Chapter 7

Road User and Congestion Charges

*DAVID MICHAEL NEWBERY**
University of Cambridge

7.1 INTRODUCTION

This chapter argues that roads should be treated as a regulated public utility, and road charges set accordingly to yield a stable and defensible revenue stream. An efficient structure of charges would confront road users with the marginal social cost of their decisions, but there are limits to the precision with which this can be done. Congestion externalities make up the larger part of the efficient road user charge, with road damage costs and externalities a relatively small part. Accident externalities are hard to measure, and could be small in comparison with other costs. Other environmental costs affect non-road-users as much as road users, and are therefore best dealt with by corrective taxes (and standards). If governments could set out and defend the total revenue to be collected for road use, and the environmental taxes, then it would be politically easier to move to a more efficient structure of road user charges, such as congestion or road pricing. The levels of road user charges dictated by the regulated public utility model are not inconsistent with an efficient set of road prices, provided that the level of road investment is set efficiently. The public utility model has the additional advantage that it is more likely to deliver efficient investment than current budgetary arrangements.

Road users require access to expensive road infrastructure and impose a variety of external costs on each other (congestion, accident risks) and on non-road-users (accident risks, pollution, noise, environmental degradation). They typically pay special excise duties on fuel and annual licence charges for the right to use highways. They may also pay special taxes on vehicle purchase, though these are less common now in developed countries. Increasingly, countries impose tolls for certain roads and bridges, often as the means to pay the private concession holder, while charges to enter congested urban areas have been introduced in Singapore, Norway, and other countries. Most of these are neither designed for, nor defended as, methods of optimizing traffic flows, as

*I am indebted to Richard Arnott and Reiner Eichenberger for the detailed written comments, to the participants at the OCFEB conference for their contributions, and to Eurof Walters, Steven Haberman, and Fintan Hurley for help with the mortality calculations in Appendix 7.A.

they rarely vary by time of day or in response to traffic conditions. Instead, they are normally justified as a fair means of financing improved transport systems (for motorists and through better public transport). Nevertheless, they remind us that road pricing is likely to be a more efficient way of dealing with traffic congestion than the existing blunt instruments of fuel excises and public transport subsidies.

Figure 7.1 shows the excise taxes (excluding value added tax (VAT)) on road fuels across the European Union (EU), together with the USA and New Zealand, which stand out for their relatively low tax rates. The countries are ranked by the tax on gasoline (petrol), and it is noticeable that diesel is less heavily taxed in all countries except the UK, despite the greater fuel efficiency of diesel vehicles (and hence the lower tax per kilometre even when equally taxed). Heavy vehicles in New Zealand pay weight- and distance-related taxes so that there is no road user charge reason to tax diesel fuel. Road fuels have always been lightly taxed in the USA, in contrast to Europe, raising sharply the question of whether, as Parry and Small (2002) ask, the optimal gasoline tax is closer to the US or European level.

There are conceptually two quite distinct ways of deciding on the appropriate level of road user charges. An ambitious student of optimal public finance might attempt to maximize social welfare subject to a set of tax instruments and a government budget constraint. Social welfare would depend on individual utility, defined over transport services, labour, time spent travelling, accident risk, pollution, leisure, and all other goods. Pollution, accident risk, and travel time would depend on location, demand for travel, and the level of traffic and fuel use. The problem is then to determine the optimal level of such

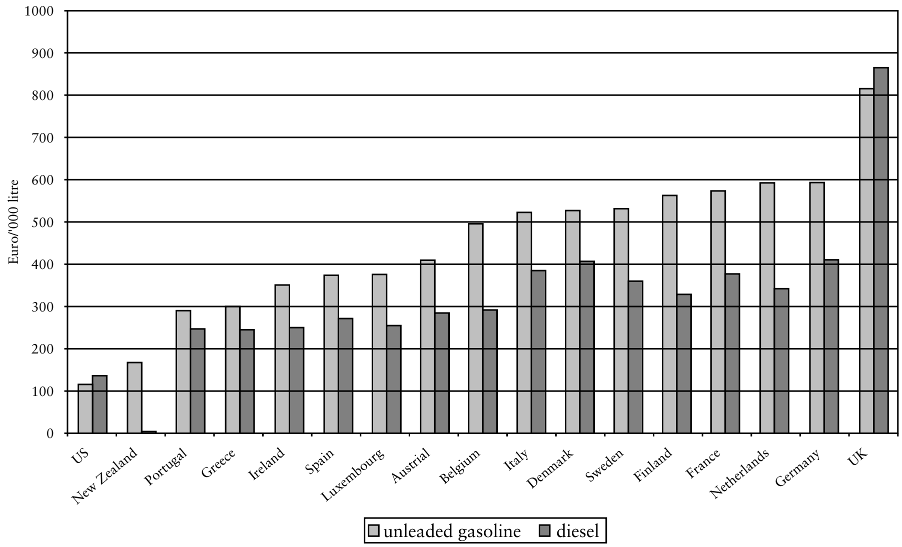

Figure 7.1. *Road Fuel Excise Taxes, 2001*

instruments as the gasoline tax (and all other taxes, possibly subsumed into a labour tax). Parry and Small (2002) provide an excellent example of this approach and show how the gasoline tax should be set to deal with pollution, congestion, and social welfare more generally, balancing the distortionary effects on fuel and vehicle use against the reduction in labour tax distortions. Under certain assumptions, the gasoline tax can be set without regard to these wider policy objectives.

This ambitious top-down or general equilibrium approach can be contrasted with a more partial or bottom-up approach that concentrates on the road sector initially in isolation and only considers wider issues (such as raising additional revenue) at a later stage. Both approaches have their advantages and limitations. As with any exercise in optimal taxation, the model employed has to be greatly simplified to be tractable. It risks overlooking features of congestion and road investment that may be critical for the design of road user charges. The bottom-up approach breaks the problem down into manageable components that can be quantified, and for which tax and charging instruments can be properly tailored. It is relatively silent on the larger question of how much additional revenue should be raised from road users to contribute to general taxation. That answer will depend on the kind of issues addressed by optimal tax theorists and on questions of political economy.[1]

The approach taken here is bottom-up, with a final section discussing some of the wider tax issues. On this approach, an efficient structure of charges and taxes on road users would contain the following components:

- efficient charges for using scarce and costly road space, including congestion charges and road damage costs;
- charges (more properly, corrective taxes) for other externalities, such as pollution, noise, and accidents;
- general taxes that apply to the majority of goods, such as the standard rate of VAT;
- additional taxes or subsidies that are justified by wider policy considerations (or are not justified by any of the preceding).

The last category can be thought of as a balancing item, as most taxing authorities do not distinguish between the separate components that make up the existing system of charging and taxation. For our purposes, it reminds us that there may be additional revenue-raising and redistributive arguments for further taxation that are not covered by any of the previous distinct categories.

The third category can be ignored once we have dealt with one important conceptual issue. The first two categories are corrective taxes or charges to ensure that road users face prices that reflect the social cost of road use. If the prices are right, then so ought to be decisions about vehicle acquisition and use. These prices would then correspond to efficient producer prices elsewhere in the economy, and as such should be subject to the standard rate of VAT. In most developed countries with a system of VAT, excise duties on fuel are also subject to VAT. In some countries, the level of fuel taxes exceeds the amount justified under the first two categories. There will then be additional VAT on the excess of these taxes over the corrective component, and that part of the total VAT should be considered to be part of the residual tax system. At present, commentators typically either exclude all VAT (the convention of the British Office for National Statistics in classifying road taxes) or include all VAT in the total level of road taxes (the practice of the British Automobile Association in arguing that motorists are overtaxed). The proposed approach is conceptually defensible although rather difficult to implement.

The remainder of this chapter shows how to set road user charges following this scheme, illustrating the method with data from Britain. Table 7.1 gives basic data for British traffic and tax revenue from fuel taxes and vehicle excise duty (VED), as well as emissions of various pollutants.

7.2 ROAD USER CHARGES

There are two apparently conflicting approaches to setting road user charges that can be reconciled under not unreasonable conditions. The first approach is to set charges that cover the total costs of operating the network (the way in which privatized network utilities operate). The second is to charge the difference between the marginal social cost (MSC) and the average private cost

Table 7.1. *Traffic Volume, Taxation, and Emissions: Britain, 2000*

	Various units	**Tax (£ million)**
Traffic (billion vehicle km)	468	27,720
Of which:		
In built-up areas	183	
Cars and light vans	429	21,735
Fuel use (million tonnes)		Fuel tax
Petrol – leaded	1.5	
Petrol – unleaded	19.9	13,665
Diesel	15.6	8,640
Total	37	22,305
Emissions		
Particulates (thousand tonnes)	38	
Nitrogen oxides (thousand tonnes)	730	
Carbon dioxide (million tonnes carbon)	36	
Motor vehicles licensed (thousands)		VED
Motorcycles	790	40
Petrol cars	20,154	3,695
Petrol light goods vehicles	525	96
Diesel cars	3,033	556
Other diesel vehicles	3,911	1,028
Total	28,413	5,415

Source: Department of Transport, Local Government, and the Regions, 2001.

(APC) of road use. If we leave on one side the non-congestive externalities, which will be dealt with below, the main reason why the MSC typically exceeds the APC is that road users impose congestive externalities on other road users. In addition, heavy vehicles cause wear and tear disproportionately to their number (damage increases as the fourth power of the axle weight), and this damage raises vehicle operating costs for other road users. There is therefore both a direct damage cost and an additional road damage externality to be included in the MSC.

Charging efficient prices (to charge for user costs and internalize these two externalities) and charging to recover average costs might appear to be quite different approaches likely to give quite different answers. Newbery (1988a, 1989) identifies the conditions under which the two are equal. Road damage externalities averaged over the network are zero provided that the highway authority maintains a condition-responsive maintenance programme – that is, it repairs roads when they fall to a predetermined level of deterioration. Charging efficient congestion prices will exactly recover the total costs of providing road infrastructure (including costs caused by weather damage) provided that the marginal cost of road expansion is constant. The proposition that short-run marginal cost (SRMC) = long-run marginal cost (LRMC) = average cost (AC) for efficiently priced and supplied constant-returns-to-scale industries will be familiar (Mohring and Harwitz, 1962; Mohring, 1970; Strotz, 1965).[2] The result here is more surprising, as AC includes the quite considerable weather damage costs, which may account for half the total operating costs.

This immediately raises two questions: whether there are economies or diseconomies of scale to expanding roads, and whether it is reasonable to suppose that roads are optimally supplied and priced. If we consider the first question, the evidence is mixed. For inter-urban roads in relatively unpopulated areas, there is some evidence of mild increasing returns to scale or decreasing costs. Doubling a two-lane road to a four-lane road almost doubles the capacity per lane and hence almost quadruples total capacity, but the cost of intersections increases considerably. Keeler and Small (1977) analyse US inter-urban data and give their best point estimate as AC/MC = 1.03 (but with a high standard error), suggesting slight increasing returns to scale. Kraus (1981a, 1981b) combines a number of estimates to get AC/MC = 1.19 explicitly accounting for intersections.

In densely populated and urban areas, the marginal cost of road expansion may be extremely high and exceed the average cost. This suggests that inter-urban and urban roads should probably be treated differently for charging purposes. If we include minor roads that act as feeders to the inter-urban road network, efficient congestion pricing would not be in conflict with average cost pricing, provided the highway authorities expanded roads when justified by social cost–benefit analysis.

The answer to the second question as to whether roads are optimally priced and supplied is almost certainly 'not in all cases'. In Britain, the typical benefit–cost ratio for potential inter-urban road projects is substantially greater than one, suggesting considerable underinvestment and marginal congestion costs that exceed the average costs of expansion. In North America, with suboptimal fuel excises, the opposite may be true. That raises the important issue of advising on the appropriate level of road charges and taxes in sub-optimally managed transport budgets.

