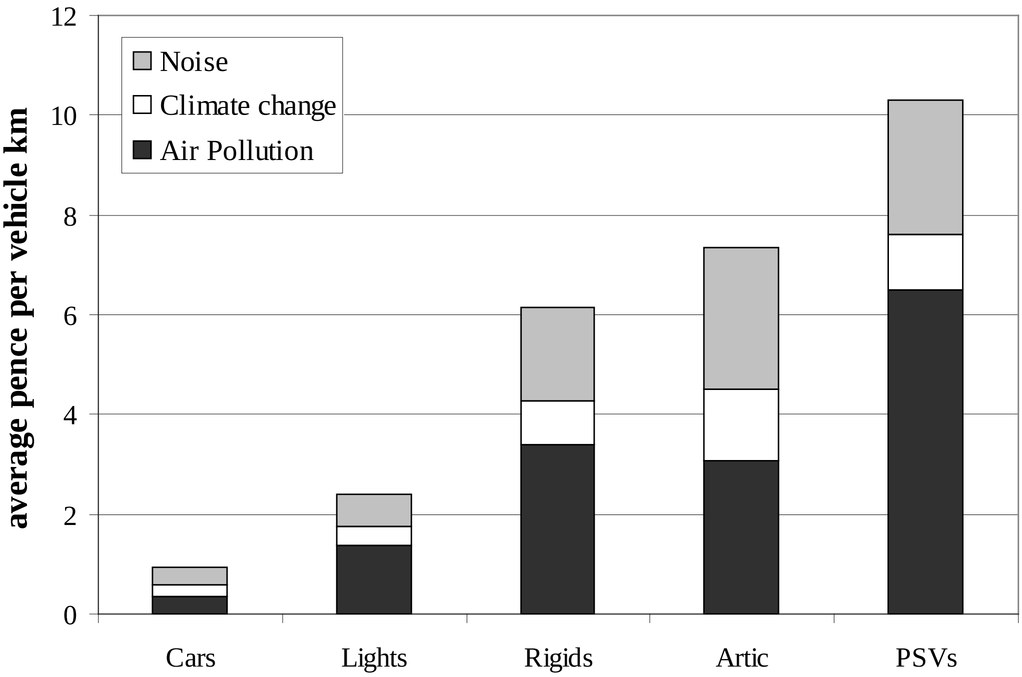


Figure C.4. Average environmental costs of road vehicles (1998 fleet, central estimate).

Some care must be taken in drawing too many conclusions from the data in Figure C.4. The graph indicates that public service vehicles (buses and coaches) have higher average environmental costs than any other vehicle. This is misleading. A high proportion of PSV journeys are in urban areas, where environmental costs are higher. Therefore, in comparing the environmental costs of different vehicle types, i.e. estimating the environmental costs per passenger km, it is essential that the costs for the same journey types are compared. The effect of the location of emissions on environmental costs can be seen in Figure C.5. This shows the relative proportion of vehicle km and environmental costs by NRTF area type.

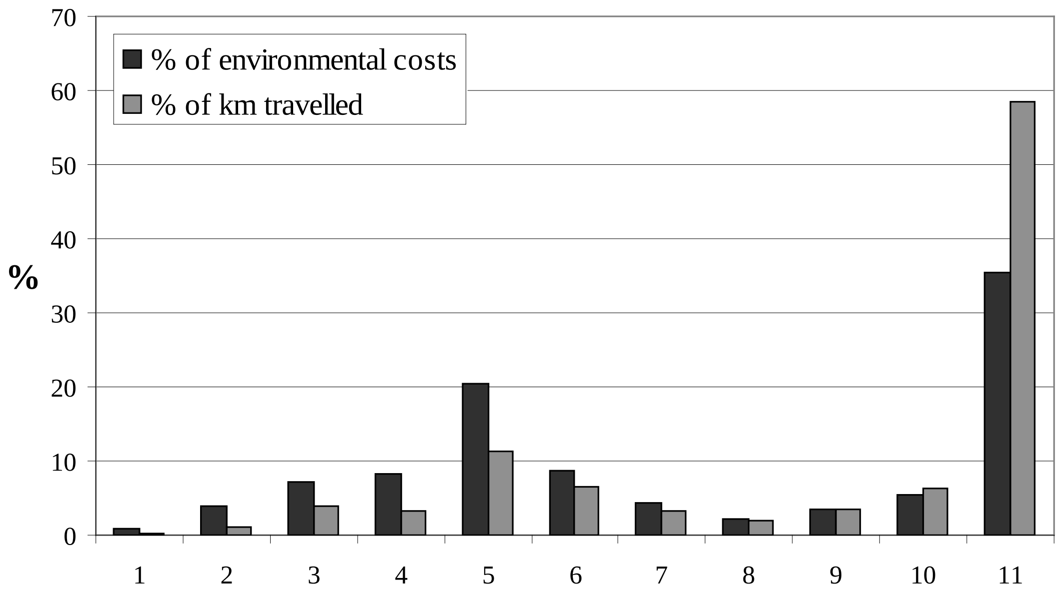


Figure C.5. Share of vehicle km and (fully allocated) environmental costs by location (1998 vehicle fleet).

Key:
1 = Central London, 2 = Inner London, 3 = Outer London,
4 = Central Conurbations, 5 = Outer Conurbations, 6 = Area>25 sq kms, 7 = Area 15-25 sq kms,
8 = Area 10-15 sq kms, 9 = Area 5-10 sq kms, 10 = Area 0.01-5 sq kms, 11 = Rural.

Those areas with high population density (i.e. the left of the figure) have a much higher level of environmental costs relative to their share of vehicle km. At the aggregated level, the 40% of km driven in urban areas are responsible for 65% of the environmental costs (and the 60% of rural km for 35% of costs). If climate change impacts are excluded (as these impacts do not vary with location), the proportion of environmental costs attributable to urban areas rises to around 70%. Clearly, urban trips have higher environmental costs than rural ones, an important conclusion in looking at vehicle taxation and charging.

Marginal Costs by Area and Road Type

The figures above show the aggregated results. A much greater level of dis-aggregation has been undertaken in the study, indeed, this is one of the most innovative aspects. It allows us to look at the differences between different vehicles, travelling on different roads in different locations.

The following figures show the environmental costs for different vehicle types on different roads in different locations. The figures are the central values. For noise the values presented are for the central high value. Note the use of the lower marginal noise value would significantly reduce the noise costs.

In all cases, the graphs reflect the 1998 average vehicle fleet, i.e. based on the proportion of km travelled by pre-Euro, Euro I and Euro II vehicles. For passenger cars and light duty vehicles, the figures represent the proportion of km driven by petrol and diesel vehicles. The values are presented for the marginal costs of one additional vehicle and therefore assume no changes occur in overall traffic speeds.

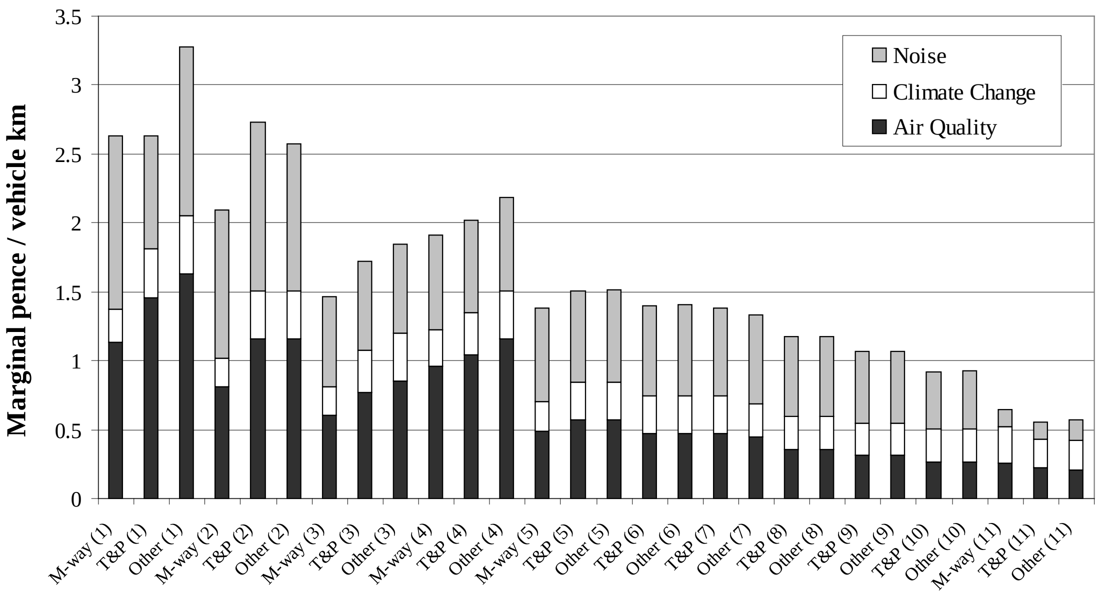


Figure C.6. Marginal Environmental Costs for the Average Car (1998).

