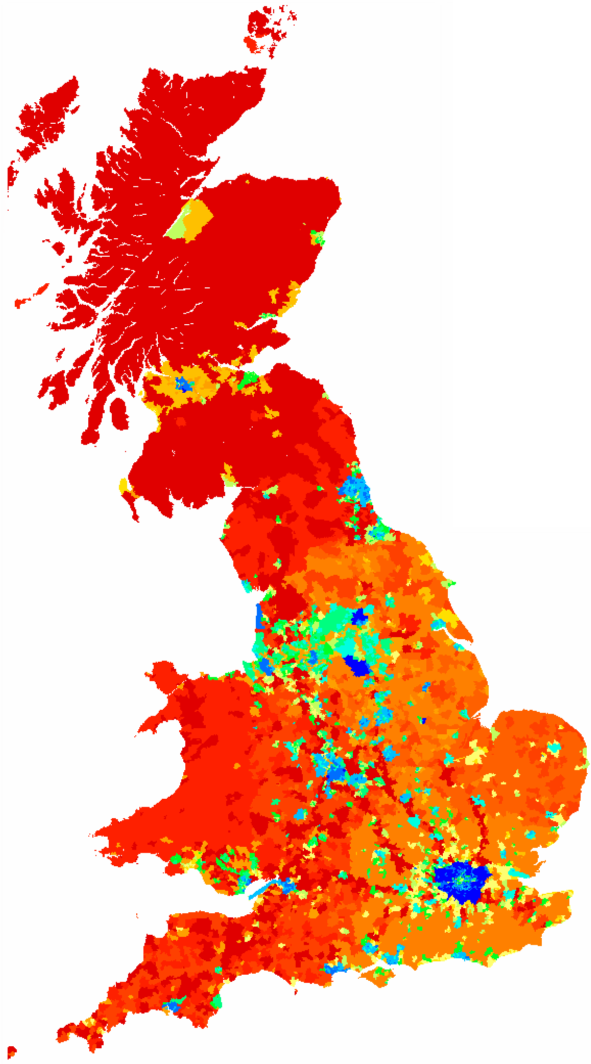
Investing in Roads: Pricing, Costs and New Capacity



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CONTENTS

Introduction

Great Britain needs more roads but would road pricing remove that need? After decades in which the volume of new road capacity has not kept pace with the volume of new traffic the shortages are certainly beginning to show: traffic congestion and travel unreliability is increasingly becoming an issue demanding the attention of politicians. Taken at face value conventional economic appraisals of many new road schemes show benefits exceeding costs to an extraordinary degree—there are few public investments offering such good value for money. The situation has arisen partly because governments over past decades have been swayed by the prospects of having to deal with objections to new road building and partly because of an unwillingness to find the requisite public funds. In the 2004 Transport White Paper the Government recognised that, in principle at least, road pricing offers a partial resolution—it would be a good way to manage traffic growth at busy times and thereby reduce the need for new capacity. It would also produce revenues that could be used for a variety of purposes – including reducing duties on road fuels, improving roads or improving public transport.

This study develops statistical estimates of costs of building roads in Great Britain in order to investigate how revenues from the prospective road user charges set out in our previous study (Glaister and Graham, 2006a) could be used as an indicator as to the case for investment in new road capacity, should those charges be in place.

Currently there is little published information concerning the costs of providing road capacity in Great Britain. A number of government and non government organisations have begun to analyse this problem, including the Highways Agency, academics and the Eddington Report group at the Department for Transport and the Treasury.

The problem of modelling the cost of capacity on roads is not new; before the technology existed to implement large scale road user charging, economists understood the potential benefits from using charge revenues to appraise investment in new capacity. The method used in this report draws upon these original studies. Models for construction, maintenance and land acquisition costs are developed empirically, as far as possible using statistical analysis of real project cost data provided by the Highways Agency. Where information is missing from the data, information is taken from existing indexes or estimated using design standards. Once models for construction maintenance and land acquisition costs have been developed, the annual rental cost of capacity is found by discounting the initial capital investment over the life of the road and including annualised routine and capital maintenance costs at appropriate intervals. Finally these annual costs for new roads are compared with revenues from road pricing.