The short-run marginal social cost (SRMSC) will be higher, on average, than the long-run marginal social cost (LRMSC) if there is underinvestment in roads. If governments then defend road charges and/or taxes by reference to the SRMSC, they are effectively exercising market power to drive up the scarcity price of the natural monopoly under their control. The standard solution to the abuse of market power for natural monopolies is regulation to prevent exploitative pricing, with the requirement to meet demand at the regulated price. Regulated utilities in the private sector are normally allowed to recover their total costs, while being encouraged to price individual outputs efficiently (subject to the overall revenue constraint). The British model of price caps and private utility regulation has been remarkably successful.[3] It suggests looking at the problem of setting road user charges as one of setting charges for a regulated natural monopoly road network.

7.3 REVENUE CAPS FOR ROAD CHARGES

Where networks are under private ownership, regulation is required to prevent the natural monopoly owner exploiting consumers. Credible regulation is also required to protect the owner against expropriation by politically influential consumers and thus to persuade investors to undertake adequate investment. Over relatively long periods of time in the USA and for more than a decade in the UK, the principles of setting charges for using natural monopolies have been clarified and codified.

The regulated charges should be set to recover the operating and capital costs of an efficiently run network. The capital cost consists of the interest (or return) on the opening value of the regulatory asset base (RAB) and the depreciation (or decrease in value) of this value. A key part of setting the charges therefore consists in determining the RAB, measuring its depreciation, and determining the rate of return allowed on the RAB. In the case of indefinitely lived assets, such as water mains and roads, depreciation may be replaced by the amount of expenditure needed to maintain their modern equivalent asset (MEA) value. Over time, the RAB is increased by new gross investment and reduced by depreciation.

In the USA, the RAB is equal to the written-down book value – that is, the purchase cost (at historic value) less the accumulated value of depreciation. The rate of return is the money rate of interest that lenders would require to invest in that risk class of assets. This approach has the advantage that the assets can be financed by issuing bonds but the drawback that the book value of assets may fall substantially short of the written-down MEA value at current prices, while money rates of interest can be quite unstable. Britain, with a longer and more painful experience of rapid and unpredictable inflation, adopted current cost accounting.[4] Assets are revalued each year by a suitable price index and earn a real rate of return rather than a money rate of return on their opening value.

Where assets are transferred from the public to the private sector, one of the critical issues to resolve is how they will be valued for subsequent resetting of price controls. This issue was essentially sidestepped with the early British privatizations and only returned to haunt the regulators at the first periodic review. Most public assets had been sold at a considerable discount to MEA value, most noticeably for water where the sales price was less than 10 per cent of the MEA. Over time, as investment increases the real value of the assets, the RAB will converge ultimately on the MEA value. In the case of water, this process of convergence was assisted by a K-factor that augmented prices sufficiently rapidly to enable the large required investment programme to be financed.[5] Electricity and gas transmission systems were sold, and remain, at a considerable discount to MEA, and as their rate of investment is relatively slow compared with their asset value, this process of convergence may take decades.

If we consider the road network, and were to adopt the same approach for setting charges to cover operating costs and the return to the owner (the State), there would be a major problem in determining the RAB. It is relatively straightforward to value inter-urban highways. Thus the British Highways Agency estimates that the strategic road network is worth £60 billion at 1998 prices (Drake, 2000). The British strategic road network carries 34 per cent of all road traffic and 67 per cent of freight.

Valuing the rest of the road network, and particularly roads in built-up areas, is intrinsically problematic. The inherited road network reflects a gradual evolution in a largely pre-motorized era and is very unlikely to reflect an efficient road network system designed for motor traffic. It is, of course, possible (in principle) to determine the number of lane kilometres of roads of varying qualities, estimate their current state of repair and the cost of building a new road to that standard, and hence calculate the written-down MEA for the entire system. In 1996, the then Department of Transport in Britain decided to undertake this exercise, but it has not yet produced a result. Newbery (1988b) had already produced estimates from rolling forward the earlier published capital value of the road network by a permanent inventory method of adding new investment to that total. That number would be between £100 billion and £150 billion (1998 prices) for the UK. If the strategic road network value of £60 billion is accepted, the rest of the network is worth between £40 billion and £90 billion, which may appear rather low. If the prime determinant of the cost of roads is the space required for vehicles, then one would expect the cost of the rest of the network to be at least as high as that of the strategic roads. Allowing for the higher costs of road building in urban areas, the amount could be substantially more – perhaps £140 billion, giving the total value as £200 billion.

The practical implications of this are that it may be useful to distinguish between urban and inter-urban roads. Inter-urban roads can probably be expanded in line with traffic demand at moderately constant costs, given sensible planning regulations. Increasing capacity on urban roads, in contrast, is often difficult or very costly. The appropriate capital value of inter-urban roads is therefore relatively simple to compute, but there will be a degree of arbitrariness in determining the RAB for urban roads, where honest opinions may differ by a factor of two or more.

The second controversial element in determining the capital charge for the road network is the rate of return, or its private sector regulatory counterpart, the weighted average cost of capital (WACC). This is typically built up from an assumed debt:equity ratio, the real rate of interest on risk-free debt, plus the (default) risk premium for private sector debt, while the equity return has a further equity risk premium. The correlation between the returns of the regulated asset and the market as a whole, or the value of beta (β), then determines the extent to which the risks cannot be diversified (and hence are socially costly).

If we take Ofgem's recent price control of the gas transport network, Transco, as an example, the risk-free real rate is taken as $i = 2.75$ per cent and the debt risk premium is $\delta = 1.5$–1.9 per cent, giving the cost of debt as $d = i + \delta = 4.25$–4.65 per cent (Ofgem, 2001). The equity risk premium is taken as $\rho = 3.5$ per cent, gearing as $g = 62.5$ per cent, and the equity beta as 1, to give the post-tax cost of equity as $n = \beta(i + \rho) = 6.25$ per cent, or a pre-tax cost of equity as $r = 8.9$ per cent, and a WACC of $gd + (1 - g)r = 6$–6.25 per cent real. This is for a privately owned and regulated network, whereas the road network is publicly owned, raising the standard public economics question of what is the correct rate of interest to use in project appraisal and also for determining the capital charge for the public sector. Under the strong conditions of the Diamond and Mirrlees (1971) theorem that optimal commodity taxation preserves production efficiency, the public sector discount rate should be equal to the private rate of return. If so, and if beta for roads is also unity, then presumably the (pre-2002) UK government test discount rate of 6 per cent real is the correct rate to use.

Atkinson and Stiglitz (1980) discuss the limitations of the result that the public and private sector discount rates should be equal, with the implication that the public sector may discount at a different and probably lower rate. The British Treasury was in 2001 revising its appraisal manual and was arguing for the considerably lower rate of 3.5 per cent real. This was based on the argument that the social discount rate should reflect the rate at which the marginal utility of consumption is decreasing over time as a result of growth in consumption per head (taken as 2 per cent per annum). The elasticity of the marginal utility of consumption was taken as -1, so the rate of fall of marginal utility is 2 per cent, which, corrected by the risk of catastrophe (taken as 1.5 per cent), gives a social discount rate of 3.5 per cent.

This is not the place to resolve the dispute over the correct treatment of the public sector discount rate that it is appropriate to use in determining capital charges, but only to note the considerable discrepancy between the two discount rates advocated for the public sector in Britain. If we take the RAB as £100–200 billion and the required rate of return as 3.5–6 per cent, then the range of annual capital costs is £3.5–12 billion (excluding depreciation, better measured by the required level of maintenance to preserve intact the capital stock). Maintenance is about £3–4 billion p.a. (Newbery, 1998a) (though perhaps ought to be somewhat higher), while fuel taxes and vehicle excise duty (the annual licence fee) collected £27.7 billion in 2000–01 (excluding all VAT – see Table 7.1). Investment in the road network is running at about £2–3 billion p.a. (Table 7.2 later), while traffic in 2000 was 468 billion vehicle kilometres (Table 7.1).

Total road costs (made up of maintenance and other operating costs, and the capital charge, but excluding any other external costs) are thus between £7 billion and £17 billion per year, or 1.5–3.6p/VKT (vehicle kilometre travelled), while road taxes were 5.9p/VKT. Section 7.5 and Table 7.2 later estimate the cost of other environmental externalities as £3–9 billion per year. Taking the preferred values of £12 billion for the road costs and £5.45 billion for environmental externalities gives £17.45 billion, on which VAT at 17.5 per cent would be £3.05 billion. Fuel taxes yield £22.3 billion and pay VAT of 17.5 per cent, or £3.90 billion, so there is excess VAT of £0.85 billion. The balancing or pure tax element is therefore £27.7 billion − £17.45 billion + £0.85 billion = £11.1 billion.

One argument for setting road charges like prices for regulated natural monopolies is that it should clarify the role of road pricing, while providing a more secure funding basis for investment. As urban congestion grows, the argument for congestion pricing to improve the efficiency of road use grows steadily stronger. Road pricing has now been made legal in Britain in the Transport Act 2000, as have workplace car park levies. In both cases, the local authority imposing these charges or levies can retain the revenue for ten years provided it is hypothecated to transport improvements. The government has indicated that the revenues so generated will be additional to any transfers made under normal central budgetary arrangements to finance local transport improvements. It has not yet explained how this additionality will be assured, nor what mechanisms will protect road users from possibly rapacious local authorities, other than the power of the local ballot box.

If the total revenue to be collected from road charges were set in the same way as the revenue of private regulated networks, then a change in the form of charging to a more efficient and targeted method, such as congestion pricing, would not increase the total level of road charges. This would reassure road users that road pricing were not an additional charge for using already heavily overcharged and undersupplied roads. Given that a minority of road users create the majority of traffic congestion, a majority of road users would benefit from a rebalancing of road charges. Less-congested and inter-urban roads would attract a lower charge (which would almost certainly be most efficiently collected through fuel and vehicle excise duties), while urban road users would pay a higher charge per kilometre than at present.

The other attraction of treating road charges as regulated utility charges is that it provides the basis for financing investment. In the private sector, the assurance that an efficiently managed utility will be allowed to earn an adequate return on its investment allows the utility to borrow against its future revenues if current profits are insufficient to finance current investment. If the government were to create an independent regulatory agency to set the level of road charges, then that same assurance for proper investment planning could be provided to the agency or agencies responsible for road investment. One can imagine a variety of such agencies – Roadtrack for strategic roads, and various agencies responsible for urban roads (such as Transport for London). A regulator (Ofroad?) would also provide the reassurance that voting motorists need if they are to support any changes in the structure of road charges. Before that happens, though, a number of difficult regulatory and accounting issues would need to be resolved.

The first issue would be the choice of discount rate and of the source of borrowing (and of the required return on the assets to pay to the State as owner). If the revenues really are guaranteed, then Roadtrack and its counterparts would be able to borrow at rather low real rates of interest. Risk would be low, and solvency assured for a public sector entity. If the government attempted to restrict or delay investment, then the solvency of Roadtrack would increase, as revenues would rise in line with traffic (until revised down at the next periodic review), and the ability to invest would increase. That would argue for a rather high valuation of the opening RAB, so that a large fraction of revenue would be payable as a dividend to the State, to prevent surplus funds accumulating and leading to less-responsible investment. A better solution might be for the regulator to monitor investment plans, as for other utilities.

The alternative is for the government to specify a required rate of return comparable to that required by private transport investors (which included Railtrack before it was forced into administration by the government). That would have the Diamond–Mirrlees logic of ensuring comparability between competing transport investments, but would require the Treasury to source the finance and charge an appropriate WACC (perhaps by requiring a specified gearing and dividend yield).

There is no simple solution to creating the right institutional structure for the management of road investment, but the model of the regulated network utility has obvious attractions. It has, with the exception of Railtrack, been a successful method of managing capital-intensive network monopolies and ensuring that they deliver adequate levels of investment. Railtrack suffered from the inherent difficulty that railways are inevitably loss-making. An independent regulator such as the Office of Rail Regulation risks continual confrontation with the Treasury if it requires higher charges to cover necessary investment. As private train operators are only viable with public subsidy, increased track charges feed through to demands for additional subsidies that will be resisted by the Treasury. Roadtrack, if anything, would be in the opposite situation of making embarrassing surpluses, with the regulator acting to restrain charges to avoid paying the Treasury excessive amounts. For our present purpose, though, we are more concerned with setting road charges than with deciding how investment should be managed, and so these difficult institutional design issues can be sidestepped here. Eichenberger (2002) offers another perspective on the institutional and political structure needed to deliver efficient investment.