Key:
1 = Central London, 2 = Inner London, 3 = Outer London,
4 = Central Conurbations, 5 = Outer Conurbations, 6 = Area>25 sq kms, 7 = Area 15-25 sq kms,
8 = Area 10-15 sq kms, 9 = Area 5-10 sq kms, 10 = Area 0.01-5 sq kms, 11 = Rural.

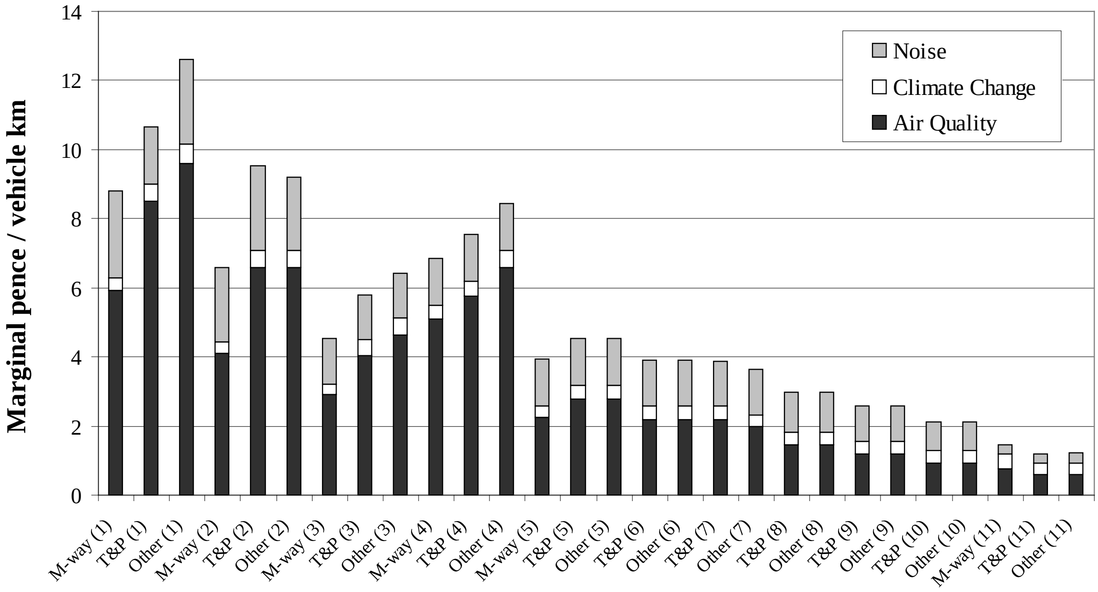


Figure C.7. Marginal Environmental Costs for the Average LDV (1998).

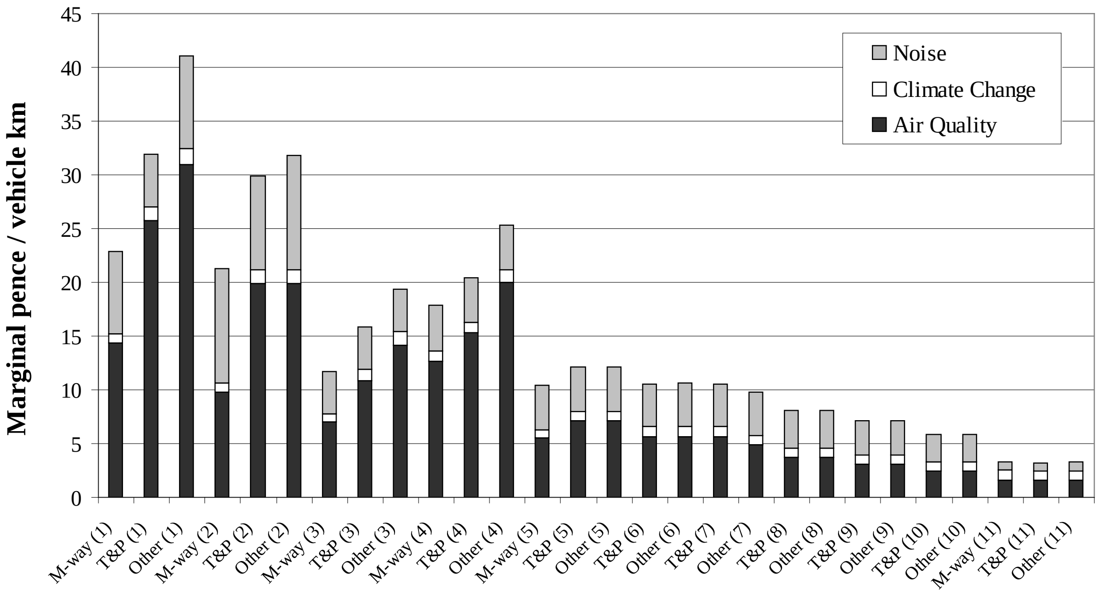


Figure C.8. Marginal Environmental Costs for the Average Rigid Vehicle (1998).

Key:
1 = Central London, 2 = Inner London, 3 = Outer London,
4 = Central Conurbations, 5 = Outer Conurbations, 6 = Area>25 sq kms, 7 = Area 15-25 sq kms,
8 = Area 10-15 sq kms, 9 = Area 5-10 sq kms, 10 = Area 0.01-5 sq kms, 11 = Rural.

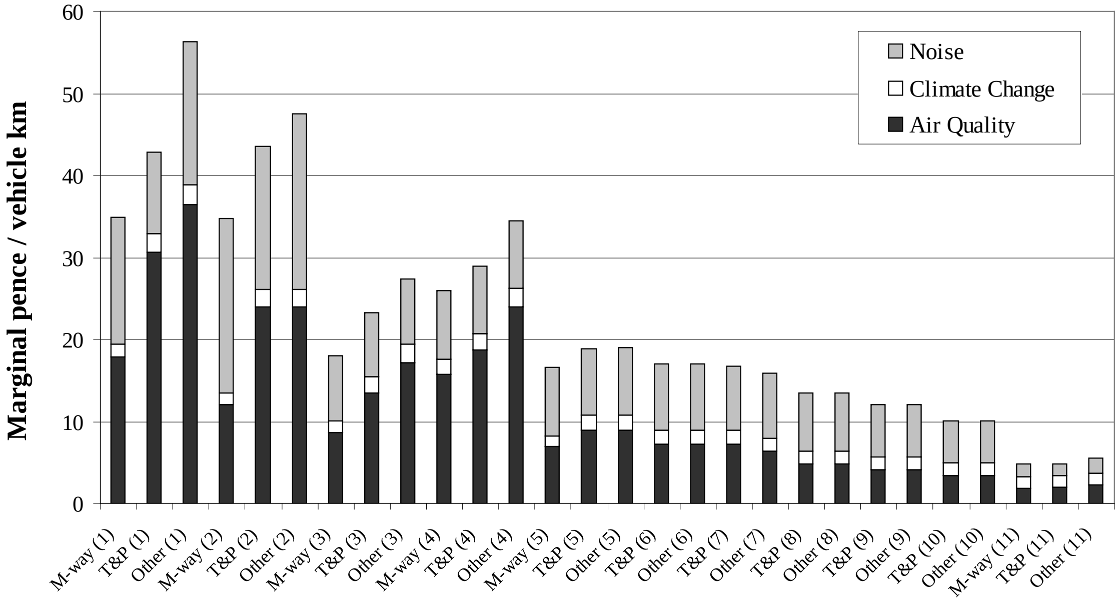


Figure C.9. Marginal Environmental Costs for the Average Artic Vehicle (1998). [23].

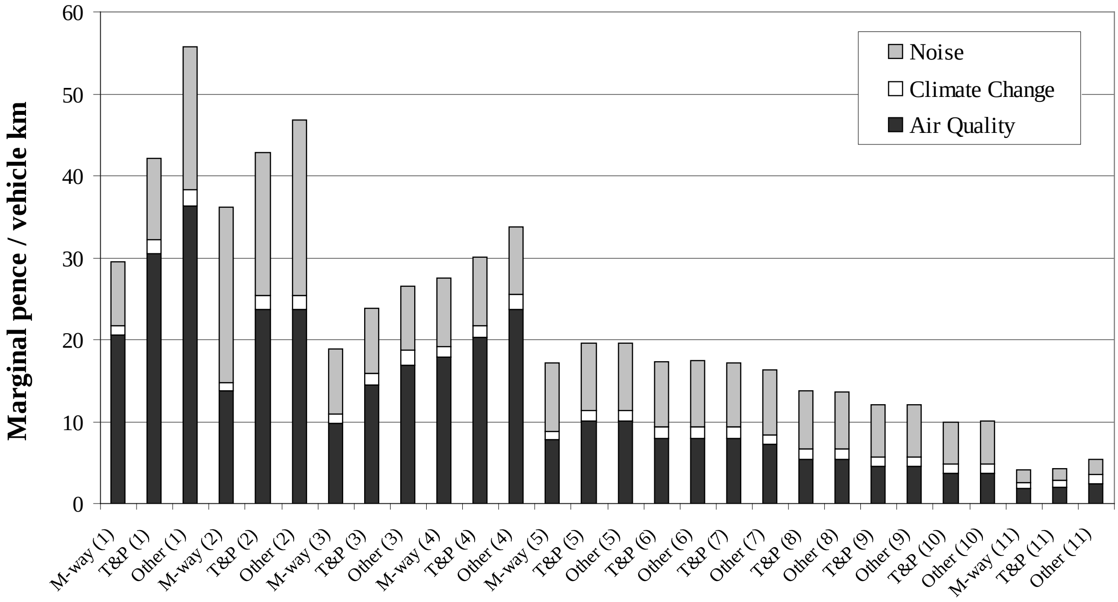


Figure C.10. Marginal Environmental Costs for the Average Public Service Vehicle (1998).