The theory

The fundamental issue addressed in this paper is: given the road network expected in 2010, as modelled in Glaister and Graham (2006a), if a system of national distance-based charges were to be introduced, what would the revenues tell us about the case for expanding road capacity? In this section we discuss the principles of how this question can be approached by comparing charge revenues with road construction and maintenance costs.

The charges developed in Glaister and Graham reflect congestion and environmental damages, but they are not necessarily the same charges that would be levied by a (regulated) for-profit owner of the road network. Our approach here is essentially a "public interest" one: when "correctly" priced and invested to the "correct" scale roads may or may not cover their costs (that is, be profitable) depending on several factors, as we shall demonstrate. Note also, that there is more than one interpretation of correct, efficient pricing (see Glaister and Graham, 2004 for an illustration of some of the alternatives). For the purposes of this paper we use charges from "revenue additional" or "revenue neutral" scenarios analysed in Glaister and Graham (2006) and summarised below. These take the existing levels of taxation as given and derive charges that better reflect congestion and environmental damages as deviations from that base. A more "pure" approach, used by the UK Department for Transport, is to strip away current taxes currently in excess of normal rates of commodity taxation and build road user charges from that base. This will produce somewhat different – though qualitatively similar—charges. In particular, the overall total payment from road users may turn out to be different from today's total.

The particular technical problem we face is that the prices derived in a study of efficient road prices reflect the *marginal* social benefits of reducing road traffic and thus reducing traffic. These translate into revenue per kilometre of existing road. The costs of new capacity are essentially costs of scaling up the existing system using information from recent actual new road schemes. Under what circumstances does it make sense to compare the two? The economic theory of highway pricing and investment is well known. The exposition that follows is a generalisation of that in Small (1992).

Let the year be partitioned into H sub-periods, each of length

$$q_h,\ h = 1,2 \ldots H.$$

In our case H is 19.

The flow in passenger car units (pcu) per hour is each period is V_h. This is made up of several vehicle types:

$$V_h = \sum_{j=1}^{J} V_h^j$$

The cost per vehicle km. to vehicle type J at time h is $c_h^j(V_h;V_k)$ where V_k is a measure of physical road capacity. This will principally be comprised of direct vehicle operating costs and time costs.

We will assume that the $c_h^j(V_h;V_k)$ are homogeneous of degree γ_c Then by Euler's Theorem

$$\frac{\partial c_h^j(V_h;V_k)}{\partial V_h}V_h + \frac{\partial c_h^j(V_h;V_k)}{\partial V_k}V_k = \gamma_c c_h^j(V_h;V_k).$$

Small assumes $\gamma = 0$, with the implication that increasing flow and capacity in the same proportions would leave the costs faced by individual road uses unchanged.

For the moment assume that the physical infrastructure—and hence V_k —is fixed. The willingness to pay of each user group is given by $D_h^j(V_h^j)$. The demand curve expresses the number of users that would like to use the road at each money cost and this is its inverse. Thus

$$p_h^j = c_h^j + \tau_h \;\; and \;\; p_h = D_h^j(V_h^j),$$

where τ_h is the road user charge. Note that we are assuming all users are liable for the same charge per PCU, since τ_h does not carry a *j* superscript. Thus, a commercial vehicle with a PCU value of 3 would pay 3 times the charge paid by a car.

The total benefit is given by

$$B = \sum_j \sum_h q_h \int_0^{V_h^j} D_h^j(z)dz .$$

Total system cost is given by

$$C = \sum_h q_h \sum_j v_h^j \; c_h^j(V_h;V_k) + \rho K(V_k).$$

The latter term is the annual cost of owning the physical infrastructure corresponding to V_k.