7.4 EFFICIENT ROAD PRICES

Continuing with the useful benchmark of the regulated network utility, the aim is to ensure an efficient structure of prices for the various services such that their total yield is no greater than the regulated revenue cap. Economists wishing to analyse road congestion and road pricing have usually relied on link speed–flow relationships estimated by traffic engineers to compute marginal congestion costs (see, for example, Newbery (1988b, 1990)).

Figure 7.2 illustrates the traditional analysis of congestion externalities. Higher traffic flows lead to lower average speeds and higher travel times and costs per kilometre. Additional traffic imposes an external cost on all other road users. Under congested conditions, particularly in urban areas, and in the absence of efficient road pricing, traffic will be undercharged and hence excessive. In Figure 7.2, the average social cost (ASC) excludes road taxes, while the average private cost (APC) includes road taxes, CB. If the inverse demand is as shown, the equilibrium will occur at point C, where the marginal willingness to pay is equal to the APC. The efficient equilibrium is at point D, where the marginal social cost (MSC) is equal to the marginal willingness to pay. This would be supported by a congestion charge DE (which, as shown, would replace the poorly targeted road tax levied on fuel, CB). The inefficiency of incorrect pricing (the deadweight loss) is then measured by the area DCM.

One obvious objection to this link speed–flow approach is that observations of traffic flows on links may be a very poor guide to traffic conditions in densely meshed urban networks, where most traffic interactions and delays take place at intersections, not on the links between them. This in turn casts doubt on estimates based on these measured simple speed–flow relationships. Fortunately, sophisticated traffic assignment models have been developed to simulate equilibrium traffic flows over a network. SATURN (Simulation and Assignment of Traffic to Urban Road Networks) is an example of such a software package which simulates the results of demands for trips specified by a matrix giving the number of trips between all origin and destination (O–D) pairs (Van Vliet and Hall, 1997). SATURN finds the Wardrop equilibrium, defined as the assignment of traffic in which no trip-maker can reduce total trip cost (the value of the time taken and vehicle operating costs) by choosing a different route from that assigned. Newbery and Santos (2002) use this to compute area-wide counterparts to those shown in Figure 7.2.

There are, however, two major problems with this line of investigation, one conceptual and the other practical. The conceptual problem is that each

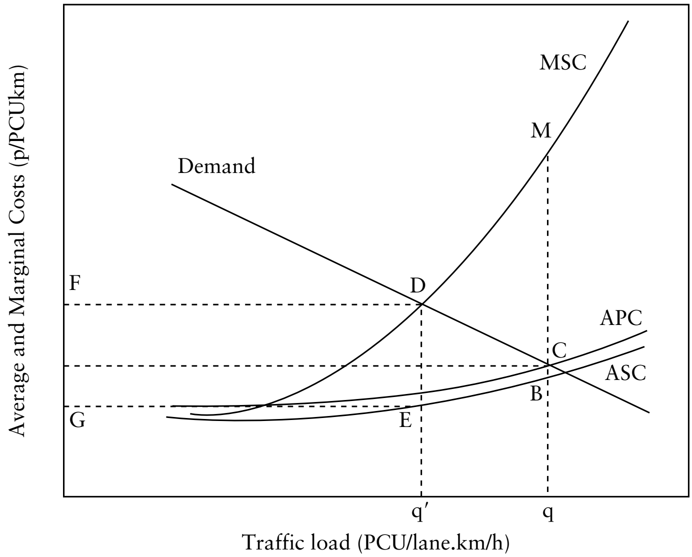

Figure 7.2. *The Standard Analysis of Congestion Externalities on a Link*

segment of each trip will give rise to a different marginal congestion cost, and there is a problem of aggregation if these are to be represented as a single value, as in Figure 7.2. The practical problem is that (supposedly) first-best congestion charging for each link and intersection varying with the prevailing level of traffic is infeasible. It is currently technically impractical, and even if it became technically feasible, it would likely impose excessive information processing costs on drivers. As the aim is to discourage cost-ineffective trips, routes, or times, any pricing signal will have to be sufficiently clear and simple to induce appropriate responses.

Newbery and Santos (2002) show how to address the conceptual problem of aggregation by considering the optimal equiproportional reduction in all O–D trips, for each of which there would then be associated a trip-specific (but not route-specific) charge, the average of which would be as shown. The deadweight loss (DWL) relative to this (second-best) equilibrium would be accurately measured by the area DCM. While this approach has its advantages and allows a swift screening of towns to select candidates for practical road pricing schemes, the best equiproportional traffic reduction would not be the most effective way to improve traffic efficiency and would itself be hard to implement.

The practical problem of road pricing can be addressed by searching for a feasible set of instruments. The natural choice is a cordon toll, where vehicles are charged for crossing a cordon, typically enclosing the centre of the city. The charge can depend on the time of day and be possibly directional (for example, charging for entering in the morning peak and leaving during the evening peak).

Cordon tolls have been implemented in Hong Kong, Singapore, and three towns in Norway, and were successfully introduced into London on 17 February 2003 (May, Bonsall, and Hills, 1998; Larsen and Ramjerdi, 1991; Menon, 2000; www.cclondon.com). The early cordon tolls were primarily set to raise revenue, in the case of Oslo to pay for the transport improvements that were part of the political deal (Larsen and Østmoe, 2001). As such, they set charges that were frequently constant over the whole day, not charging more in the peak than off-peak, and not optimized to maximize social welfare. It is, at least to an economist, a natural step to require that the cordon tolls be optimally set, where the objective is social welfare, measured as the consumer benefit from travel less the total social cost of that travel.

Designing an efficient cordon toll or tolls turns out to be very complex, and as yet essentially unsolved. The choice variables include the exact location of the cordon and the prices at each crossing point and at each time of day. The net social benefits, after allowing for the quite considerable costs of installing and operating the cordon tolls, are sensitive to all of these (Larsen and Østmoe, 2001; May et al., 2002; Newbery and Santos, 2002). The problem is one of complexity – even in a small town, the number of possible locations rises exponentially with the number of links. A typical cordon may have five to fifteen crossings, and the scheme can yield higher benefits if the charges are varied across these crossings (by up to 40 per cent more compared with finding the optimum uniform toll). Adjusting tolls by time of day makes sense to avoid bunching of traffic just before the start and to encourage efficient time-switching, but it raises the complexity by a further order of magnitude. For example, Larsen and Østmoe (2001) show that dropping the (already time-of-day differentiated) Oslo toll on Saturday increases consumer surplus by 40 per cent. To date (October 2002), all estimates of the correct level of toll and the resulting benefits are based on assumed traffic-flow relationships and behavioural responses, either or both of which could be wrong. It will clearly be important to monitor the performance of and responses to practical schemes to validate the calculations and allow tolls to be adjusted.[6]

Finally, there is no available evidence about the longer-run land-use impacts of cordon tolls, and given that cordon tolls are second- or third-best, there are no useful theorems that ensure that these land-use impacts will be efficient if the tolls are optimally adjusted to achieve short-run efficiency. Eliasson and Mattson (2001) show that in a simulated and symmetric city, the land-use effects of link-based road pricing are small compared with traffic impacts, and they cite a small number of other studies that also suggest small effects. If spatial distortion costs are large and the impacts are long-lasting, small locational changes could still produce significant costs or benefits.

If the problem of optimizing the design of cordon tolls appears daunting, it does not follow that such schemes are not worth implementing. In their study of road pricing for eight British towns, Santos, Newbery, and Rojey (2001) found that the predicted benefits of optimal uniform cordon tolls considerably exceeded the costs of implementation in most cases, provided that the tolls were set correctly. The same appears to be true in Oslo (Larsen and Østmoe, 2001). Detailed investigation of Cambridge (reported in Newbery and Santos (2002)) suggested that the location of the cordon made a considerable difference, and, as a simple rule, maximizing the ratio of traffic terminating within the zone to that passing through (before the toll) increased the benefit–cost ratio. Other studies suggest that additional tolling of particularly congested isolated links can enhance benefits, as can combining cordon tolls with distance charges (though this is likely to require more-sophisticated equipment). One major argument for conducting simple road pricing trials (such as time-of-day cordon tolls) is to test the models that predict driver response and traffic improvement against the reality, as well as to test the political acceptability of road pricing. Refinements and improvements are likely to be simpler once the principle has been adequately tested.

7.4.1 *Integrating Local Road Pricing into a System of Road Charging*

Supposing that initial experiments with local area road pricing, such as cordon tolls, are successful, what would this imply for the overall design of road charges? Suppose also that total road charge revenue is capped and regulated, so any road pricing scheme that generates additional revenue will be associated with reductions in fuel duties and/or VED. This helps to ensure that road pricing commands sufficient voter support. In that case, urban road pricing schemes can be introduced wherever they are sufficiently cost-effective. Each selected town would have a compatible form of electronic charging, and all road vehicles would be equipped with the appropriate transponders to register these charges in whatever town they passed through.[7] As a starting point, road fuel taxes would then be set to cover the average long-run marginal cost of inter-urban roads for typical cars, with VED set to adjust total payments by typical vehicles in each size class to the costs they impose on inter-urban roads. Ideally, urban road prices would recover the remaining revenue.

As most practical forms of road pricing, such as cordon tolls, would only charge for part of the congested area, and as the net social benefits of tolls are sensitive to the level of the toll, there is no guarantee that the revenue collected will be the required amount. If road fuel taxes and VED are set correctly for inter- and non-urban roads, and if the road supply costs are not very much higher in urban areas, then these taxes alone would collect about the right total amount (because fuel efficiency is lower in urban congested areas). Additional road charges would risk exceeding the allowed revenue. If these taxes are set correctly just for inter-urban roads that are currently heavily used, they may not adequately cover the costs of lightly used rural roads, and the surplus from urban areas might balance out the shortfall from the non-strategic rural roads. Again, if the marginal cost of capacity expansion is very high in urban areas, the required revenue per vehicle kilometre may need to be substantially larger from urban roads than from inter-urban roads, and the road charges may help make up the shortfall.

In any case, the difference between the allowed or regulated revenue and that collected from the initial set of fuel taxes, VED, and road prices, either positive or negative, would then be collected from or returned to road users in the least distortionary way. This could be done by adjusting fuel taxes and VED. As a general rule, adjusting the fixed element, or VED, is likely to be more efficient. If there is a shortfall, increases in the VED would be regressive. Increasing the charge on fuel in practice means lowering current rates by less as road pricing is introduced, and is clearly simpler and more in line with willingness to pay for the public good of the road network. If the charges need to be reduced, then some reduction in VED may be attractive, though there is a limit to how much can be returned while retaining the ability to adjust total charges by vehicle class.

There is a significant practical transition problem of introducing urban road prices one town at a time (as is the plan in Britain). In the early years, the road prices would only cover a small fraction of the total vehicle fleet. If all road users continue to pay the old road taxes but some face additional road prices, they will be effectively overcharged and will surely resist the new road prices. Ideally, the revenue from the new road prices would be recycled to the set of road users affected in a non-distortionary way. Practical and politically acceptable schemes might provide transfers to car owners living within the political jurisdiction of the charging authority. The first priority would be to provide any metering equipment for free and provide it with a certain initial level of credit. Road improvements that directly benefit road users are an attractive solution that worked well in Oslo but will not always be available. Providing car-parking vouchers where parking fees are charged, or credits against annual licence fees, may exhaust the remaining credits. As road pricing becomes more prevalent, fuel taxes can be lowered and VED raised, so that the discounts against VED will be targeted on those facing road prices. Surprisingly little attention has been paid to the design of such transitional arrangements, which are likely to be critical for the public acceptability of road pricing.