Key:
1 = Central London, 2 = Inner London, 3 = Outer London,
4 = Central Conurbations, 5 = Outer Conurbations, 6 = Area>25 sq kms, 7 = Area 15-25 sq kms,
8 = Area 10-15 sq kms, 9 = Area 5-10 sq kms, 10 = Area 0.01-5 sq kms, 11 = Rural.

[23] The values for freight vehicles are similar to the analysis undertaken in the NERA/AEA Technology Environment study (2000), though the higher level of dis-aggregation considered in the early study mean that the range of some vehicles are outside the average values presented in the current framework.

A common pattern can be seen across all figures. Higher environmental costs occur in urban areas, i.e. those on the left hand side. These differences occur because of two reasons.

Firstly, because of variations in the environmental costs (per tonne emitted) due to the local population density. Emissions in London (on the left of the graphs) are emitted in areas where the population density is extremely high and the urban area is very large. Urban areas therefore have much higher costs per tonne than rural locations. Similarly, noise effects are greater in urban areas where population density is higher.

Secondly, the speed of the vehicle affects its emissions – road vehicles emit much higher levels of pollutants at very low and very high speeds. Because speeds in urban areas can be very low, this can further magnify the size of the environmental costs. The graphs above clearly show this effect. For example in figure C.10, environmental costs in central London (the first three bars on the left of the figure), vary by almost a factor of two between 'motorway' and 'other' roads in central London. These differences are due to the very low speeds on 'other roads' in London.

The combination of these two factors lead to very high environmental costs in congested urban areas (especially London).

The opposite effect occurs in rural areas, where there is effectively a dampening effect for emissions. The differences between speeds are low, because congestion effects are minimal. Secondly, any differences that do occur are less important as the costs per tonne are low (as population is low). The low population density also results in low marginal noise costs.

The marginal environmental costs shown above are for one additional vehicle and assume no changes in overall vehicle speeds. More significant marginal increases (e.g. 10%+ changes in vehicles numbers) will change speeds and therefore change the marginal environmental costs. In many cases, these changes will be relatively small. The exception is likely to be with congested urban areas, where further speed decreases may have a very large effect in increasing emissions and costs, because of the U shaped nature of speed emissions curves.

The figures above provide some interesting information – it is clear that the environmental costs of the same vehicles differ according to the type of area and road they are driving along. The results show the marginal environmental costs of vehicles travelling in urban areas are many times higher than rural areas – to illustrate, the marginal environmental costs per km for a passenger car can be over 2 - 3 pence per vehicle km in urban areas. This compares to a value of 0.5 pence per vehicle km for rural areas. This information is extremely valuable for the optimal design of economic instruments for efficient transport charging.

The values also show the importance of considering specific trips when comparing vehicle types, for example, to look at the environmental costs per passenger km. It is clear from the above figures that the use of average data is likely to provide misleading comparisons when comparing private and public transport.

Analysis by Fuel and Euro Standard

The previous section showed the importance of area and road type in determining marginal environmental costs. However, there are other factors that are at least as important, most notably fuel type and technology (vehicle emissions standards).

The detailed analysis within this study has allowed us to investigate the potential differences between petrol and diesel vehicles, and also to show how important an impact the progressive European emission standards (Euro I and Euro II) have had in improving the environmental performance of road vehicles.

Figures C.13 and C.14 show the importance of fuel type and Euro standard for passenger cars. The figures show the environmental costs for different vehicles in urban and rural locations (assuming typical population densities and speeds).

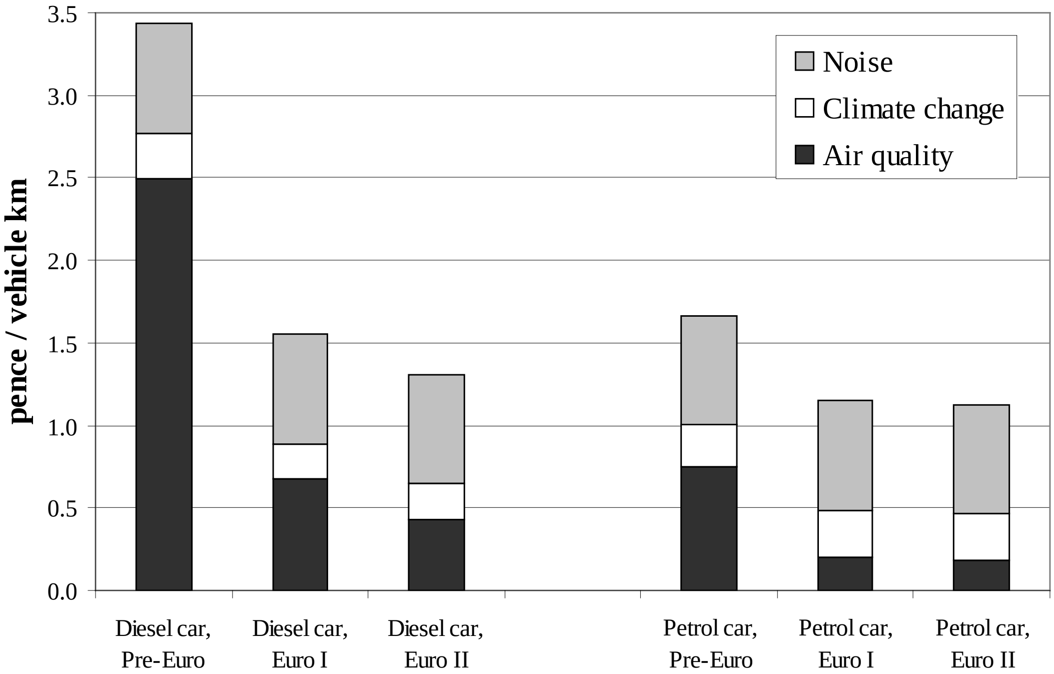
The environmental costs of diesel vehicles are much greater than petrol vehicles when travelling in urban areas. The differences between petrol and diesel vehicles are most pronounced for older vehicles (pre-Euro). The reason for these differences is that diesel vehicles emit higher levels of particles and SO_2. These are the two primary pollutants of concern with respect to both human health impacts and building damages. The emissions of these pollutants are lower from petrol vehicles – however, these vehicles emit higher NO_x and hydrocarbon levels. These pollutants have less direct effects on health and materials. Instead they lead to environmental impacts through the formation of secondary pollutants, notably, ozone and (for NO_x) secondary particles. Because these pollutants form over time and distance, the location of emissions has a smaller role in determining the size of impacts.

For both fuels, the introduction of stricter emissions standards (Euro I and II) have led to major reductions in environmental costs. The improvement is most marked for urban driving (because environmental costs are so much higher in these areas). The standards have also reduced the difference between fuel type – although diesel vehicles still lead to higher environmental costs in urban areas, they have lower environmental costs in rural areas. The age of a vehicle, and the fleet mix therefore has a very large impact on determining the size of the environmental costs. As older vehicles are removed from the fleet and newer vehicles introduced, the environmental costs for the road sector will change dramatically. For this reason we highlight the analysis of future years as a priority for further research following on from this study.

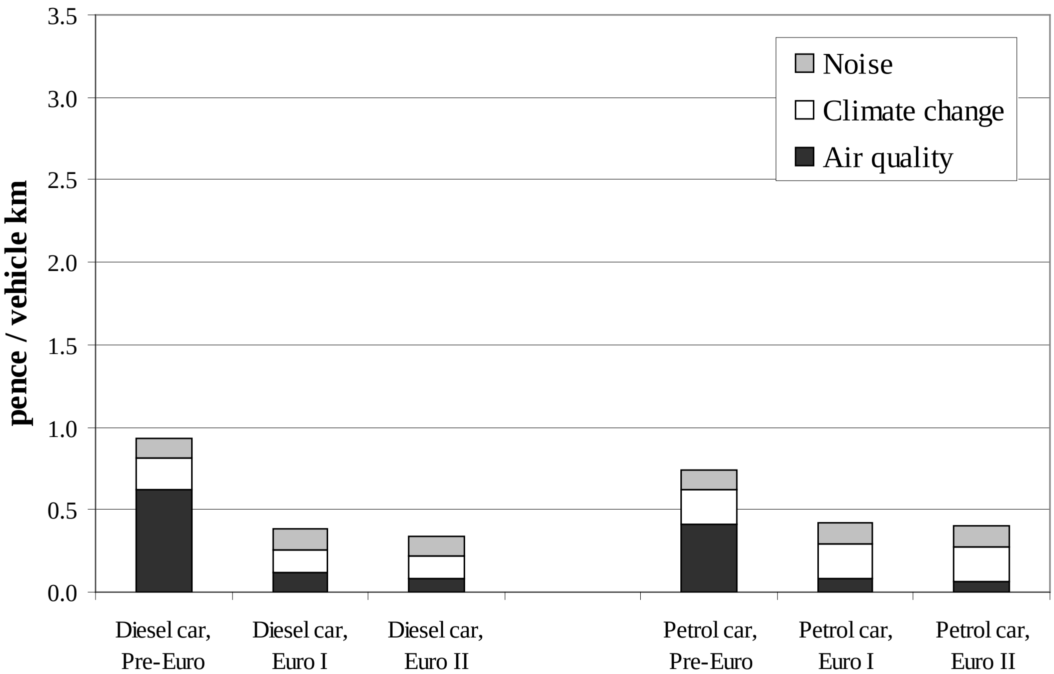
Similar trends emerge for freight vehicles – Euro II vehicles have very much lower environmental costs than pre-Euro vehicles.