Maximising $B - C$ with respect to V_h^j gives the first order condition

$$q_h - D_h^j\left(V_h^j\right) - q_h\left(\sum_j V_h^j \frac{\partial c_h^j}{\partial V_h}\left(V_h;V_k\right) + c_h^j\left(V_h;V_k\right)\right) = 0\,.$$

This implies that

$$\tau_h = \sum_j V_h^j \frac{\partial c_h^j}{\partial V_h}\left(V_h;V_k\right), \quad h = 1 \ldots H.$$

This condition states that at each time period the user charge per PCU km. should equal the total of all costs imposed on users of all types because of the extra congestion caused by one extra PCU km. It means that the total cost faced by each user type is

$$p_h^j = c_h^j\left(V_h;V_k\right) + \sum_j V_h^j \frac{\partial c_h^j}{\partial V_h}\left(V_h;V_k\right),$$

so every user faces the full, social cost of the decision to "consume" an extra PCU km; that is, their own, private cost plus the cost imposed on others.

Now consider the choice of capacity, V_k, on the assumption that these pricing rules are adopted. Benefit B, does not explicitly depend on V_k so the solution only involves minimising C above. The first order condition is

$$\sum_h q_h \sum_j V_h^j \frac{\partial c_h^j}{\partial V_k} + \rho K'\left(V_k\right) = 0\,.$$

But by Euler's Theorem, above

$$\frac{\partial c_h^j}{\partial V_k} V_k = \gamma_c c_h^j - \frac{\partial c_h^j}{\partial V_h} V_k\,.$$

So

$$\sum_h q_h \sum_j V_h^j \left(\frac{\partial c_h^j}{\partial V_h} V_h - \gamma_c c_h^j \right) = \rho K'(V_k) V_k \,.$$

Using the pricing condition for τ_h this becomes

$$\sum_h q_h V_h \tau_h = \gamma_c \sum_h q_h \sum_j V_h^j c_h^j + \rho K'(V_k) V_K \,.$$

Let

$$\gamma_k = K'(V_k) \frac{V_k}{K}$$

be the elasticity of the capacity cost function. Then the investment rule reads

Total charge revenue $= \gamma_c$ x total private costs $+ \rho \gamma_k K$.

One special case is particularly useful as a "benchmark": if $\gamma_c = 0$ (as assumed throughout by Small) and $\gamma_k = 1$ then

Total charge revenue = total capacity cost.

That is, in these circumstances the optimal capacity will be exactly paid for by the user charges. On the other hand, if there are increasing returns to providing capacity, γ_k < 1 (because cost goes up less rapidly than capacity does) it is optimal that

Total charge revenue < total capacity cost.

This is a familiar result: in the presence of increasing returns to scale in infrastructure provision it is optimal for revenues to fall short of costs.

Note that γ_c defines the relationship between marginal and average costs:

$$\gamma_c = \frac{K'(v)}{K/V} = \frac{MC}{AC}.$$

The pricing rules require the use of marginal costs, but our empirical work to follow is more akin to estimating average costs: γ_c makes the link between the marginal and the average.

Environmental Charges

Glaister and Graham included environmental charges as well as congestion charges. Let e^j be the environmental damage cost imposed on non road-users per PCU km travelled by user of type j. We assume this to be a constant. Then there is a new cost to be added to those identified before:

$$\sum_h q_h \sum_j e^j V_h^j .$$

The derivative of this with respect to V_h^j is

$$q_h e^j$$

and by analogy with the earlier analysis the optimum user charges become

$$\tau_h^j = \sum_j V_h^j \frac{\partial c_h^1}{\partial v_h}(V_h;V_k) + e^j .$$

Note that the user charges now depend on both the period in question (because of varying congestion conditions) and the type of user (because of varying environmental damage costs). As before, every user ends up paying their full social costs.