7.5 CHARGING FOR OTHER EXTERNAL COSTS

Efficiency requires that road users pay the marginal external cost (for noise, pollution, accidents, etc.) that they impose on society. Again, the limited number of instruments available limits the usefulness of this textbook prescription. Logically, the first task is to identify and quantify the external costs, then establish the functional relationship between these costs and road (or fuel) use, and finally set the available taxes or controls at optimal levels. Note that this approach is potentially different from the requirement that road users pay the *total* amount of any social costs, unless, coincidentally, the marginal and average external costs are equal, i.e. damage is a linear function of road use.

Some environmental impacts may be very non-linear, in which case the marginal cost will be very different from the average. Noise pollution is a good example where the marginal cost is below the average cost – doubling noise levels has the same perceived nuisance cost at low and high levels (provided the levels remain below the threshold of physical damage). Increasing the number of cars on a quiet road from nine to ten per hour creates the same nuisance as increasing the number of vehicles from 900 to 1,000 per hour on a busy main road. Thus the marginal noise cost of an extra vehicle in the second case is only 1 per cent of that of the extra vehicle on the quiet road where traffic is only 1 per cent of the level on the main road.

7.5.1 *Accident Costs*

The number of road fatalities in Britain in 2000 was 3,409, of whom 997 were pedestrians, cyclists, or bus passengers. In addition, a further 38,000 people were seriously injured. The Department for Transport estimates the total cost of all road accidents as £17 billion, of which the 'human costs' that reflect willingness to pay to avoid the loss of life or injury amount to about half (Department for Transport, 2002). Some fraction will be an internal cost to the person causing the accident. The average fatal accident caused 1.1 fatalities, 0.41 serious casualties, and 0.5 slight casualties, so if the person causing the fatal accident were killed, the self-inflicted cost would be 87 per cent of the total. Seventeen per cent of fatal accidents involved only one car, and presumably created no external cost (other than grief to friends and relatives). Some costs (for example, to property, which accounted for £5.2 billion) are likely to have been covered by insurance and reflected in insurance premiums. Other costs are borne by the State (health service, police, etc.) and are included in the current estimates of road costs. The remaining costs are external costs visited upon other road users, some very asymmetrically, such as to pedestrians and cyclists. Some external costs are not recorded, and of these the consequential traffic congestion and delays may be appreciable (Arnott, 2002).

The next question is whether road users should be charged for external accident costs, or whether they are better dealt with in some other way (through the criminal justice system or by strict liability and insurance). Where the fault can be proven to lie with the motorist, then penalties or compensation seem appropriate, although there are obvious problems in compensating for death. Logically, the value of a life (£1.44 million in Britain in 2000) should be payable (by the insurance company) to the estate of the victim, though this does not appear to happen. The practical questions are what fraction of external costs are not reflected in insurance costs and how much should be related to distance driven (and weight of vehicle, via fuel taxes).

If, as with other elements of road charging, the aim is to influence behaviour (cause motorists to take proper care), then the question to ask is what is the extra external accident cost per kilometre driven (which is likely to vary with type of vehicle, location, and time of day). As with noise pollution, it is important to distinguish between average and marginal cost. In 1985, 5,165 road users were killed on the roads of Great Britain (Department of Transport, 1996, p. 84), equal to 16.68 per thousand million vehicle kilometres. Ten years later, in 1995, 3,621 road users were killed, or 8.40 per thousand million vehicle kilometres, almost as low as half the 1985 rate despite a nearly 40 per cent increase in traffic.[8] Increases in traffic do not seem to lead to increased numbers of accidents in total, though of course many factors are responsible for the considerable fall in the accident rate. More traffic lights, better vehicle and road design, more use of seat belts and air bags, better campaigns and more stringent enforcement against drinking and driving, and perhaps even slower speeds associated with more congestion have no doubt all contributed to greater road safety.

One less obvious factor is drivers' response to perceived risk – if roads seem more dangerous, drivers take more care, balancing the need to travel quickly against the desire to arrive in one piece. If so, more traffic on the roads makes overtaking and other potentially dangerous manoeuvres less attractive and less frequent, keeping down the total number of accidents even though vehicle kilometres driven increase. If this is indeed the case, then the marginal social cost of the increased risk of accident facing other road users as a result of an extra vehicle will be much lower than the average social cost of accidents.

Of course, the total social cost of accidents is still huge – at £17 billion per year, it amounts to more than half of total road taxes of £28 billion. The *average* accident cost of road fatalities on this estimate would be 3.4p/km or 33p/litre,[9] but the *marginal external distance-related* accident cost might be zero.[10] If all the non-motorist costs (excluding property damage) were attributed to motorists, the figure would be £3 billion per year or 6p/litre. If the likelihood of such accidents increases less than in proportion to traffic, only some fraction of this is attributable, while penalties and insurance costs might reduce this further. Finally, safety standards, such as air bags and survivability, increase the cost of driving and provide additional internalization of risk. There are further complications, discussed by Newbery (1988b) and Lindberg (2001), in allowing for the external costs to non-protected (or poorly protected) road users (such as pedestrians and cyclists), and possibly allowing for the suffering to friends and relatives (which, according to Lindberg, might add a further 36 per cent to total costs).

Lindberg (2001) summarizes the present state of theory and evidence. The number of accidents is proportional to traffic on inter-urban roads and urban links, but increases with traffic at intersections (giving rise to a positive externality, as the risk elasticity is between 0.25 and 0.45). Surprisingly, the risk of an accident with a non-protected road user *decreases* with traffic, and the risk elasticity is estimated to be -0.5. Lindberg estimates the marginal external cost in Sweden as 12 per cent of the average cost for non-urban cars, 33 per cent for urban cars, 33 per cent for heavy non-urban vehicles, and 40 per cent for heavy urban vehicles, though some part of these marginal costs will be paid through insurance. For cars, the external cost would justify charges of €0.14 per litre non-urban and €0.35 per litre urban. If these figures are translated and applied to Britain, the total charge would be £6 billion, but the accident rate is somewhat higher in Sweden. The figure seems high compared with the total cost to non-protected victims of £3 billion.

Newbery (1988b) estimated accident externalities at perhaps 25p/litre for cars (for 1985, when the accident rate was more than twice the 2000 figure, and using costs of accidents slightly higher in pounds than those used above). This estimate was based on very sketchy information about the risk elasticity, which was taken as 0.25. Halving the cost to reflect the fall in the accident rate would make it similar to Lindberg's estimate.

The conclusion is that accident externalities might be appreciable, but the appropriate level of charges might be considerably reduced if punishment and insurance charges already induce sufficient care. In the absence of convincing calibrated research, accident costs will not be added to the total road user costs, though their value is given in Table 7.2 later.[11] J1

7.5.2 *Implications of Paying for Environmental Damage*

The idea that road users (and others) should pay for environmental damage has far-reaching implications. To an economist, the obvious way in which road users should pay is through the tax system, as the environment is held in trust for all – there is no obvious owner to whom payments should be made other than the State acting as custodian. Taxes are not the only way, and, indeed, the idea of levying environmental (or 'green') taxes is a fairly novel concept in Britain. The normal way in which polluters have in the past paid is by being forced to undertake otherwise unattractive expenditures to meet mandated standards of quality. The most obvious example in transport is the vehicle emission standards that are set by the government for new vehicles. These require catalytic converters and/or more expensive electronic ignition, and improved fuel, but they have reduced particular emissions per kilometre by between one-half and three-quarters since 1993 (Department of Transport, Local Government, and the Regions, 2001, table 2.6). There are also a host of regulations about noise levels and safety standards (alcohol levels, vehicle lights, seat belts, road worthiness, etc.) designed to control the impact vehicles have on the environment and other road users (some literally). However, using green taxes, in addition to various standards, has a number of economic advantages and political attractions.

The political attraction of green taxes is clear – they are likely to command more support than other kinds of taxes. The main economic advantage of taxes that reflect the marginal damage is that they leave the user to decide how best to respond, rather than forcing him or her to make one particular kind of decision. They are also more accurately targeted to the damage caused, and therefore likely to be more effective at lower cost. Perhaps the best-known example is the higher tax on leaded than on unleaded petrol (gasoline). In 1993, 63 per cent of British motorists bought unleaded petrol, compared with only 5 per cent in 1988. Forcing all motorists to switch to unleaded petrol would have required major premature scrapping of older vehicles and would not have been politically acceptable. Just requiring new vehicles to be able to run on unleaded petrol would have discouraged the replacement of older vehicles, as the newer ones would require more expensive engines. Nor would it have provided any incentive actually to buy unleaded petrol. Discouraging replacement would have had a perverse effect on pollution, while not encouraging a fuel switch would have led to a smaller reduction than was possible.

If green taxes are to be both politically attractive and economically effective, they must be clearly distinguished from other taxes or charges, set at levels determined by acceptable methods of computing the cost of the damage done, and applied uniformly to all sources of the same damage. That is, environmental taxes should be *distinct*, *non-discriminatory*, and *defensibly quantified*. These criteria pose considerable challenges and, if applied, would have radical consequences for fuel taxes more generally.

The principle that environmental taxes should be distinct carries particular force, as it virtually requires that other road taxes be treated as regulated charges for using road space. It forms part of the political compact with road users justifying the total level of taxes, and specifically any changes in those taxes.

7.5.3 *Non-Discriminatory Environmental Taxes*

Suppose that the government reviews road taxation and reforms the system to distinguish road charges from other forms of taxation, allowing for a separate category of green or environmental taxes, which charge for the environmental damage caused by road users. Unless these taxes were applied in a non-discriminatory way, the full benefits to the environment would not be realized, and the justification for imposing environmental taxes on transport would be undermined. Let us take three simple examples of air pollutants caused by transport: greenhouse gases (GHG), mainly carbon dioxide (CO_2), the main cause of global warming; nitrogen oxides (NO_x), a precursor of acid rain; and particulates (PM_{10}), which cause increased mortality.

Figure 7.3 shows the share of road transport in the total production of these (and other) air pollutants in the UK in 1999. Clearly, road transport is a major contributor to the total emissions of these three pollutants (and also of volatile organic compounds (VOCs), though not of sulphur dioxide (SO_2), the other main cause of acid rain). However, except for carbon monoxide (CO), road transport causes less than half the UK's emissions, and in the case of GHG – singled out as the reason for fuel tax increases – only 22 per cent of the total (though one of the fastest-growing components).

It follows that to tax only transport emissions would involve a very partial and discriminatory environmental tax policy. Carbon taxes have been advocated as one of the simplest forms of green taxation, for they can be imposed very precisely on the source of the problem – the carbon content of the fuel, which is easily measured and completely defines the damaging potential of the CO_2. Such carbon taxes have been proposed by the EU, but were soundly rejected by the Trade and Industry Committee of the House of Commons

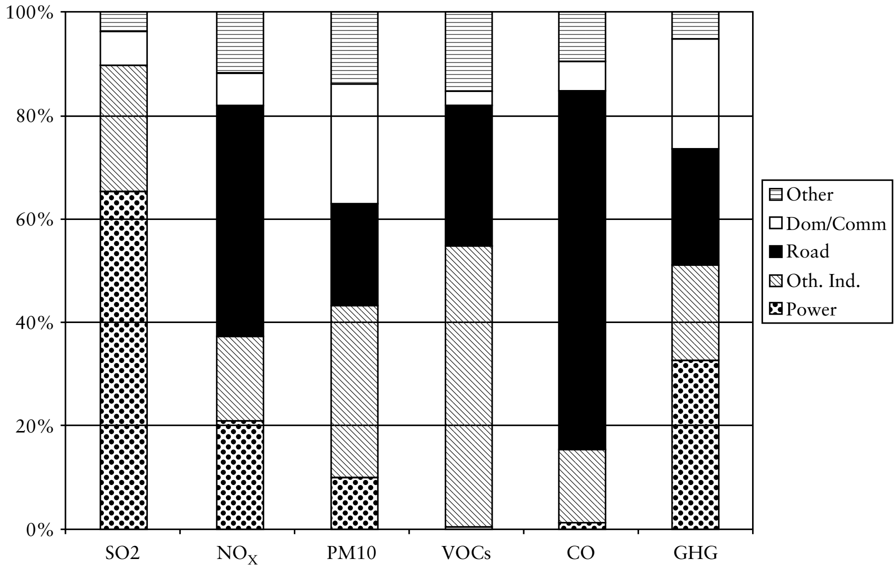

Figure 7.3. *Sources of Air Pollution: UK, 1999*

when it came to examine the market for coal, as being likely to accelerate the decline of the British coal industry. Since then, the Conservative government has been defeated in its attempt to raise VAT on domestic energy from 8 per cent to the standard rate of 17.5 per cent, while the new Labour government has actually reduced the rate to 5 per cent, thus effectively subsidizing domestic gas and electricity use by 12.5 per cent. It then introduced a climate change levy on all forms of electricity generation except renewables, thus taxing non-GHG-emitting nuclear electricity, and taxing electricity generated by low-carbon-containing gas at the same rate per kWh as the considerably higher carbon content of coal- and oil-fired generation. Again, domestic customers were exempted.