This leads to some interesting conclusions with respect to the use of economic instruments. Changes (increases) in fuel duty provide an incentive to increase energy efficiency. However, their role in promoting fair and efficient pricing is limited – the graphs show that environmental costs are dominated by the conventional pollutants, and that the greatest environmental improvements are achieved by the introduction of stricter emissions standards (e.g. Euro I, II and III[24]).

[24] Interestingly, fuel efficiency is actually lower for some Euro I vehicles (relative to pre-Euro) because of the fitting of a catalyst – such vehicles would actually be penalised by fuel tax increases, whilst the analysis here shows that they may have lower environmental costs by a factor of two.



Urban Area



Rural Area

Figure C.13. Environmental costs for different fuels and Euro standards for passenger cars (in urban and rural locations).

Location assumed for urban emissions are NRTF code 6: = Area>25 sq kms. Note, much higher environmental costs would be found in areas 1 - 5.

In contrast, Vehicle Excise Duty (VED), which has traditionally been seen as a crude and ineffective means of changing behaviour, actually has a much greater potential. It allows lower costs to be passed through to vehicle owners or fleet managers that switch to less polluting (newer) vehicles. The move to this type of incentive is already being recognised in the UK, such as through the lower VED introduced for retrofitting heavy goods vehicles, and the analysis here provides a very strong justification for those decisions and their wider use. These conclusions also provide interesting information for the debate concerning locally based schemes, such as the benefits of low emission zones in urban areas.

Valuation Range, Sensitivity, and Analysis by Uncertainty Band

This section presents a summary of the uncertainty analysis undertaken in the study. The results reported above are the central estimates. Additional analysis has been undertaken with a low and a high value (though it should be noted that the high-low range only relates to monetary valuation and as such represents a restricted range). Figure C.14 shows the fully allocated costs for the road sector (1998) for the low, central and high values.

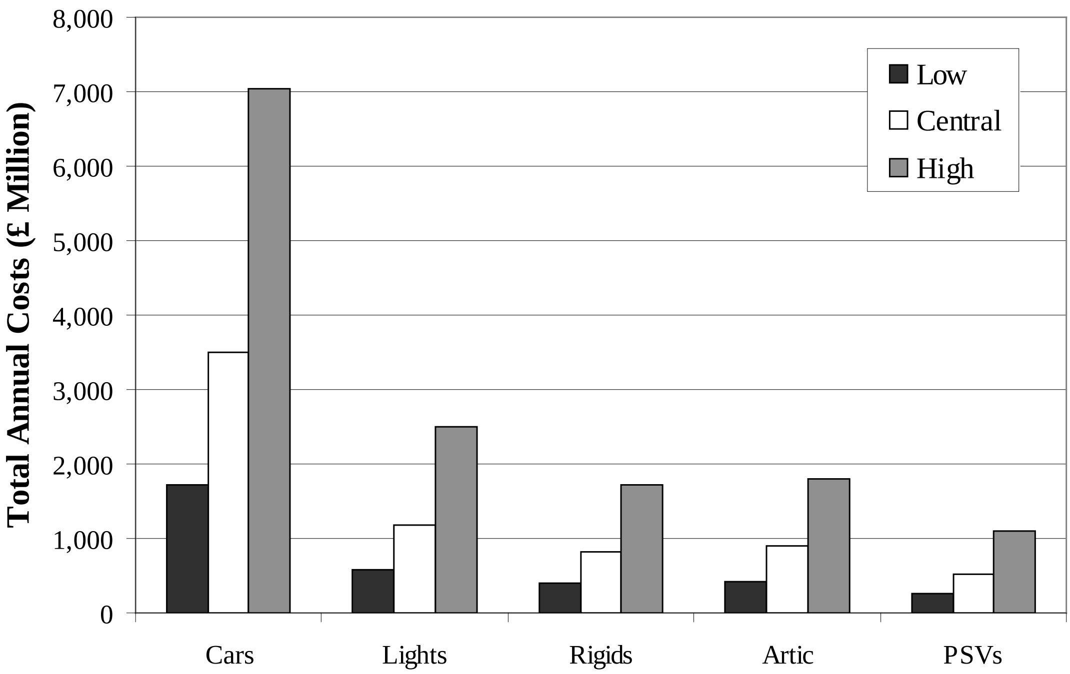
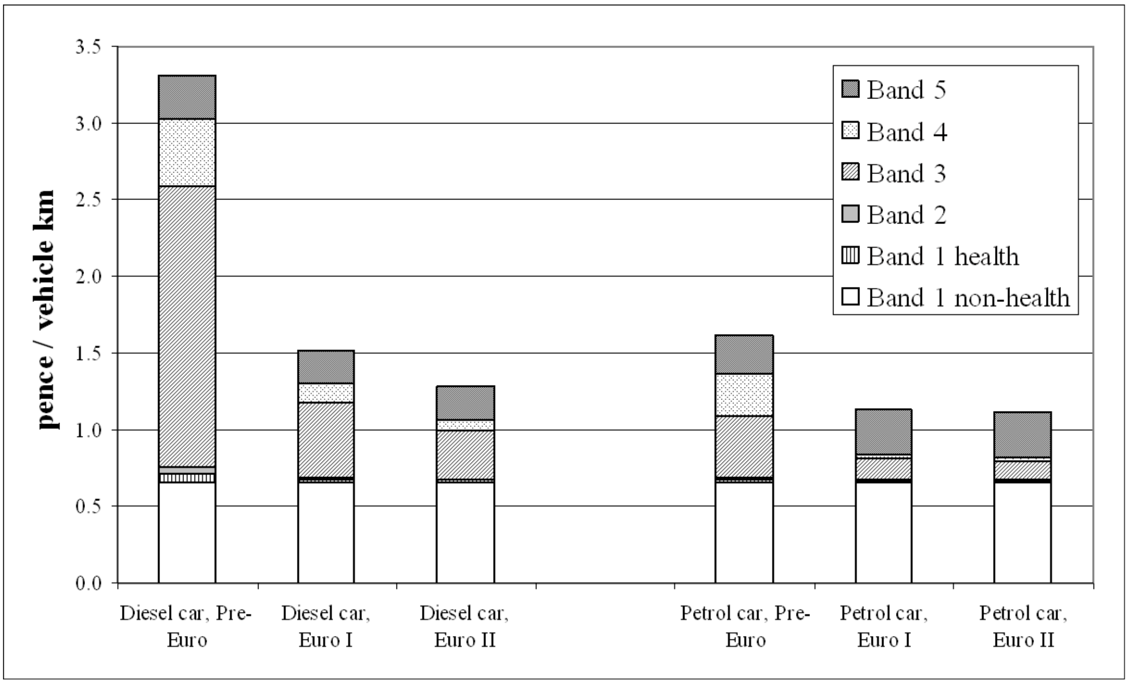
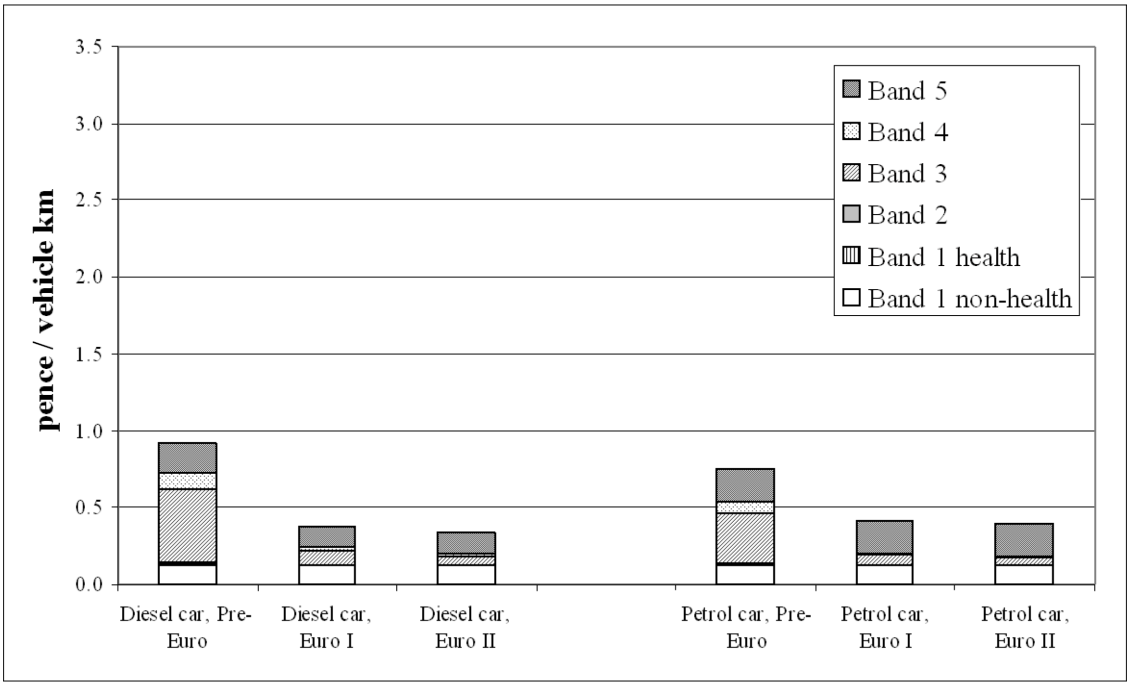


Figure C.14. Total Environmental Costs for the Road Sector (1998) by vehicle type.