Turning to the capacity choice condition, since the new term in environmental costs does not depend on V_k the first order condition is unchanged. And, as before, after deploying Euler's Theorem the condition is

$$\sum_h q_h \sum_j V_h^j \left(\frac{\partial c_h^j}{\partial V_h} V_h - \gamma c_h^j \right) = \rho K'(V_k) V_k .$$

But now

$$\tau_h^j = \sum_j V_h^j \frac{\partial c_h^j}{\partial V_h}(V_h; V_k) + e^j$$

so the condition can be rewritten as

$$\sum_h q_h \left(\sum_j \tau_h^j . V_h - \sum_j V_h^j e^j - \sum_j V_h^j \gamma_c c_h^j \right) = \rho K'(V_k) V_k$$

or

$$\sum_h \sum_j q_h V_h \tau_h^j - \sum_h q_h \sum_j V_h^j e_j = \gamma_c \sum q_h \sum V_h^j c_h^j + \rho K'(V_k) V_k .$$

Therefore the investment role now reads

Total charge revenue net of total environmental costs

$= \gamma_c$ x total private costs $+ \rho\gamma_k K$.

All the previous conclusions remain unchanged, except that charge revenues are to be computed net of environmental costs.

Sumptuary taxation

Glaister and Graham's (2006) model took as its base traffic flows and fuel costs at current (2005) level. Charges were calculated as deviations from these base fuel costs. This causes an additional complication to the above analysis because fuel costs to the end user contain a large portion of sumptuary taxation. At the time of the study petrol was 80p per litre, of which 47p + VAT was fuel duty over an above the normal VAT on the producer-price. So duty + VAT on duty constituted 69 percent of the price paid by road users.

The question is, how to account for this in our evaluations the case for building new roads?

If every £1 of sumptuary taxation levied on fuel were spent on some form of public expenditure, yielding £1 of benefit, it could be argued that this transfer can be ignored. However, £1 of sumptuary fuel tax means that £1 less has to be raised through the conventional direct and indirect tax systems (assuming a given level of public expenditure). But the economic cost of raising £1 through the conventional tax system is more than £1 because of the distortionary effect of conventional taxes – call this $£(1+\beta)$. This is sometimes known as the shadow cost of public funds.

This consideration can be fitted into our formulation above as follows:- Let f^j be the expenditure on fuel per vehicle kilometre by of type j.

Now let α be the product of the proportion of fuel prices that is sumptuary taxation and the shadow price of public funds over and above the amount collected. Thus, if an 80p litre of petrol carries a duty of 47p + VAT at 17.5 percent and if the economic cost of raising £1 of tax revenue is £1.30 then

$$\alpha = \frac{47x1.175}{80}.\beta = \frac{47x1.175}{80}.0.3 = 0.207\,.$$

Then the total social cost of the road network identified above will carry an additional (negative) term:

$$-\sum_h q_h \sum_j \alpha f^j v_h^j\,.$$

This is exactly similar to the term representing environmental costs, with $-\alpha f^j$ written for e^j. Therefore, the analysis of the case with environmental costs stands, but with e^j replaced by $\left(e^j - \alpha f^j\right)$.

Discussion

We use these results in the following to derive pointers as to where there may be under-investment in the system. If the congestion cost relationship were homogeneous of degree zero and in flow and capacity, and if the capacity cost function had constant returns to scale (that is, capacity cost is proportional to capacity provided: capacity cost is homogeneous of degree one in capacity) then, neglecting environmental considerations, revenues should match capacity costs. If revenues exceed costs then there is *prima facie* case for expansion.

But this is a necessary but not sufficient condition because the analysis has assumed that capacity is continuously variable. To abstract from some of the problems of returns to scale and the "lumpy" nature of some types of road expansion we only consider here the case for adding a little more length to the existing roads in the database. This leaves open the question of *how much* new length would be justified, because as new capacity is added the prices would fall and one would have to recalculate to establish a final equilibrium.

In general there is a practical problem: if capacity is "lumpy"—because, for example, one can only add a complete new lane—then, if the capacity were provided the charges would be reduced and the "new" revenues might no longer be able to sustain the cost of the expansion. In other words, the discrete nature of capacity expansion might mean that it is optimal to earn an excess of revenues above costs even in the long run, and not to undertake any expansion.