British tax policy towards greenhouse gases is thus in a state of disarray. To put the imbalance in the treatment of different fuels in perspective, until recently the British government raised the excise tax on road fuels *each year* by 5 per cent above the rate of inflation. The annual increase of about 3 p/litre amounts to £47/tonne carbon or $US75/tonne carbon, or nearly $10/barrel, which was the original suggested *total* EU carbon tax (and only half was to be on the carbon content of the fuel, the rest being on the energy content).

Matters are perhaps slightly more even-handed with NO_x, for the power generation and industrial sectors are subject to emission limits which force them to install improved combustion controls or catalytic converters, much as is the case with vehicles (though the cost-effectiveness of reducing NO_x emissions from stationary sources is considerably higher than that for small mobile sources such as vehicles). The same is true for particulates, though for the wrong reason – they are not subject to much control, except when they are from large combustion sources.

If environmental taxes are to be employed as part of a decentralized market-friendly environmental policy, then some of these more obvious imbalances across fuels and sectors will have to be addressed for this element of the total road charge to be defensible.

7.5.4 *Quantifying the Size of the Environmental Costs of Transport*

If environmental taxes are to be justified as correcting externalities, these will have to be quantified. Where the environmental damage can be measured, valued, and attributed to particular causes, then the principle is clear – set the tax equal to the marginal cost of the damage caused and levy it in a way that gives the clearest signals to the polluter responsible. The results of the analysis below are summarized in Table 7.2, and their implications for tax rates in Table 7.3, later.

Global Warming

The only pollutant that is simply related to fuel consumption is CO_2, where there is a direct relationship between fuel used and damage done. The logical tax is a carbon tax on all carbon-containing fuels. Determining the correct level is highly contentious, and the answer depends on the precise question asked, quite apart from any difficulty in quantifying the damage done. Is the tax to be set equal to the global marginal damage on the assumption that all countries impose the same tax, or to the global marginal damage on the best prediction about what other countries may do (but still unselfishly counting all the damage done not just to the UK but to the rest of the world), or to the marginal damage to the UK, based on some view of the response function of other countries to its choice of tax rate? The three answers are likely to be very different.

Even if we agree on the question, there are wide differences between various estimates. Maddison et al. (1996) estimated the shadow prices of controlling the last unit of CO_2 released assuming optimal abatement, where the marginal cost is $US(1993)5.9/tonne carbon (tC). This is only slightly less than the cost assuming 'business as usual', calculated as $6.1/tC. European Conference of Ministers of Transport (1998, p. 70) cites estimates ranging from $2/tC to $10/tC, considerably below the EU's original proposed carbon tax discussed above. Tol et al. (2000) review various estimates and argue for marginal damage costs below $50/tC. The UK Department of the Environment, Transport, and the Regions decided in early 2001 to take as its working assumption a central estimate of $80/tC, with a range from $40 to $160. British road transport emissions were 36 million tC in 2000, implying a cost of £0.9–3.6 billion. It is worth noting that a carbon tax of $80/tC would amount to $53/tonne of coal, or rather more than 100 per cent of the international price. The Danish carbon tax introduced in 1992 was at a rate of 100DKK/tonne of CO_2 or \$38/tC, while Finland levied a carbon tax on all energy at about 500FMK/tC or \$70/tC, roughly twice as high. Parry and Small (2002) review the literature and select a central figure of \$25/tC, with range \$0.7–100/tC.

Even this modest range of citations suggests a range of almost 100:1, with preferred estimates differing perhaps by 10:1. However, even the high figure represents a small fraction of existing road fuel tax rates. There are 0.64tC/t gasoline (0.87tC per thousand litres), so a carbon tax of \$80/tC would be \$0.07/litre, about 0.7 cents/km, or less than 10 per cent of the 2000 UK petrol excise tax. While carbon taxes are potentially of central importance for other fuels, they are relatively small compared with EU road fuel excises.

The Health Costs of Vehicle Emissions

The transport pollutants that are most damaging to health are particulates, NO_x, lead, and SO_2 (though not in most developed countries, where transport fuel has very low levels of sulphur). In most developed countries, tailpipe emission standards on new vehicles have resulted in a dramatic reduction in total levels of road transport emissions, despite the continuing increase in traffic. Newbery (1998a) argues for estimating the social costs of the health effects of pollution by estimating the number of quality-adjusted life years (QALYs) lost through premature mortality and morbidity. These costs should then be compared with what it costs the taxpayer to enable the National Health Service (in the UK, or its counterpart in other countries) to achieve an extra year of quality life. The numbers used in the evaluation of transport should be consistent with numbers used elsewhere in health economics. This would enable the money raised in green taxes (which are mainly the costs of health damage) to be allocated to the National Health Service, which should be able to compensate for the quality life years lost through pollution by an equal saving of quality life years gained from improved health services.

Recent work presented at a United Nations Economic Commission for Europe (UN/ECE) symposium, 'The Measurement and Economic Valuation of the Health Effects of Air Pollution', suggests an encouraging convergence in estimates of the mortality effects of the more damaging pollutants.[12] Severe urban pollution reduces life expectancy, and a *permanent* increase in air pollution of $10\,\mu g/m^3$ of PM_{10} is estimated to raise the daily mortality rate by 1 per cent. That in turn would reduce average life expectancy in Britain by 34 days (weighted by the British age distribution and based on current age-specific mortality rates). In order to relate the loss of QALYs to the annual consumption of fuel, the correct calculation is the total loss of QALYs for a one-year increase in emissions, leaving future mortality rates at the zero emission level. Appendix 7.A shows that road transport may be responsible for $4.4\,\mu g/m^3$ of PM_{10} in Britain, reducing the loss of life expectancy per person exposed to 0.21 days per year of exposure. If we err on the high side and suppose that QALYs do not decrease with age (as they do), and take the exposed population as all 58 million people, the total number of QALYs lost by one year's traffic particulate emissions is 34,000.

The UK Department for Transport assumes a value of a statistical life saved (VoSLS) in traffic accidents as £1.44 million. The weighted average age of the victim of a fatal traffic accident if all are equally exposed is 38, and life expectancy is then 40 years. We can therefore take a statistical life as 40 QALYs, making the value of a QALY £36,000. The UK National Institute of Clinical Excellence was reported (*The Times*, 10 August 2001) as tentatively accepting a figure of £30,000 per QALY, suggesting a convergence on the valuation side. At £36,000/QALY, the cost of traffic pollution is £1.2 billion per year, negligible compared with road taxation of £27.5 billion in 2000–01 (excluding all VAT). This raises several interesting issues. For example, do we equate the 34,000 QALYs above with 850 statistical lives, and if so, does this mean that traffic pollution is 25 per cent as serious as traffic fatalities, of which there were 3,409 in 2000? One is inclined to think that pollution, which may reduce the life expectancy of a large number of people by a very small amount, is less socially costly than traffic accidents, which reduce the life expectancy of a small number of people by a large amount. If so, then the value of a QALY used above may overstate the pollution cost.

Earlier estimates, in Newbery (1998a), suggested a range of values for total air pollution costs of £0.6–3.6 billion, on average rather higher than here, but these pre-dated the UN/ECE evidence and the ability to make the detailed calculations shown in Appendix 7.A. Most (89 per cent in Britain) of this cost is attributable to diesel vehicles, and would amount to 5.6 p/litre of diesel (or 0.9 p/km) and 0.45 p/litre of petrol (or 0.04 p/km). Note that the particulate tax should be 40–50 per cent higher for pre-1993 vehicles than this average value and 50–80 per cent lower for post-1997 vehicles (with diesel cars experiencing the greater improvement). These figures do not include the cost of morbidity (which is not likely to be a large fraction of mortality costs), nor do they include other health costs attributable to other pollutants (which are also likely to be modest compared with particulate mortality costs).

This figure can be contrasted with the estimates from McCubbin and Delucchi (1999) for the USA, where the range for light (i.e. gasoline-powered) vehicles is 0.6–7.7 US (1990) cents/mile. This would be 0.5–6.8 US (2000) cents/km, and higher if all vehicles were included. Parry and Small (2002) select a central figure of 1.3 US cents/km, with a range of 0.3–6.3 cents/km, again for light vehicles. Again, these figures seem on the high side, given the recent downgrading of the health costs of transport pollution based on more careful assessments of effects on mortality rates.

The costs of other emissions are modest and are presented in Table 7.2. They are taken from Newbery (1998a) without further analysis, though the allocation across fuels in Table 7.3 is based on data from Department of Transport, Local Government, and the Regions (2001). Maddison et al. (1996) give higher values but they appear to be double-counting particulates, as they distinguish between direct (from mainly carbon in exhausts) and indirect (caused by nitrates and sulphates derived from NO_x and SO_2 emissions). The figures computed here are derived from measured concentrations of particulates, presumably from all sources.

Noise

Noise relationships are extremely non-linear and it is therefore incorrect to compute the total cost of noise and then apportion it to vehicles, as in Tinch (1995).[13] The approach adopted here is to take the traffic noise functions from Department of Transport (1988) and compute the extra noise arising from additional vehicles of different types on different roads. The details are given in Appendix 7.B. The intriguing feature of the noise relationship is the claim that noise costs are linear in decibels (more precisely, dB(A)), which are a logarithmic measure of noise intensity. Consequently, a 1 per cent reduction in traffic on a distant motorway is as valuable to those affected as a 1 per cent fall in traffic on a busy city street or a leafy suburb, for someone sitting outdoors facing the road or inside their double-glazed house. It follows that concentrating traffic on busy roads (such as the M25) reduces total noise damage, for transferring half the traffic on a minor road to a motorway might only increase traffic there by 5 per cent, reducing the cost of noise by 45 per cent. Newbery (1998a) estimates the average marginal cost of noise pollution at 0.2–0.36 p/km. The allocation across fuels in Table 7.3 reflects the higher noise nuisance of heavier (diesel) vehicles.

Water Pollution

Run-off from highways places a considerable load on sewage systems, and a considerable part of that is directly attributable to road traffic. The UK figure for this source of water pollution is 15 per cent of the total cost of sewage treatment, estimated in 1995–96 as £3 billion per year. The marginal cost could be lower, though the capital value of the water infrastructure used to determine costs greatly understates its replacement value, so the long-run marginal costs of total sewage handling would be higher, perhaps as high as £8.9 billion. Some part of highway run-off would take place regardless of traffic, though the extra foul water caused by vehicles puts additional stress on sewage treatment. Newbery (1998a) takes these figures to give a range of £0.5–1 billion per year or 0.1–0.2 p/km, while Delucchi (1997) estimates costs of 0.05–0.13 p/km, which are similar.

7.5.5 *Charging for Environmental Damage*

Tables 7.2 and 7.3 collect together the various estimates of costs and express them in charges per kilometre or per litre of fuel. In some cases, the costs correlate more closely with fuel than with distance (particularly for emissions).