The study has also looked at the breakdown of different effects by uncertainty band. Figure C.15 shows an example for a range of petrol and diesel passenger cars in urban and rural areas. Band 1 impacts represent those that are most certain and band 5 those that have greatest uncertainty (both in terms of the effect itself and the quantification method).



Urban Area



Rural Area

Figure C.15. Uncertainty analysis for Passenger Cars – Marginal Costs

Key: Band 1 = most certain, Band 5 = greatest uncertainty.
Band 1. Noise (fully allocated), health effects as recommended by COMEAP, non-health effects.
Band 2. Additional health effects (Europe).
Band 3. Chronic mortality
Band 4. Other health effects (based on US)
Band 5. Climate change

If only band 1 impacts (non-health impacts, noise and the health effects recommend for quantification by COMEAP) are included, then the values are much lower than when all effects are included. Moreover, it is the highest uncertainty bands, i.e. band 3 (chronic mortality), band 4 (other health effects) and band 5 (climate change) that dominate the overall values.

Interestingly, there are differences between diesel and petrol vehicles according to the proportion of impacts in each band. The uncertainty analysis shows that if only band 1 effects are included, there is little difference between petrol and diesel vehicles. However, if impacts up to band 3 (chronic mortality) are included, diesels have very much higher environmental costs than petrol vehicles. This differential is not reduced until all categories (i.e. including climate change) are included.

The uncertainty analysis also provides some interesting information with respect to economic instruments. The impact for which there is greatest uncertainty (band 5, climate change) is also the only impact for which a specific economic instrument exists for addressing environmental issues (the former fuel duty escalator).

National Fully Allocated Costs (total and per km) for Rail

The estimated environmental costs from the rail sector, based on the 1998 train fleet, are shown in Figure C16. With all categories included, the total annual costs (central estimate) are just over 250 million pounds.

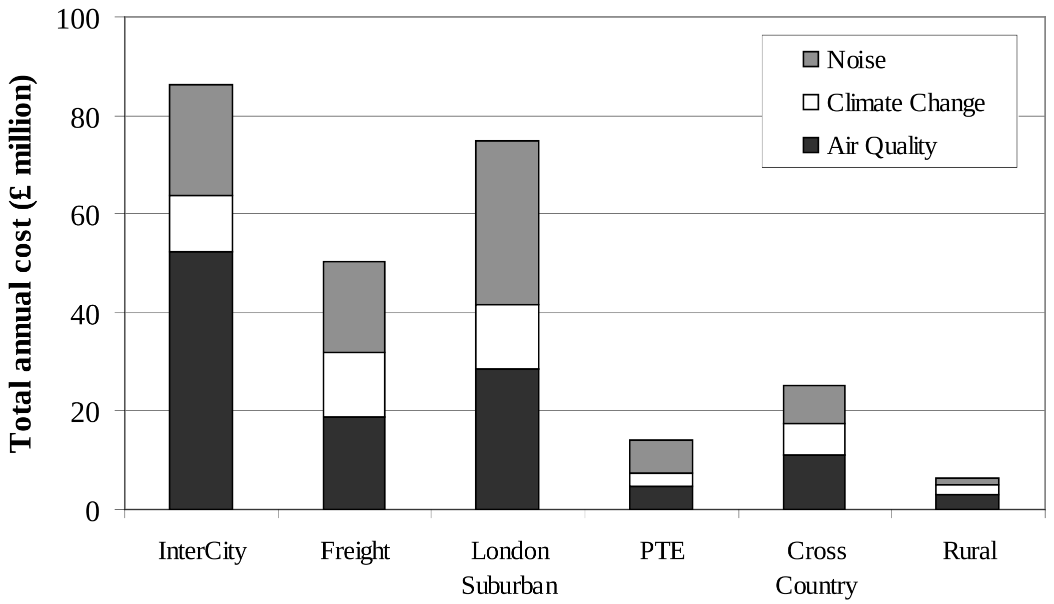


Figure C.16. Total Environmental Costs for the Rail Sector (1998) by trip type.

These costs are dominated by InterCity, freight[25] and London commuter trains. Figure C.17 shows the relative proportion of km travelled and environmental costs between train journey types.

[25] Note freight transport is based on the 1998 mix, and therefore does not include the new class 66 locomotives being introduced into the rail freight stock.

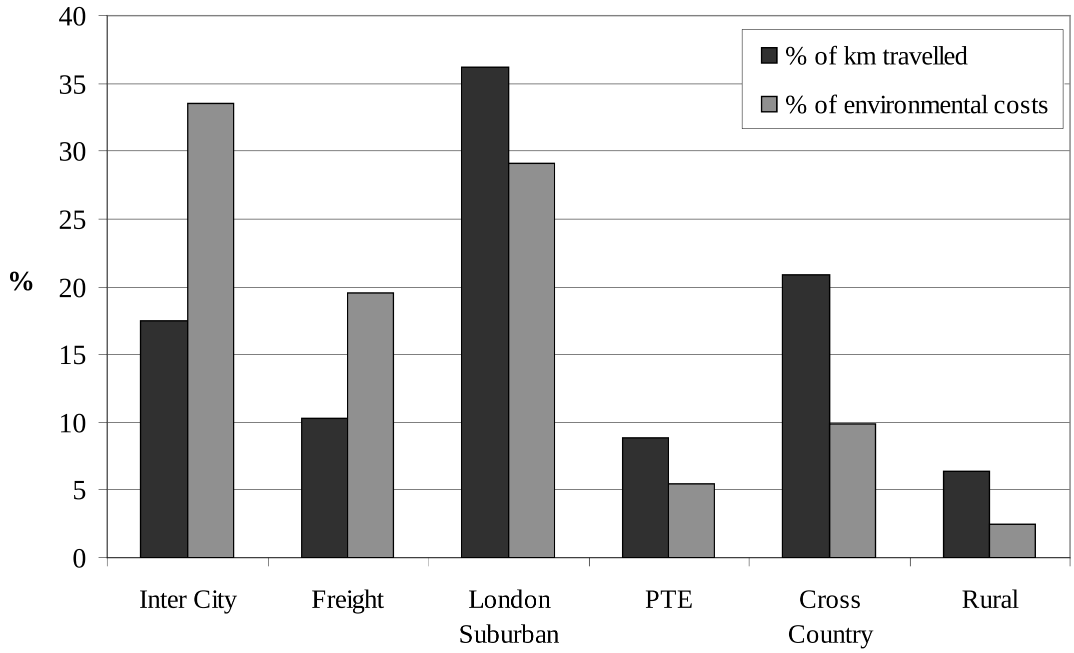


Figure C.17. Km travelled and environmental costs by train type (1998).

InterCity trains and freight trains contribute a high proportion of environmental costs (>50%), though their km share is relatively low (~25%). For InterCity trains, this is because of higher power needed to travel at high speeds when compared to the multiple units used for other trips. The difference between journey types can be clearly seen when the average costs per km are derived from these national figures.

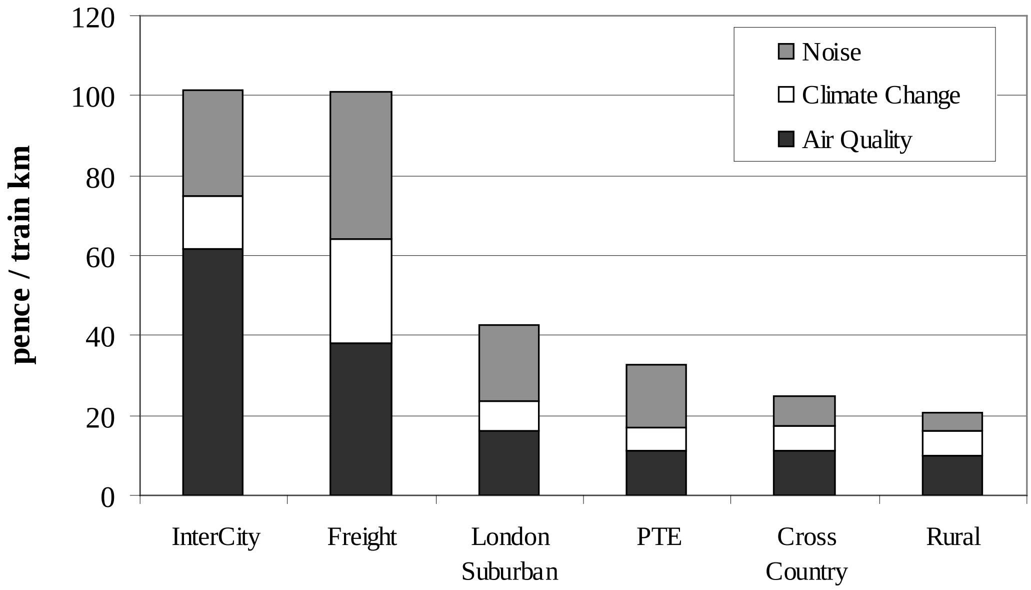


Figure C.18. Environmental costs by train type (1998).