This analysis is further complicated by

(a) the possibility of non-homogeneous congestion cost function,

(b) the possibility of increasing or decreasing returns to scale in the "technology" of providing new road capacity,
(c) the presence of environmental charges as a component of total charges to reflect damages done to non-road users,
(d) the element of sumptuary taxation in current road fuel duties.

Previous estimates of the cost of road capacity expansion

Sansom et al (2001) estimated the cost of capital for infrastructure as part of their fully allocated cost analysis. The steps used to arrive at these figures are:

Estimate the net value of road infrastructure assets
Apply the public sector discount rate, representing the interest foregone.
Allocate 85% of total to vehicle types on the basis of PCU-km and the remaining 15% to gross maximum vehicle weight-km.

They note that NERA (1999) report an estimate of the value of the current asset stock of £57.4 billion for 1994/95 in 1994 prices. While Newbery (1998) reports a value for the capital stock of £120 billion in 1998 prices, which was calculated by adding the gross value of investment in roads each year to the last figure for the capital value of the road system published in 1981.

On the basis of these figures Sansom *et al* (2001) adopt low and high range asset values of £60 and £120 billion, yielding cost of capital of £3.6 and £7.2 billion. In pence per vehicle kilometre the cost of capital is 0.78 and 1.34.

Estimates by Starkie

Starkie (2002) quotes figures on the average costs of road construction. He notes that incremental costs of supply can vary considerably across the network. He gives a table of values for road construction costs that were submitted by the Department of Transport to the House of Commons Select Committee in 1995 shown in Table 1.

Table 1. Costs of Construction of One Kilometre of Lane Capacity (2003 prices)

			A	B	C
	Ave cost (£m/km)	No of Lanes	Lane Cost (£m/km)	Lane Capacity (veh/hr)	Col A/ Col B/ (£hr/veh km)
Non-Motorways					
Bypass – single carriageway	2.13	2	1.07	1,150	930
Bypass – Dual carriageway	4.54	4	1.14	1,700	671
Dual Carriageway Improvement from single	2.07	2	1.04	1,700	612
Motorways					
New Motorways (3 lane)	6.46	6	1.08	1,900	568
Widening	6.16	2	3.08	1,900	1,621

Note: Includes costs of land, statutory undertakings, ancillaries and main works but excludes preparation and supervision costs and VAT. Source: Starkie (2002), converted from miles to kilometres and from 1993 prices to 2003 prices.

Estimates by Bayliss and Muir Wood.

Bayliss and Muir Wood (2002) estimate the additional trunk road capacity that would be required in order to meet the traffic demand forecasts given in "Motoring Towards 2050". They calculate that on the basis of these forecasts there would be 55 billion vehicle kilometres per year of growth that would have been accommodated through expansion of the physical capacity of the road network. Their calculations indicate an overall total of additional capacity of:

750 kms of new Motorways

750 kms of new trunk roads

850 kms of widened motorway

400 kms of widened trunk road.

Bayliss and Muir Wood estimate that the total cost of this investment would be £70billion as shown in Table 2.

Table 2. Estimate of costs of a road programme (2002 prices)

ELEMENT	LENGTH	NUMBER	RATE	COST
New open M'ways[1]	600kms		£20m/km	£12.0bn
New tunnelled M'ways[2]	150kms		£90m/km	£13.5bn
New open OTRs[3]	660kms		£10m/km	£6.6bn
New tunnelled OTRs[4]	150kms		£60m/km	£9.0bn
Widened M'ways[5]	850kms		£12m/km	£10.2bn
Widened OTRs[6]	400kms		£9m/km	£3.6bn
New underpasses[7]		50	£36m	£1.8bn
New bridges[8]		200	£5m	£1.0bn
Other improvements to junctions[9]				£3.0bn
Feeder road improvements[10]	1,000kms		£5m	£5.0bn
Management & info systems[11]	15,000kms		£0.1m/km	£1.5bn
Environmental enhancements to existing sections[12]	5,000kms		£0.4m/km	£2.0bn
Total Cost				Say £70bn

Source: Private communication of background to Bayliss and Muir Wood (2002)

Notes to Table 2.