Table 7.2. *Road User Costs and External Costs: Britain, 2000*

			£ billion
Central and local government road expenditure			
Capital expenditure			2.28
Recurrent expenditure			2.60
Accident costs borne by NHS			0.57
Estimates of various road costs	Low	High	Central
Interest on capital value	3.5	12	7.75
Depreciation	3	4	3.5
Other operating costs	0.5	1	0.75
Total road costs	7	17	12
External costs			
Accident	0	6	1.5
Air pollution:			
Particulates	0.6	1.8	1.2
Nitrogen oxides	0.1	0.3	0.2
Other	0.1	0.3	0.2
Global warming	0.9	3.6	1.8
Water pollution	0.5	1	0.75
Noise	0.9	1.7	1.3
Total environmental costs	3.1	8.7	5.45

Sources: See text and Newbery (1998a).

Table 7.3. *Road Charges and Taxes per Kilometre and per Litre: Britain, 2000*

Category	**Total (£ million)**	**Pence per kilometre**	**Pence per litre of petrol**	**Pence per litre of diesel**
Fuel tax	22,305	4.77	48.8	48.8
VED	5,415	1.16	13.0	8.9
Total	27,720	5.92	61.8	57.7
Road costs	12,000	2.56	25.2	25.2
Accident costs	1,500	0.32	3.2	3.2
Air pollution	1,600	0.34	1.2	6.6
Global warming	1,800	0.38	4.9	4.9
Water pollution	750	0.16	1.6	1.6
Noise	1,300	0.28	3.1	2.1
Total (excluding accident costs)	17,450	3.7	36.0	40.4

Sources: Tables 7.1 and 7.2; Department of Transport, Local Government, and the Regions, 2001.

Pollution damage also varies widely across different vehicles of the same type, raising the question of what form of averaging is appropriate. Fairness (and political support) suggests that the level of charges should not be such that most transport users pay more than the damage done, and that suggests setting any taxes at the rate appropriate for the *median* vehicle user, which may be about half the *average* level.[14] What, then, to do with those who greatly exceed this representative level of damage? There are two possibilities – one is to impose extra charges (or offer rebates to those who meet the standards of lower emissions) and the other is to set standards with penalties for exceeding them.

The main problem with all transport pollution taxes is that the link between cause and effect is not very close. Most of the damage is done as a consequence of emissions, and hence related to distance and fuel use, but the damage per litre of fuel varies widely across vehicle types and ages. The only current instrument in the UK that can be adjusted to the type of vehicle is VED, which is a fixed charge, independent of distance. Vehicle excise duty rebates to lorries have been used to encourage the use of low-emission technology, so the principle has been accepted in the UK at least. The problem is that high fixed charges and low variable charges encourage higher mileage and hence more emissions than the correct vehicle-specific variable charges. Vehicle excise duty rates for cars and light vehicles for vehicles first registered after 2001 are differentiated by CO_2 emissions (g/km) and fuel type, which seems perverse given the greater suitability of fuel as the base of a straight carbon tax.

Parry and Small (2002) argue that emissions damage is proportional to distance driven, rather than fuel consumption, as emissions standards are set in grams per kilometre driven, not grams per litre of fuel. Higher fuel taxes lead to a reduction in distance driven and an increase in fuel efficiency (largely through vehicle choice), with the two effects contributing roughly equally. Taxing fuel is therefore rather an inefficient way of taxing for distance travelled, and hence a doubly indirect instrument for pollution damage (except for carbon taxes). This argument ignores the greater emissions per kilometre of heavier vehicles, and simple calculations show that emissions per litre are more stable across vehicle types than emissions per kilometre. Taxes per litre are simpler than charges per kilometre, although the Swiss government imposes distance (and vehicle-specific) charges for heavy vehicles (Suter and Walter, 2001).

Santos and Newbery (2001), reporting results from Santos, Rojey, and Newbery (2000), examine the effect of cordon charges on pollution and find an extremely close relationship between the congestion and environmental benefits of cordons, at least up to the optimal level of the cordon charge. Their paper examines eight different pollutants – carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_x), particulates (PM), methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3), though only health impacts and global warming effects were valued in the cost analysis. They also find that environmental benefits are a small fraction of the congestion benefits (typically between 1 per cent and 9 per cent across towns and taking a wide range of values for the costs of emissions, with the high value considerably above those defended above).

If road pricing is introduced, then the road charging system can be adapted to levy vehicle-specific charges, but until then any pollution taxes will be relatively crude. It follows that other instruments are likely to be needed as well. Such methods will probably include setting emissions standards not just for new vehicles, but also for existing vehicles, with spot checks for enforcement and fines for exceeding the levels set (perhaps continuing on a daily basis until an emissions test indicates that the underlying problem has been addressed). Other solutions might be to license polluting vehicles only for rural use or to ban vehicles that lack a 'green' licence plate from entering large urban areas on days of high pollution. In windy developed northern cities, such complex solutions are unlikely to be cost-effective.

Accident externalities are even more problematic (Calthrop and Proost, 1998; Jansson, 1994; Johansson, 1997; Newbery, 1988b; Lindberg, 2001). The relationship between distance travelled and accident rate is not well understood, nor do we know how those who are involved in accidents might respond to various disincentives. Taxing fuel is indirect, though it may partially capture the higher external costs of heavier vehicles, which transfer more of the impact to lighter vehicles, but it fails to deal with variations across drivers. The approach consistent with internalizing externalities would be an *ad valorem* tax on the component of car insurance that covers accident costs (as opposed to theft, etc.). Elsewhere, such ideas have been criticized as encouraging drivers to avoid taking out insurance.

7.6 OPTIMAL TAX ARGUMENTS FOR ADDITIONAL ROAD USER TAXES

The theory of optimal taxation sets out conditions under which commodity tax rates should be uniform, in which case there would be no case for differential commodity taxes. These conditions are stringent but in many cases difficult to reject empirically (Deaton, 1987). If there is an optimal non-linear income tax, individuals differ only in the wage rate, and the direct utility function $u(.)$ has goods, $\boldsymbol{x}$, weakly separable from labour, L, (so $u(\boldsymbol{x}, L) = u\mathrm{N}(\boldsymbol{x}), L)$, then optimal indirect taxes are uniform (Mirrlees, 1979; Stern, 1987).

Weaker conditions not assuming optimal income taxation apply with linear Engel curves and weak separability between leisure and goods (Deaton and Stern, 1986). The argument that separability removes the case for differential commodity taxation is that, in such cases, the only determinant of the supply of labour is the cost of goods consumed, and this is minimized when relative prices are undisturbed. The case for differential commodity taxes therefore requires that separability breaks down, in which case there is an argument for more heavily taxing goods that are complementary with leisure (Corlett and Hague, 1953).

Parry and Small (2002) use this argument to identify the 'Ramsey' tax element or the additional taxation justified by the impact of road user charges on labour supply. They argue that if leisure is weakly separable in utility, then personal travel is a relatively weak substitute for leisure if the expenditure elasticity for distance travelled is less than one (which, in developed countries, is normally the case). That provides a case for relatively higher taxes on travel, but there is an additional effect to consider. Congestion increases the costs of travel to work, and road prices that reduce congestion therefore increase labour supply and hence reduce the distortionary costs of labour taxation. It follows that there is an additional benefit from reducing congestion over and above the pure efficiency effect, justifying yet more gasoline taxation. If diesel is primarily used for commercial purposes, then there would be no comparable case for additional diesel taxes.

Parry and Small (2002) estimate that the Ramsey component of the optimal gasoline tax would be 6–7 US cents per litre and the congestion feedback would be 0.3–2 cents per litre (the low figure being for the USA, the high figure for the UK). Together, they amount to about one-quarter of the optimal gasoline tax rate. These estimates ignore redistributional effects, which raises serious problems, at least in developed countries, as fuel consumption is relatively income-inelastic. Optimal commodity taxes that may score well on efficiency grounds may do poorly on equity grounds, and in some cases the effects almost entirely cancel out. Mayeres (1999) examines distributional considerations in an applied general equilibrium model of transport in Belgium and finds that if extra fuel tax revenue is used to reduce labour taxes, then, as expected, the rich benefit. On the other hand, recycling fuel tax revenue through lump-sum transfers reduces this effect, and that is the relevant comparison for an optimally designed tax system, where marginal adjustments should be made to the lump-sum element. Much depends on how the government sets taxes, and optimal tax theorists may be placing unjustifiable confidence in the Benthamite credentials of the finance minister.

There is a related literature arguing that corrective taxes (such as environmental taxes) need to take account of distortions elsewhere in the economy (Bovenberg and Goulder, 1996). Newbery (1992) argues that if fuel taxes are used to charge for road use and congestion, then total road taxes should rise by more (perhaps 20 per cent more) than the pure carbon tax, as the carbon tax will induce greater fuel efficiency and hence reduce the tax base on which the road charges are set. Parry and Small (2002) make a similar point, though they estimate rather larger effects. As we have argued that the environmental component of taxes is modest, these corrections are less important.

7.7 ASSESSMENT

Table 7.3 shows that justifiable road user charges for Britain in 2000 are 2.6 p/km. This translates into 2.1p/PCUkm (PCU = passenger car units, the appropriate measure of road space demands and congestive effects). This is equivalent to 25 p/litre of fuel, although it would be more appropriate to relate this more accurately to vehicle type (and hence fuel) and rely on VED to improve cost-targeting. Other externalities (ignoring accidents) were estimated at 0.7–1.9 p/km, with a preferred value of 1.2 p/km. Allocating this by fuel would justify green taxes of 11 p/litre on petrol and 15 p/litre on diesel. These might be somewhat reduced to reflect lower emissions from post-1997 vehicles if higher VED rates on older vehicles were imposed in compensation. Accident externalities might add as much as 13 p/litre, though our (weakly) preferred rate is 3 p/litre. Parry and Small (2002) estimate these as 21 US cents per US gallon or about 4 p/litre, with the accident component about the same size. Green taxes might therefore increase road charges by 45 per cent on average. The pure road charge and green tax elements would amount to 36 p/litre for petrol and 40 p/litre for diesel (€0.6/litre and €0.67/litre respectively) in Britain. If this applied generally across the EU, the Netherlands and Germany would be taxing gasoline at about the right rate and only the UK is overcharging gasoline (see Figure 7.1). All countries except the UK are probably undercharging diesel.

The most controversial element is the 'optimal tax' component, whose value depends sensitively on preferences (specifically, the various elasticities, which are hard to measure), the tax instruments available (road prices versus fuel taxes, optimal income taxes versus proportional labour taxes), and the social welfare function (attitudes to inequality). In practical terms, the British Chancellor of the Exchequer, attempting to justify the current excessive petrol tax rates, might appeal to such arguments (indirectly, by arguing that they are necessary to finance public services such as health and education). It seems doubtful that the US Congress would pay much heed to such arguments, given that the rest of the tax system is hardly a model of the relentless application of Benthamite social welfare optimization.

More to the point, the spirit of building up a defensible cost-based charging structure for road use, combined with general green taxes that apply equally to all pollutants, is contrary to an approach that singles out road use for delicate optimal tax adjustments. Given that the additional tax that might be justified is only a further 30 per cent on top of the road charge and green element, and given the large uncertainties about almost all components of the total, it is difficult to accept that the modest social welfare benefits of such corrective taxes are worth sacrificing the clarity of the approach advocated here.

Arguably the most important aspect of a systematic approach to designing road charges is the philosophy of regulating total revenue, which encourages revenue-neutral adjustments to improve efficiency by shifting over to better-targeted congestion taxes such as cordon tolls and road pricing. Perhaps even more important, once the revenue stream is identified and subject to independent economic regulation, road finance can be put on a sound footing, with even larger potential improvements in transport and economic efficiency (Newbery, 1998a, 1998b).

APPENDIX 7.A: THE HEALTH COSTS OF VEHICLE PARTICULATE EMISSIONS

The most damaging vehicle emissions are particulates, usually measured by PM_{10} and mainly produced by diesel vehicles. Emissions increase the risk of mortality. The hazard rate, h, (the 'force of mortality') can be estimated from the annual number of deaths, d, of people of a given age, divided by the mid-year population of that cohort, m, so that $h = d/m$ (Miller and Hurley, 2002). The probability of surviving to the end of the year, s, assuming that the hazard rate is constant over the year, is then the ratio of the numbers of that cohort surviving to the end of the year, $m - \frac{1}{2}d$, over the number at the start of the year, $m + \frac{1}{2}d$. This can be rearranged to give $s = (2 - h)/(2 + h)$.