When average passenger occupancies are introduced, it is possible to compare road and rail travel by mode. For example, the average car trip has an environmental cost of 0.8 pence per passenger km based on an average occupancy of 1.2. This falls to 0.6 pence passenger km with an average occupancy of 1.6. The corresponding value for rail trips, based on total passenger km recorded (DETR, 2000), is around 0.6 pence per passenger km. A similar analysis can be undertaken for freight. Based on total tonne km carried for road and rail, average values for 1998 equate to 0.3 pence per tonne km for rail and 0.5 pence per tonne km for road. Note, however, to properly compare modes, it is necessary to look at the specific environmental costs for specific trips, e.g. a city to city journey. The use of the average values can be misleading, due to the proportion of overall km in urban and non-urban areas skewing the average values.

The study has also undertaken analysis at a more dis-aggregated level for rail. This allows comparison of the environmental costs by fuel type (electric and diesel). The total environmental costs, and average costs per km derived from them, are shown for diesel and electric trains in Figure C.19 and C.20.

As with the road analysis, the total environmental costs reflect the number of km travelled by vehicles on specific routes. For example, the use of electric traction for freight movement or rural passenger trips only contribute a small proportion to total environmental costs, because the number of electric train kilometres for these types of trips is low. The analysis of the pence per km shows a more accurate representation of the relative environmental costs between electric and diesel train types.

The figures show interesting conclusions. Firstly the variation in environmental costs (per km) vary more widely with diesel trains than with electric. Secondly, there are some major differences in environmental costs between diesel and electric trains of the same type.

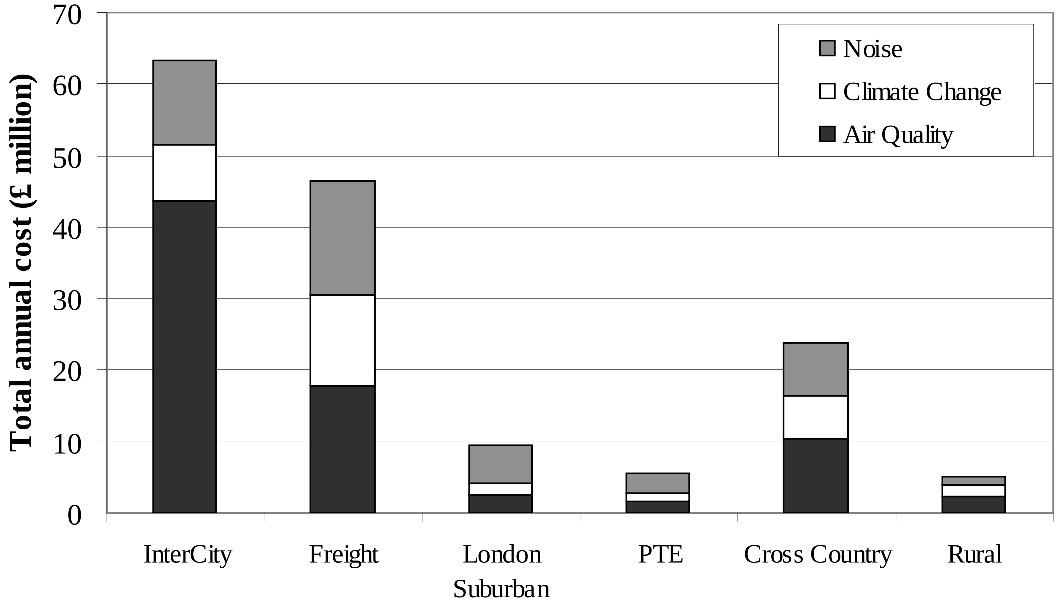
This difference is greatest for InterCity trains. The results indicate that much lower environmental costs arise for electric rather than diesel traction: the average environmental costs for a diesel InterCity train is almost three times greater than an electric InterCity train.

These differences occur because of air quality impacts from the two fuels and the relative balance of pollutants emitted. Diesel trains emit much higher levels of particles, the key pollutant in health impacts. For example the average emission from an InterCity diesel is around 8.5 gPM_{10}/km, whereas for the East coast line, an electric InterCity only emits around 1 gPM_{10}/km[26].

Similar differences are found between electric and diesel freight traction for the same reasons. For other passenger trip types, the difference between diesel and electric vehicles is lower, though the rail results do not differentiate by location. Diesel trains operating on the London suburban routes are likely to emit pollutants in areas of higher population density and are likely to have higher impacts than rural routes.

[26] Note the location of emissions is less important than for road. For diesel trains, most emissions are emitted along rural corridors. For electric trains, pollutants are emitted from tall power station stacks.

Further investigation of differences between trip types would be possible with a greater level of dis-aggregation.



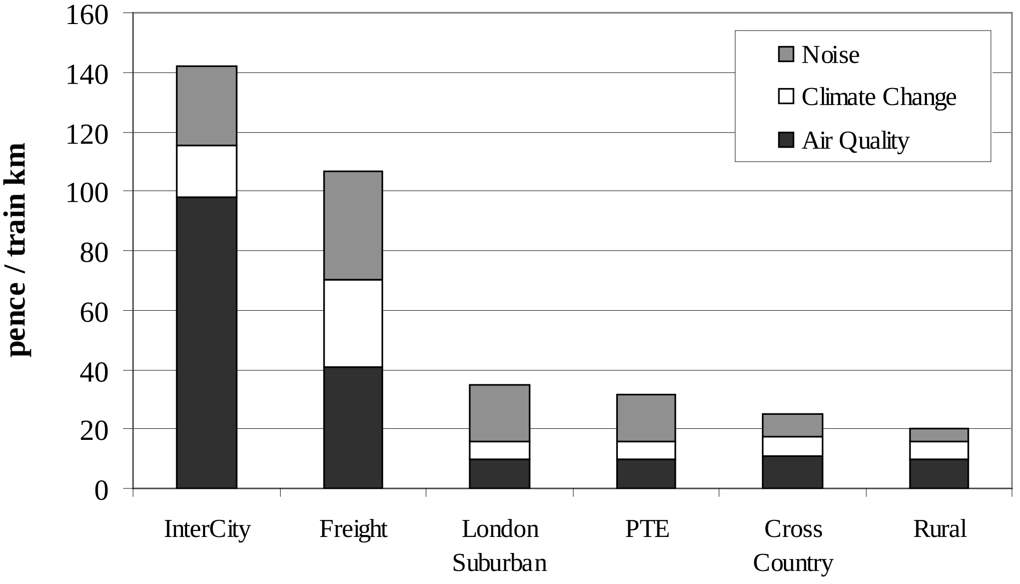


Figure C.19. Total and average environmental costs for diesel trains (1998).