1. This is based on Highways Agency estimates of £5.54m (rural) to £8.24m (urban) for all purpose roads averaged to £7m, inflated by 100% for more elaborate structures and with £1m a kilometre for land, £½m a kilometre for planning and design with VAT bringing this up to £18.2m rounded up to £20m for higher quality design including putting some sections in cutting.
2. This is based on advice from Muir Wood based on detailed analysis of recent costs with VAT added (£72m + VAT = £85m) plus some land take at portals
3. This is based on Highways Agency estimates of between £4.7m for D2 rural to £8.24 for D3 urban plus £1m a kilometre for land and planning etc. with VAT this comes to £9.4m rounded up to £10m/km.
4. Based on Muir Wood figure of £48m with VAT added (£48 + VAT = 56.4m) plus some land take for portals.
5. This is based on Highways Agency estimates of £7.85m (rural) to £9.59m (urban) plus £½m a kilometres for land and planning. With VAT this gives about £10.6m and is rounded up to £12m.
6. Based on Highways Agency estimates of £5.54m to £8.24m with land, VAT etc. this comes to just short of £9m.
7. Based on Muir Wood estimates plus VAT and an allowance for land. This provides for new underpasses where dual trunks cross Motorways.

8 Based on Highways Agency estimates of £2.3m to £2.5m with allowance for land, planning and VAT.

9. Token figure to recognise that junctions some junctions on existing Motorways will have to be strengthened. This would allow for 60 junctions to be improved at a cost of £50m each.

10. This provides for approach roads to Motorways and busy trunk roads to be improved. This would range from traffic management and improved surface crossings to carriageway widenings and some grade separation of junctions. The costs would vary from zero to perhaps £10m/km. An average of £5m for 5kms each side of 200 junctions has been taken.
11. The TCC is to cost £160m over ten years. It is not known what the cost of new technology will be but an average investment of £100,000/km is assumed.
12. Token figure to provide some environmental retrofit for troublesome parts of the existing network.

These costs are at current prices and make no allowance for inflation or real factor cost increases. They do not provide for local road improvements, other than those required to accommodate additional access traffic to the trunk road network. If these were to be added on the basis of the proportions in the Ten Year Plan this would increase the £70bn by a further £60bn. (£13.3bn compared with £16.2bn on strategic roads in the 10YP) They do not provide for additional capacity requirements beyond 2031.

In a background note Bayliss and Muir Wood give the information in Table 3.

Table 3. New and Widened Roads Costs – Strategic Network

	Pavement	Urban	Rural
All purpose Dual 2 lane £m/km	2.98	6.9	4.7
Dual 3 lane £m/km	3.59	8.24	5.54
Widening Dual 2 to Dual 3 £m/km	3.00	8.24	5.54
Motorway Widening Dual 3 to Dual 4 £m/km	Widening approx 5.3 to 10.00 incl structs 5.00	9.59	7.86

Sources: Highways Agency cited by Bayliss and Muir Wood, private correspondence.

Notes to Table 3
Generally the rates are at 2002 prices and include construction, preparation and supervision costs but exclude land, VAT and any substantial stats diversions.

All Purpose: The all in rates for D2APR and D3APR are derived from a road cost model built in the mid 90's with data taken from real schemes that includes an allowance for structures. The pavement only rates come from the rates that we use for the road works element in our network valuation for accounting purposes. Widening rates vary but experience seems to suggest that on line widening of D2's is often difficult so that we often widen asymmetrically, rebuilding the whole carriageway and structures in the process.