The evidence suggests that the increase in hazard rate is linear in pollutants, so that if in one year pollution increases, the hazard rate will increase to $h' = h(1 + \theta)$. We are interested in relating the mortality impact to the emissions in a single year, which in turn can be related back to the level of traffic in that year, so a single-year change is appropriate. The hazard rate varies with age, a, and can be approximated by an exponential function (which fits extremely well above the age of 30; below that, hazard rates are low in any case). For our purposes, we are interested in the impact of pollution on life expectancy, and particularly on the expected number of QALYs (quality-adjusted life years). The value of QALY per year decreases with age, but we ignore this effect and assume any change in life expectancy is an equal change in QALYs. This will exaggerate the impact of pollution slightly. Let the expected life of a person aged a be L_a and the proportion surviving the year be s_a. Life expectancy of someone dying in the year is taken as half a year, and otherwise survival brings the life expected of a year-older person, giving the recursion relation

$$L_a = s_a(1 + L_{a+1}) + \frac{1}{2}(1 - s_a). \tag{1}$$

The effect on life expectancy of an increase in s_a to s_a' is then

$$\Delta L_a = (s_a - s_a')\left(\frac{1}{2} + L_{a+1}\right) = -\theta h_a\left(\frac{1}{2} + L_{a+1}\right). \tag{2}$$

This can be summed over the population, weighting the change in life expectancy by the number of people exposed of that age. The information to make this calculation is available from population statistics, and ONS (2001, section 5) contains the relevant data. As risks are linear in pollution, it is legitimate to take average values, provided the population over which the average is taken has the same pattern of life expectancy.

Many countries monitor concentrations at various sites and identify the contributing sources. Thus for the UK in 1999, 20 per cent of total PM_{10} emissions came from road transport sources, while the annual average concentration of PM_{10} was 20 $\mu g/m^3$ measured at two rural sites, 23 $\mu g/m^3$ in twenty-five urban central and industrial sites, 22 $\mu g/m^3$ in fifteen urban background and four suburban sites, 27 $\mu g/m^3$ at four busy roadside sites, and 37 $\mu g/m^3$ at three city-centre kerbside sites, averaging 22 $\mu g/m^3$.[15] The country-wide average of pollution caused by traffic is then 20 per cent of 22 $\mu g/m^3 = 4.4\ \mu g/m^3$.

It may be that rural traffic contributions to pollution are small, and urban contributions high, as Maddison et al. (1996) argue. Rather than compute the traffic proportion by location and then sum over the affected population, it seems more direct to take the country average share of traffic as 20 per cent, take the country-wide average pollution level, and apply this to the total British population in 1999 of 58 million, relying on the linearity of the damage equation above.

The next step is to relate changes in pollution to changes in hazard rates. The estimated effect of an increase of $10\,\mu g/m^3$ in pollution is to raise the daily mortality rate by about 1 per cent (Maddison et al., 1996). Somewhat later estimates from highly polluted developing countries suggest figures as high as 1.3 per cent ($\pm$ 0.5 per cent), the average value found for Bangkok (EF&EE, 2002, p. 5). Thus UK traffic pollution might account for increased mortality rates of $1\% \times 0.44 = 0.44$ per cent, raising mortality rates by a factor of 1.0044 at all ages, and making $\theta = 0.0044$.

This number is in itself hard to interpret, and it is not clear whether it is large or small. In fact, it is very small in terms of reduced life expectancy per person. Using the formula above, the average reduction in life expectancy of a single year's traffic pollution is 0.21 days. The total number of QALYs lost by one year's traffic pollution in Britain is therefore 58 million $\times$ 0.21/365 years = 34,000 QALYs. At £36,000 per QALY, this amounts to £1.2 billion per year.

Figure 7.A1 shows why the reduction in life expectancy is so small.[16] It shows the effect of a 10 per cent increase in mortality rates (corresponding to an increase of pollution of $75\,\mu g/m^3$ for ever in a developing country, rather than $4.4\,\mu g/m^3$ for one year). Mortality rates are so low for most people that a 10 per cent increase in the *rate* is barely perceptible (note that it is not an

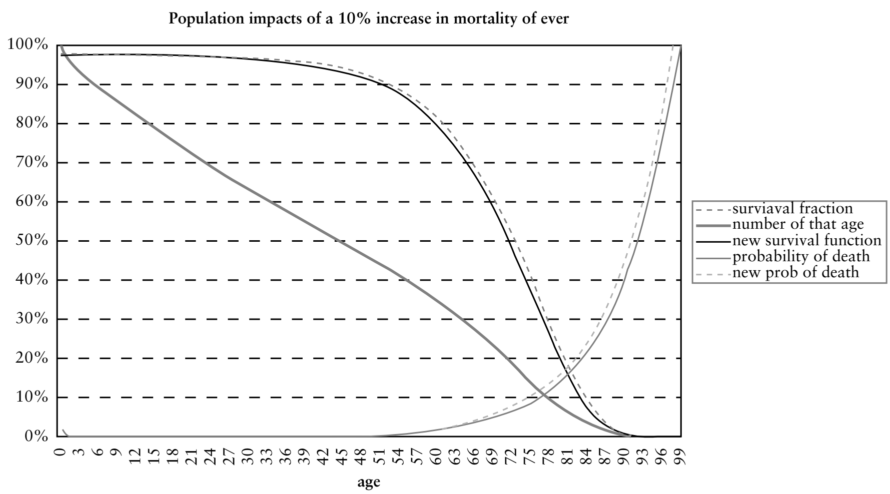

Figure 7.A1. *Effects of a Permanent Increase in Pollution of 75 $\mu g/m^3$: Population Impacts of a 10 Per Cent Increase in Mortality for Ever*

increase to 10 per cent, which would be shockingly high). The shift in the mortality rate to the left is only visible at advanced ages and high background mortality rates, where the fraction of the population at risk is also very small.

APPENDIX 7.B: THE MARGINAL SOCIAL COST OF VEHICLE NOISE

The basic equation for the eighteen-hourly average value of L_{10} (which is the average value of the hourly L_{10}, itself defined as the noise level in dB(A) which is exceeded only 10 per cent of the time) is

$$N = 4.343 \ln Q + 14.33 \ln (v + 40 + 500/v) + 3.343 \ln (1 + 5p/v) - 38.9, \quad (3)$$

where N is noise in dB(A), ln is the natural logarithm, v is speed in kilometres per hour, $Q = C + F$ is the eighteen-hour traffic flow in vehicles (C is the number of cars or equivalent light vehicles and F is the number of heavy vehicles), and p is the percentage of heavy vehicles in the flow ($100F/Q$). There are additional additive corrections for distance (these values are at the roadside) and barriers or reflections, which are not relevant to the calculations we need to perform.[17]

J2

The effect of increasing the number of vehicles, Q, without changing the proportions of heavy vehicles, p, or their speed[18] can be found by differentiation:

$$\frac{dN}{dQ} = \frac{4.343}{Q}, \quad (4)$$

from which it follows that a 1 per cent increase in traffic (i.e. $\Delta Q/Q = 0.01$) leads to an increase in noise, ΔN, of 0.0434dB(A). Tinch (1995) suggests that the best estimate for the willingness to pay for a 1dB(A) improvement is £7.75/head ($\pm$ £2.25) at 1995 prices, or £9.15 at 2000 prices. Taken literally, this would suggest that a 1 per cent increase in traffic would cost each person 40 pence per year or £23 million for the extra 4.7 billion vehicle kilometres, or 0.5 pence per vehicle kilometre. The intriguing feature of the noise relationship, and the claim that noise costs are linear in dB(A), is that a 1 per cent reduction in traffic on a distant motorway is as valuable to those affected as a 1 per cent fall in traffic on a busy city street or a leafy suburb, for someone sitting outdoors facing the road or inside their double-glazed house. The damage done from a proportional increase in traffic everywhere is also proportional to the affected population, which is here taken as 58 million (i.e. everyone).

These implications encourage a degree of scepticism. The figures might reasonably be halved, as not all the population is likely to be really troubled, since as noise gets worse, so people take evasive action (deciding where to take their weekends or whether to install double glazing, etc.). A more important implication is that transferring traffic from less to more heavily trafficked roads reduces total noise (as the reduction would be a greater percentage of a smaller number than the increase would be of the larger number). Provided that not too many more people are affected by the busier road, there will be a net saving in noise costs. Transport corridors and very-high-capacity motorways are therefore environmentally advantageous.

The next step is to apportion the costs between light and heavy vehicles, as their contributions interact in a rather complex way. Differentiate (3) with respect to the number of cars, *C*, and heavy vehicles, *F*, holding other vehicle numbers constant, to give, after some simplification,

$$\Delta N = 4.343\left(1 - \frac{p}{100}\right)\left(\frac{1}{1 + 5p/v}\right)\frac{\Delta C}{C} \tag{5}$$

for cars and

$$\Delta N = 4.343\left(\frac{p/100 + 5p/v}{1 + 5p/v}\right)\frac{\Delta F}{F} \tag{6}$$

for heavy vehicles. This has the implication that a 1 per cent increase in heavy vehicles creates less increase in noise than a 1 per cent increase in light vehicles in towns if the traffic speed is 50 kph and the percentage of heavy vehicles, p, is less than 9 per cent, or on motorways if $v = 100$ kph and p is less than 15 per cent. Put another way, an extra heavy vehicle at these critical proportions is respectively eleven or seven times as noisy as an extra light vehicle.

As the division between vehicle types depends very much on the level of traffic, the speed, and the percentage share, p, the final estimate was based on a sample of roads of differing characteristics (flow, speed, traffic composition), and the effect of a 1 per cent change in each vehicle type was averaged over these sample roads, resulting in the 9 per cent of vehicle kilometres by heavy goods vehicles (HGV) and buses accounting for 30 per cent of the total marginal cost of noise. At 2000 traffic levels and prices, the marginal cost of a car is 0.4 pence per kilometre (taking the high value of exposed population, or half that for a more cautious assessment) and of an HGV is 2 pence per kilometre (or, more cautiously, 1 penny per kilometre).

Notes

1 Eichenberger (1999, 2002) argues that the form of political institutions will influence the level and type of road taxation that will be acceptable to the electorate. The very large differences in road tax rates in North America and Europe reflect differences in the political process (as well as inertia in tax design).

2 Small (1999) notes the importance of the distinction between economies or diseconomies of scale (which refers to decreasing or increasing unit costs with output) and returns to scale (which refers to the increment of output when all inputs are increased by the same physical proportion). There can be constant returns to scale but if some inputs (such as land) are scarce and only made available at increasing unit price, while others are supplied at constant price, then overall there will be increasing unit costs.

3 For potentially profitable utilities. Railways were less successful as they required the regulator to be able to impose charges that could only be met by public subsidy.

4 Telecoms provide an interesting exception, as the regulated utility – BT – argued successfully for historic cost accounting.

5 Prices are capped by a formula that is indexed to the retail price index, RPI, *less* a productivity term, X, *plus* an amount K to enable the industry to finance the heavy level of anticipated investment, so that the average price is capped by RPI $- X + K$. K thus anticipates the future increase in the RAB that the investment will bring about.

6 Arnott (2002) raises the further question about non-recurrent congestion, which on some estimates may account for half of total congestion. Electricity networks face a similar problem in that available capacity is stochastic, and line or plant failures can precipitate outages. The normal response is to build in a reserve margin and charge very high prices as this reserve falls and the loss-of-load probability increases. In congested urban areas, tolls may have to be set at higher levels than deterministic calculations suggest, or, alternatively, stochastic optimization may be required.

7 The London road charging scheme introduced on 17 February 2003 records and digitally transcribes number plates to match them up with prepayment, so other methods are feasible. See www.cclondon.com.

8 The number of serious injuries dropped even more. From 1995 to 2000, accident rates for cars have declined by a further 10 per cent (Department of Transport, Local Government, and the Regions, 2001, table 1.6).