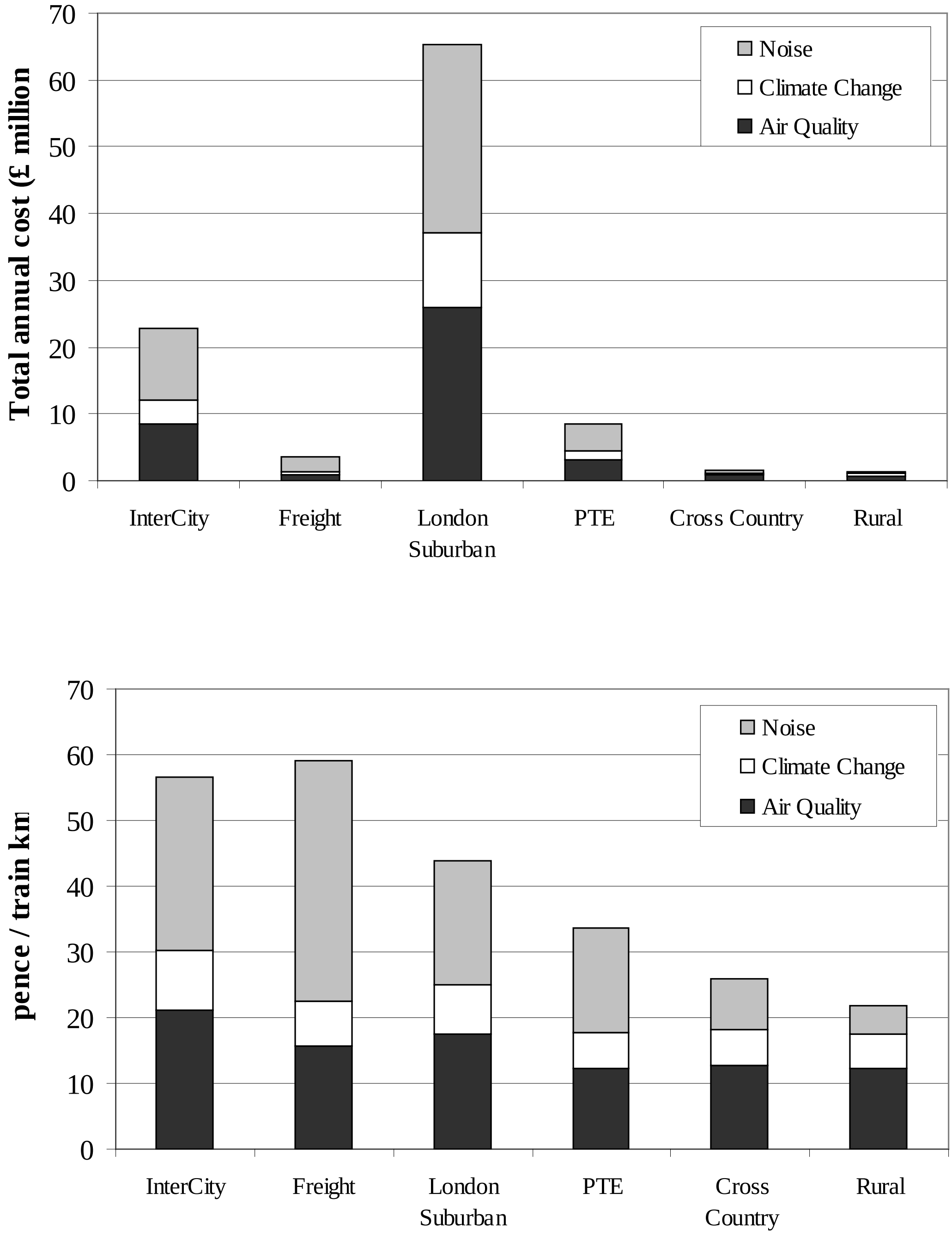


Figure C.20. Total and average environmental costs for electric trains (1998).

Of course, the electricity generation mix will have a very large impact on the size of the environmental costs from electric trains. For example, the environmental costs from the 2010 electricity generation mix may be almost half those of the 1998 values.

For diesel locomotives, large differences exist between individual train types – older trains have much higher environmental costs than newer ones. These differences are significant. For example, a new class 66 locomotive has very much lower environmental costs than the average 1998 locomotive, because of lower emissions. Analysis of the sensitivities concerning the electricity generation mix, and of the changing train fleet in future years, are highlighted as warranting further investigation.

The framework has made progress in differentiating the electric train data further. Indeed, it is possible to report the environmental costs per passenger km for electric trains by TOC. The data available for diesel trains has made such a comparison more difficult. It is believed that such an analysis could be undertaken with some further investigation of data sources. This involves the compilation of a better picture of the dis-aggregated train types across the network (in terms of the types of locomotives used and numbers of units for different types of journeys).

Conclusions

This study applies a detailed bottom-up approach to Great Britain to estimate the environmental costs of the road and rail sector. On the road side, it represents one of the most detailed and comprehensive studies of national level damages to date, working with a level of dis-aggregation covering vehicle type, Euro standard, speed and location.

Such an approach allows a more accurate picture to be built of the environmental costs of different vehicles, travelling on different roads in different locations. It also provides the information to look at the environmental costs of the transport sector at a greater level of detail than previously possible – examining the importance of different technologies and fuels. This level of information is essential in looking to produce fair and efficient transport pricing policies.

The study has estimated the total environmental costs from the road and rail sector in 1998. The estimated environmental costs from the road sector, based on the 1998 vehicle fleet, are almost 7 billion pounds, and the estimated environmental costs from the rail sector just over 250 million pounds (central values).

The environmental costs from the road sector are dominated by passenger cars, comprising 50% of total costs, though this is due to the large number of vehicle km driven (80% of all km). In contrast, heavy goods vehicles have a dis-proportionately high contribution to environmental costs (25%) despite their relatively low vehicle km share (~5%).

The dis-aggregated analysis has shown location has a strong influence on environmental costs. Urban trips have much higher environmental costs than rural ones. Indeed, urban trips account for around 65% of environmental costs, though urban trips represent only around 40% of total km. These differences occur because of two reasons. Firstly because environmental costs are larger in urban areas, per tonne of pollutants emitted, due to the higher population density in these areas. This also leads to higher noise costs. Secondly, because speeds in urban areas tend to be slower and at low speeds emissions rise sharply (per km travelled). The combination of these factors lead to very high environmental costs in congested urban areas (especially London).

Fuel type and vehicle emissions standards are as important in determining environmental costs. The environmental costs of diesel vehicles are much greater than petrol vehicles when travelling in urban areas. This is because diesel vehicles have higher emissions of particles and SO_2, the two pollutants that cause most health and non-health damages. The differences between petrol and diesel vehicles are most pronounced for older vehicles (pre-Euro).

For both fuels, the introduction of stricter emissions standards (Euro I and II) have led to major reductions in environmental costs. The improvement is most marked for urban driving. The standards have also reduced the difference between fuel type – although diesel vehicles still lead to higher environmental costs in urban areas, newer diesel vehicles have lower environmental costs than petrol in rural areas.

The large differences in environmental costs between different vehicles and fuels are not reflected in current charges. Fuel duty provides an incentive to reduce fuel consumption (and so greenhouse gas emissions) but the results here show that environmental costs are dominated by the conventional pollutants. Annual road tax offers greater potential to reflect these differences, as it allows lower costs to be passed through to vehicle owners or fleet managers that switch to less polluting (newer) vehicles. VED reforms are starting to be used in the UK and the analysis here provides a very strong justification for the continuation and wider use of such policies. Finally, in all cases, the relative environmental costs of different vehicles, technologies and fuels provide information for the analysis of other locally based schemes, such as the benefits of low emission zones in urban areas. Further analysis of all these issues with the dis-aggregated information generated in the study would be extremely valuable in helping to inform transport decision making.

For the rail sector, the dis-aggregated analysis has shown that InterCity and freight trains cause a high proportion of rail environmental costs (>50%), though their km share is relatively low (~25%). The study has also compared the environmental costs by fuel type (electric and diesel).

There are also some major differences in environmental costs between diesel and electric trains of the same type. This difference is greatest for InterCity trains. The average environmental costs for a diesel InterCity train are more than double that of an electric InterCity train, i.e. electric traction has environmental advantages over diesel traction for high speed journeys. The reason for this difference lies in the relative balance of pollutants emitted. Diesel trains emit much high levels of particles, the key pollutant in health impacts. Similar differences exist for diesel and electric freight traction. For other trains, the difference between diesel and electric vehicles is low, though further work on the location of emissions is needed to confirm this.

The values above represent the central estimate from the study. An upper and lower bound (based around valuation) has also been derived. The study has also undertaken an uncertainty analysis examining the confidence in different impacts. This has allowed us to examine the potential effects on results from only including those effects that we are most certain of. This analysis has shown that a large proportion of the environmental costs is associated with impacts that have a higher uncertainty.

Research Priorities

The study has highlighted a number of research priorities. These are split into two types. Those concerned with improving the data, or level of dis-aggregation in the existing framework, and those concerned with extending the framework.

The research areas to improve the existing framework are:

- To improve data availability and dis-aggregation for rail. Better data on the breakdown by locomotive unit for different routes, and better freight data overall, would significantly improve the framework. With some additional data collection (e.g. by using the data collated in the National Rail Model) it would be possible to dis-aggregation by TOC, by locomotive type, and by area;
- To make a more detailed assessment of the marginal and full allocated costs of road and rail noise. The study has started to develop a bottom-up approach to evaluate noise, but more data collation and a more thorough analysis is required to properly estimate national fully allocated costs, and importantly to estimate marginal costs. Such an evaluation is especially important in light of EU draft noise directive. Further consideration of other noise issues is also recommended including time of day effects, vibration, perception, possible health effects and valuation;
- To dis-aggregate the reported framework down to the level of fuel type (petrol and diesel) and different emissions technologies (pre-Euro, Euro I, etc). This would allow a more accurate analysis of potential effects of different economic instruments (e.g. fuel taxes, duty differentials, VED, and local pricing schemes such as congestion charging), as well as providing justification for locally based schemes such as low emission zones;
- Consideration of environmental costs from upstream activities. Recent studies (e.g. ExternE, 2000) show the upstream emissions and environmental impacts from fuel production and from vehicle manufacture are very important: increasing total environmental costs by up to 50%. Clearly such changes can have a very strong influence on the relative environmental costs of different modes and technologies;
- To consider possible speed effects on marginal environmental costs; and,
- To evaluate other possible environmental effects from transport that were not included, including water pollution, effects on ecosystems and habitats, visual intrusion and landscape effects, and possible social-economic effects such as community severance.

The research areas to extend the existing framework are:

- To extend the framework to future years. The average vehicle fleet is continually changing due to tightening emissions standards. This will lead to very large changes in the future environmental costs for the road sector, especially as more of the higher polluting, older vehicles are retired. The environmental costs in 2005 and 2010 will therefore be very different relative to 1998. This needs to be considered for looking at possible policy and economic instruments. Potential changes from alternative fuel vehicles could be considered in this analysis. A similar analysis should also be undertaken for the rail sector, looking at locomotive types and average electricity generation mix for future years; and,

- To extend the analysis to cover other modes, especially air and shipping. The comparison of costs of competing modes, e.g. rail and short-haul air for regional trips is identified as a particular priority.

Annex C: Areas for Future Research

Introduction

Future research opportunities are discussed under six headings. These are not in order of priority, nor are they mutually exclusive areas of research. The six areas are:

- Enhancing the content of the existing framework;
- Extension of the framework to cover future years;
- Extension of the framework to enable the magnitude of marginal-cost based prices to be determined;
- Development of a more disaggregate road framework;
- Development of a more comprehensive rail framework; and,
- Other areas of research.

Enhancing the content of the existing framework

The methodological approach and the results set out in this report demonstrate the need to both enhance the existing cost and revenue estimates, and to fill in important gaps. These relate to the fully allocated cost (FAC) and/or marginal cost (MC) analyses. Particular areas that would merit attention are:

- Road cost of capital (FAC) – re-estimation of the asset value of the road system;
- Rail cost of capital (FAC) – examining the potential to include land associated with alignments in the asset base, to ensure comparability with road FAC estimates;
- Road congestion (MC) – further testing of the sensitivity of estimates to alternative assumptions about speed-flow curves;
- Road accidents (FAC) – determination of the way in which the external cost of accidents involving 2 or more parties should be attributed to the parties involved;
- Road accidents (MC) – examination of appropriate assumptions about risk elasticities[27];
- The Mohring effect for bus and rail (MC) – incorporation to reflect the benefits of changes in service frequencies;
- Road and rail upstream environmental activities (MC, FAC) – inclusion of impacts from fuel extraction and production and vehicle/train manufacture;
- Road air pollution, climate change and noise (MC) - incorporating variation with speed;
- Road and rail environment (MC, FAC) – consideration of other possible environmental effects, including water pollution, effects on ecosystems and

[27] A synthesis of UK research in this area is being carried out by Halcrow/TRG Southampton under the Highways Agency's Managing Integration research commission.

habitats, visual intrusion and landscape, and possible social-economic effects such as community severance;

- Road and rail noise (MC, FAC) – further investigation of the marginal vs total cost of noise, together with consideration of other noise issues including time of day effects, vibration, perception, possible health effects and valuation; and,
- Road fuel duty (MC) – incorporating variation with speed.

Extension of the framework to cover future years

The analysis contained in this report has been undertaken for a specific year (1998) but could readily be carried out for future years. This would yield research outputs that are relevant to current and future charging policy needs. The impact on costs of the following issues may be examined:

- new capacity provision – this will affect virtually all cost and revenue categories;
- changes in environmental emissions – the change in vehicle and train fleet composition over time, in particular emission standards, will affect environmental values; the changes in electricity composition over time will also affect rail environmental values;
- trend rates in accident reductions; and,
- fall in Train Operating Company subsidies over time.

This is proposed as a single research topic, although it could be separated into:

- extension of the road framework to cover future years; and,
- extension of the rail framework to cover future years.

Extension of the framework to enable the magnitude of marginal-cost based prices to be determined

The existing framework can be used to indicate the direction of changes in prices needed to achieve marginal cost-based prices. As previously discussed, however, a mechanism for taking account of the impact of changes in prices on demand and then marginal costs would be needed in order to determine the magnitude of marginal cost-based prices to be applied in an equilibrium situation. This research area is specified separately for road and rail.

Extension of road framework to enable the magnitude of prices to be calculated. For road, there are three ways in which the price/demand/cost inter-relationships could be incorporated:

- simple elasticity method – the change in price for an individual link at a given time period, combined with a demand elasticity, could be used to increase/ decrease demand. The demand elasticity could vary by area type/ vehicle type/ time period etc., but this modelling method would not involve demand being re-allocated to another area type/ time period;

- cross-elasticity method – the above method would be used, but with the use of cross-elasticities that reflect the likely re-allocation of demand across area types and time periods;
- use of the NRTF model – for a more thorough treatment of re-allocated demand, the "fitting-on" component of the NRTF model could be exploited. This would take the same approach as the cross-elasticity method, but develop an interface between the external cost estimation carried out in this project and the NRTF model.

In each case, the main non-linear marginal cost category, congestion, would be the main demand-dependant cost category involved in iterations. In addition, accident costs (only if non-zero risk elasticities are incorporated) and environmental costs, may also be incorporated.

Extension of rail framework to enable the magnitude of prices to be calculated. For rail, a model of the way in which TOCs would reflect changes in track access charges in their passenger fares would be needed. This could examine the likely price/demand/cost interactions:

- without existing regulatory constraints on fares – this scenario would not place constraints on the way in which fares could respond to costs;
- with regulatory constraints – in this scenario, the dampening effect of fare regulation would limit impacts on passenger demand and hence changes in marginal costs.

Development of a more disaggregate road framework

The policy questions that the framework addresses could be answered at a greater level of detail, and with a greater degree of accuracy, if a more highly disaggregated framework were developed. This research area is proposed as a single topic.

Areas in which this could be undertaken are:

- vehicle types – up to 37 vehicle classes have been incorporated in the NERA (1999) study, mainly for infrastructure and accident costs. This level of detail could be taken forward for all cost and revenue categories;
- road types/ area types – there would be scope to extend the framework to cover specific road networks and geographic areas. This could cover the full road system, or selected areas - e.g. the English trunk road system, or major towns and cities;
- fuel types, engine types – the output of the framework could distinguish between petrol/diesel vehicles, and emission standards; and,
- time periods – 19 time periods are included in the NRTF traffic database, and it would be possible to enhance the framework on this basis.

These further disaggregations would enhance the way in which the output from the framework could be used to examine how different pricing instruments can be used. As examples:

- vehicle type disaggregation – although existing tolling systems incorporate a limited number of vehicle classes (typically 5-10), potential exists to vary charges by a wider variety of factors – e.g. variation by fuel type/engine type to reflect relative environmental damage; and,
- time period disaggregation – the Singapore Electronic Road Pricing system incorporates charges that vary by the half-hour period (as did the now defunct inter-urban State Route 91 in California) -

The calculations would be supported by pre-existing datasets: for infrastructure costs, congestion, accidents, and environmental costs.

Greater disaggregation is also beneficial for the examination of marginal cost estimates that reflect underlying cost drivers. Fully allocated costs become more tenuous with greater disaggregation (e.g. allocating infrastructure costs to alternative time periods cannot be intuitively justified). For these reasons, it is recommended that further disaggregation is only taken forward for the marginal cost analysis.

Development of a more comprehensive rail framework

For the rail framework there are two priority areas for further research:

- development of more disaggregate train operator data – more detailed train operator data could be incorporated into the framework. This would allow for more accurate estimates of marginal operating costs (distinguishing between peak and off-peak) and environmental costs to be made, and greater geographic disaggregation. For instance, to identify separately conurbation commuter services, cross country services and rural services. Issues of commercial confidentiality would need to be explored, but the output could be reported in an anonymous way; and,
- examination of the passenger demand/ train service relationship – changes in passenger demand and the service operator's response to such changes determine the marginal cost of provision per passenger km. Operator responses may include: no response (occupancy rises, and crowding may become a factor); increase train size (if infrastructure allows); and, increase train frequency (bringing into play the Mohring effect), or of course a mix of all three.

Other research areas

Other areas of potential research include:

- mixed policy levers model – inevitably, there will be a time lag between the initial introduction of road pricing systems (e.g. perhaps 3 cities, motorway network) and a more comprehensive system of road pricing. It would be possible to examine how a mixed system of electronic road pricing in some areas plus sole reliance on fuel duty in other areas could be optimised;
- electronic road pricing viability model – incorporation of the set-up and ongoing costs of road pricing systems for discrete parts of the road network would allow the economic performance of road pricing to be examined. This could be used

to prioritise among area/ road types where intervention would be most beneficial;

- extension of the NRTF model – development of a pricing module that incorporates the cost estimates and functions developed in this project. The cost functions could be integrated within the existing NRTF modelling framework in order to complement the model's current capabilities;
- developing a practical approach to estimating LRMC. This would require simulations of capacity, congestion, safety and environment at various rates of investment, and for various traffic growth scenarios;
- extension of the framework to include aviation – both passenger and freight transport; and,
- comparative analysis of the effectiveness of alternative charging tools – e.g. simulation of the effectiveness of fuel duty taxation versus, or in combination with, banded vehicle excise duties.

As this last list of topics indicates, the research headings identified in this section are not mutually exclusive – e.g. combination of more disaggregate road framework plus price/demand/cost interactions would yield a framework that may be used to explore practical issues in the design of inter-urban road charging systems.

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