9 Expressing the cost per litre allocates accidents more in proportion to vehicle weight, which is likely to be more accurately targeted.

10 Of course, the issue is more complex, for there is some cost in having to take more care as a result of the greater perceived risk, and this should be included. The fact that children are not allowed to play in streets and are driven to school rather than walking lowers the child accident rate but has a social cost. Although motorists may be better at avoiding killing each other, they are still killing cyclists and pedestrians at an alarming rate: the ratio of cyclists killed or seriously injured per million kilometres travelled to that of car occupants rose from 14.6 in 1984 to 21.6 in 1994 (Department of Transport, 1996, p. 13), while the ratio for pedestrians rose from 11.2 to 14.6. (That is, in 1994 the risk of being killed or seriously injured per kilometre travelled on a cycle was 21.6 times that in a car.) Improvements in road safety are therefore benefiting car occupants more than cyclists or pedestrians, though the accident rate (killed or seriously injured per kilometre travelled) has fallen for all – by 5.8 per cent per year for car occupants, 1.5 per cent per year for cyclists, and 3.3 per cent per year for pedestrians.

11 Arnott (2002) cites evidence that the partial elasticity of car insurance rates across US states with respect to traffic density is large and highly significant. Without being able to examine the evidence, it is hard to know what other variables might explain this or whether accident *rates* are correlated with traffic.

12 The Network of Experts on Benefits and Economic Instruments website of the conference is at www.unece.org/env/nebei. The symposium took place in London on 19–20 February 2001.

13 I am indebted to Paul Nelson of the Transport Research Laboratory and John Knowles of the Department for Transport for discussions on the measurement of traffic noise.

14 The median vehicle owner is the one for whom half the vehicles of that type are less polluting (and half more), and causes much less damage than the average, since a small fraction of vehicles appear to produce most of the pollution.

15 Department for Environment, Food, and Rural Affairs, 2001.
16 Another way to put this into perspective is to note that male mortality rates were uniformly more than 50 per cent higher than female rates in Britain in 1999 and 150 per cent higher for men aged 25–34, though female life expectancy is only 7 per cent higher despite women's considerably lower mortality risk.
17 For example, for a person at a distance *d* metres, the term $-\ln(d/13.5)$ is added. Presumably the use of average traffic flows implies that this is the relevant average noise for measuring average noise nuisance.
18 The conceptual experiment is thus across roads of similar traffic and speed. Clearly, increasing traffic is likely to reduce speed on any given road.

References

Arnott, R. (2002), 'Comments on "Road user and congestion charges" by D. Newbery', Boston College, mimeo, April.
Atkinson, A. B., and Stiglitz, J. E. (1980), *Lectures on Public Economics*, Maidenhead: McGraw-Hill.
Bovenberg, A. L., and Goulder, L. H. (1996), 'Optimal environmental taxation in the presence of other taxes: general equilibrium analyses', *American Economic Review*, 86: 985–1000.
Calthrop, E., and Proost, S. (1998), 'Road transport externalities: interaction between theory and empirical research', *Environmental and Resource Economics*, 11: 335–48.
Corlett, W. J., and Hague, D. C. (1953), 'Complementarity and the excess burden of taxation', *Review of Economic Studies*, 21: 21–30.
Deaton, A. (1987), 'Econometric issues for tax design in developing countries', in D. M. Newbery and N. Stern (eds), *The Theory of Taxation for Developing Countries*, New York, NY: Oxford University Press.
—— and Stern, N. (1986), 'Optimally uniform commodity taxes, taste differences and lump-sum grants', *Economics Letters*, 20: 263–6.
Delucchi, M. (1997), *The Annualized Social Cost of Motor-Vehicle Use in the U.S., 1990–91: Summary of Theory, Methods, Data and Results*, Davis, CA: Institute for Transportation Studies.
Department for Environment, Food, and Rural Affairs (2001), *Digest of Environmental Statistics*. Available at www.defra.gov.uk/environment/statistics/des/index.htm.
Department for Transport (2002), *Highway Economics Note No. 1: 2000*. Available at www.roads.dft.gov.uk/roadsafety/hen2000/index.htm.
Department of Transport (1988), *Calculation of Road Traffic Noise*, London: DoT.
—— (1996), *Transport Statistics Great Britain 1996 edition*, London: DoT.
Department of Transport, Local Government, and the Regions (2001), *Transport Statistics Great Britain 2001 edition*, London: DTLR.
Diamond, P. A., and Mirrlees, J. A. (1971), 'Optimal taxation and public production, I: production efficiency', *American Economic Review*, 61: 8–27.
Drake, G. (2000), *An Established Privatised Road Maintenance and Operation System: A Government Perspective*, London: Highways Agency.
EF&EE (2002), *Sri Lanka Vehicle Emissions Control Project: Inception Report*, Sacramento, CA: Engine, Fuel, and Emissions Engineering, Inc.
Eichenberger, R. (1999), 'Mit direketer Demokratie zu besserer Wirtschafts- und Finanzpolitik: Theorie und Empriie,' in H. H. von Arnim (Hrsg.), *Adäquate Institu-*

tionen: Voraussetzung für 'gute' und bürgernahe Politik?, Berlin: Duncker & Humbolt.
—— (2002), 'Road pricing: a political-economic perspective', University of Fribourg, mimeo.
Eliasson, J., and Mattson, L-G. (2001), 'Transport and location effects of road pricing: a simulation approach', *Journal of Transport Economics and Policy*, 35: 417–56.
European Conference of Ministers of Transport (1998), *Efficient Transport for Europe: Policies for Internalization of External Costs*, Paris: Organisation for Economic Co-operation and Development.
Jansson, J. O. (1994), 'Accident externality charges', *Journal of Transport Economics and Policy*, 28: 31–43.
Johansson, O. (1997), 'Optimal road pricing with respect to accidents in a second-best perspective', *International Journal of Transport Economics*, 24: 343–65.
Keeler, T. E., and Small, K. A. (1977), 'Optimal peak-load pricing, investment, and service levels on urban expressways', *Journal of Political Economy*, 85: 1–25.
Kraus, M. (1981a), 'The problem of optimal resource allocation in urban transportation', in B. Maurice and B. Ballabon (eds), *Economic Perspectives: An Annual Survey of Economics*, 2, New York, NY: Harwood Academic Publishers.
—— (1981b), 'Scale economies analysis for urban highway networks', *Journal of Urban Economics*, 9: 1–22.
Larsen, O., and Østmoe, K. (2001), 'The experience of urban toll cordons in Norway', *Journal of Transport Economics and Policy*, 35: 457–71.
—— and Ramjerdi, F. (1991), *Road Pricing as a Means of Financing Investment in Transport Infrastructure: The Case of Oslo*, Oslo: Institute of Transport Economics.
Lindberg, G. (2001), 'Traffic insurance and accident externality charges', *Journal of Transport Economics and Policy*, 35: 399–416.
McCubbin, D. R., and Delucchi, M. A. (1999), 'The health costs of motor-vehicle-related air pollution', *Journal of Transport Economics and Policy*, 33: 253–86.
Maddison, D., Pearce, D., Johansson, O., Calthrop, E., Litman, T., and Verhoef, E. (1996), *Blueprint 5: The True Costs of Road Transport*, London: Earthscan.
May, A. D., Bonsall, P. W., and Hills, P. J. (1998), *The Impacts of Different Road User Charging Systems: Proceedings of Transportation into the Next Millennium*, Singapore: Nanyang Technological University.
——, Milne, D., Shepherd, S., and Sumalee, A. (2002), 'The specification of optimal cordon pricing locations and charges', presented at the 81st Annual Conference of the US Transportation Research Board.
Mayeres, I. (1999), 'The distributional impacts of policies for the control of transport externalities: an applied general equilibrium model', Fondazione Eni Enrico Mattei (Global Network of Environmental Economists), Working Paper 8.99. Available at www.feem.it/web/activ/_wp.html.
Menon, A. P. (2000), 'ERP in Singapore: a perspective one year on', *Traffic Engineering and Control*, 41(2).
Miller, B. G., and Hurley, J. F. (2002), 'Life table methods for quantitative impact assessments in chronic mortality', *Journal of Epidemiology and Community Health*, 57: 200–6.
Mirrlees, J. A. (1979), 'The theory of optimal taxation', in K. J. Arrow and M. D. Intrilligator (eds), *Handbook of Mathematical Economics*, Amsterdam: North-Holland.
Mohring, H. (1970), 'The peak load problem with increasing returns and pricing constraints', *American Economic Review*, 60: 693–705.

—— and Harwitz, M. (1962), *Highway Benefits: An Analytical Framework*, Evanston, IL: Northwestern University Press.

Newbery, D. M. (1988a), 'Road damage externalities and road user charges', *Econometrica*, 56: 295–316.

—— (1988b), 'Road user charges in Britain', *Economic Journal* (Conference), 161–76.

—— (1989), 'Cost recovery from optimally designed roads', *Economica*, 56: 165–85.

—— (1990), 'Pricing and congestion: economic principles relevant to pricing roads', *Oxford Review of Economic Policy*, 6(2): 22–38.

—— (1992), 'Should carbon taxes be additional to other transport fuel taxes?', *Energy Journal*, 13(2): 49–60.

—— (1998a), *Fair Payment from Road-Users: A Review of the Evidence on Social and Environmental Costs*, Basingstoke: Automobile Association.

—— (1998b), 'Fair and efficient pricing and the finance of roads', the 53rd Henry Spurrier Memorial Lecture, *The Proceedings of the Chartered Institute of Transport in the UK*, 7(3): 3–19.

—— and Santos, G. (2002), 'Estimating urban road congestion charges', CEPR, Discussion Paper 3176. Available at www.cepr.org/.

Ofgem (2001), *Review of Transco's Price Control from 2002: Final Proposals*. Available at www.ofgem.gov.uk/temp/ofgem/cache/cmsattach/315_26sep01_pub1.pdf.

ONS (2001), *Annual Abstract*, London: HMSO.

Parry, I. W. H., and Small, K. A. (2002), 'Does Britain or the United States have the right gasoline tax?', Resources for the Future, Discussion Paper 02-12. Available at www.rff.org/disc_papers/2002.htm.

Santos, G., and Newbery, D. (2001), 'Urban congestion charging: theory, practice and environmental consequences', CESifo, Working Paper 568. Available at www.cesifo.de.

——, ——, and Rojey, L. (2001), 'Static vs demand sensitive models and the estimation of efficient cordon tolls: an exercise for eight English towns', *Transportation Research Board Record*, Record 1747, TRB, National Research Council, Washington, DC.

——, Rojey, L., and Newbery, D. (2000), 'The environmental benefits from road pricing', University of Cambridge, Department of Applied Economics, Working Paper 0020.

Small, K. A. (1999), 'Economies of scale and self-financing rules with noncompetitive factor markets', *Journal of Public Economics*, 74: 431–50.

Stern, N. (1987), 'The theory of optimal commodity and income taxation: an introduction', in D. M. Newbery and N. Stern (eds), *The Theory of Taxation for Developing Countries*, New York, NY: Oxford University Press.

Strotz, R. H. (1965), 'Urban transportation parables', in J. Margolis (ed.), *The Public Economy of Urban Communities*, Washington, DC: Resources for the Future.

Suter, S., and Walter, F. (2001), 'Environmental pricing – theory and practice: the Swiss policy of heavy vehicle taxation', *Journal of Transport Economics and Policy*, 35: 381–97.

Tinch, R. (1995), *The Valuation of Environmental Externalities*, London: Department of Transport.

Tol, R. S. J., Fankhauser, S., Richels, R., and Smith, J. (2000), 'How much damage will climate change do? Recent estimates', *World Economics*, 1: 179–206.

Van Vliet, D., and Hall, M. (1997), SATURN 9.3 – User Manual, Leeds: Institute for Transport Studies, University of Leeds.

Author Query

[J1] Is it OK to change 'traffic' to 'traffic levels' at the end of note 11?
[J2] In note 17, would 'Thus' be better as 'For example,' and should '$-\log(d/13.5)$' be '$-\ln(d/13.5)$'?