Motorway Widening: The rates here are derived from a list of 14 motorway widening schemes that pulled together for pricing the 10 Year Plan (ie 1999-2000 prices). The average is about £8.6m; most lie between £5.3 and £10m depending on the work required to structures. The cheapest project had a construction cost of £3.7m, but widening at junctions can be very expensive. I understand that recent work coming out of the Multi-Modal Studies is coming in at the top of this range.

Note that Table 2 indicates construction costs for roads in tunnel at between four and a half and six times the cost of the equivalent road in the open. Tunnels have higher operating costs because of the need for lighting and emergency ventilation, but they are likely to have lower land costs and to incur lower disruption and landscape costs (see Bayliss and Muir Wood, 2002 for a discussion of tunnelling).

A statistical cost analysis by Glaister and Graham

In Glaister and Graham (2003) we reported a statistical analysis of 56 of the schemes detailed in DETR (1998b). This gives estimated scheme costs (present values discounted at 6 per cent pa) and lengths for a variety of scheme types. Table 4 shows our results.

Table 4. Capital costs of Trunk road schemes

	Ave cost (£m/km)	No of Lanes	Lane Cost (£m/km)
Bypass – single carriageway	3.14	2	1.57
Bypass – Dual carriageway	5.65	4	1.41
Dual Carriageway improvement from single	3.71	2	1.86
Motorway widening	6.69	2	3.35

Estimates by the Highways Agency

In the UK recent work on estimating road costs has been done by the Department of Transport or the Highways Agency and consultants in their employ. The most recent of these studies was undertaken by EC Harris on behalf of the Highways Agency. The work, which is still in progress, seeks to calculate typical construction costs for different road types in rural and urban areas. The data is broken down by road type then factored for year, location and value using the Highways Agency Road Construction Tender price index. The average cost of the schemes is then taken for each road type and hence an average cost per km is derived. Footnotes in the analysis suggest reasons for the discrepancies in the results and large deviations from the mean, such as small sample sizes or a high occurrence of major structures in the schemes. However, the effects of these structures on cost are not quantified. Furthermore, since the data are broken up by road type before analysis, there is no way of examining trends across the various road types, except in the final result. Dividing the data in such a way will also compound the problem of small sample sizes, increasing the uncertainty of results and leading to possible irregularities such as the cost per kilometre of a rural six lane motorway being £11.5M while a urban six lane motorway at £6.6M (Highways Agency have acknowledged this and are seeking to improve the estimate). Further seemingly irregular results are present in the data such as the cost per km of a four lane motorway (D2M) being greater than a six lane motorway (D3M). However, the averages can only return the results for the data analysed - projects valued or constructed in the last 15 years - and in the case of the four D2M and D3M schemes analysed, such a pattern has emerged.

Data and method of analysis

There are several methods available to model the cost of capacity, these either involve a theoretical approach, such as that applied by Mohring (1976) to account for network density or an empirical approach, developing models from real cost and flow data, applied by numerous studies including Joseph (1960), Meyer, Kain and Wohl (1965), Keeler & Small, (1977) and Kraus (1981). Unlike many previous studies which have only analysed urban freeways in a particular area, the present project provides a model which can be applied across the whole UK road network. In order to enable the model to account for the multitude of factors affecting cost of capacity and therefore the huge amount of variation in costs across the country we have used a statistical approach.

Data

It was decided that best way to collect a suitably large sample, was to approach the Highways Agency directly in to order analyse their records of road construction and maintenance projects. We are grateful for their help. In addition to the two data sets detailing highway construction and major maintenance costs received from the Highways Agency, a number of other secondary sources were used. These included reports from the National Audit Office and the Valuation Office Agency and the Department of Transport's Design Manual for Roads and Bridges.

Data Cleaning

The two main Highways Agency data sets, whilst being extremely useful records of nearly 1000 schemes and parts of schemes put to tender in the last fifteen years, contained a number of errors and omissions. In order to prepare the data for further analysis these errors had to be identified and where possible corrected. Where possible any omissions in the data were resolved. In both cases this was done either by comparing information given for roads in the two data sets or using other sources such as Google Earth.

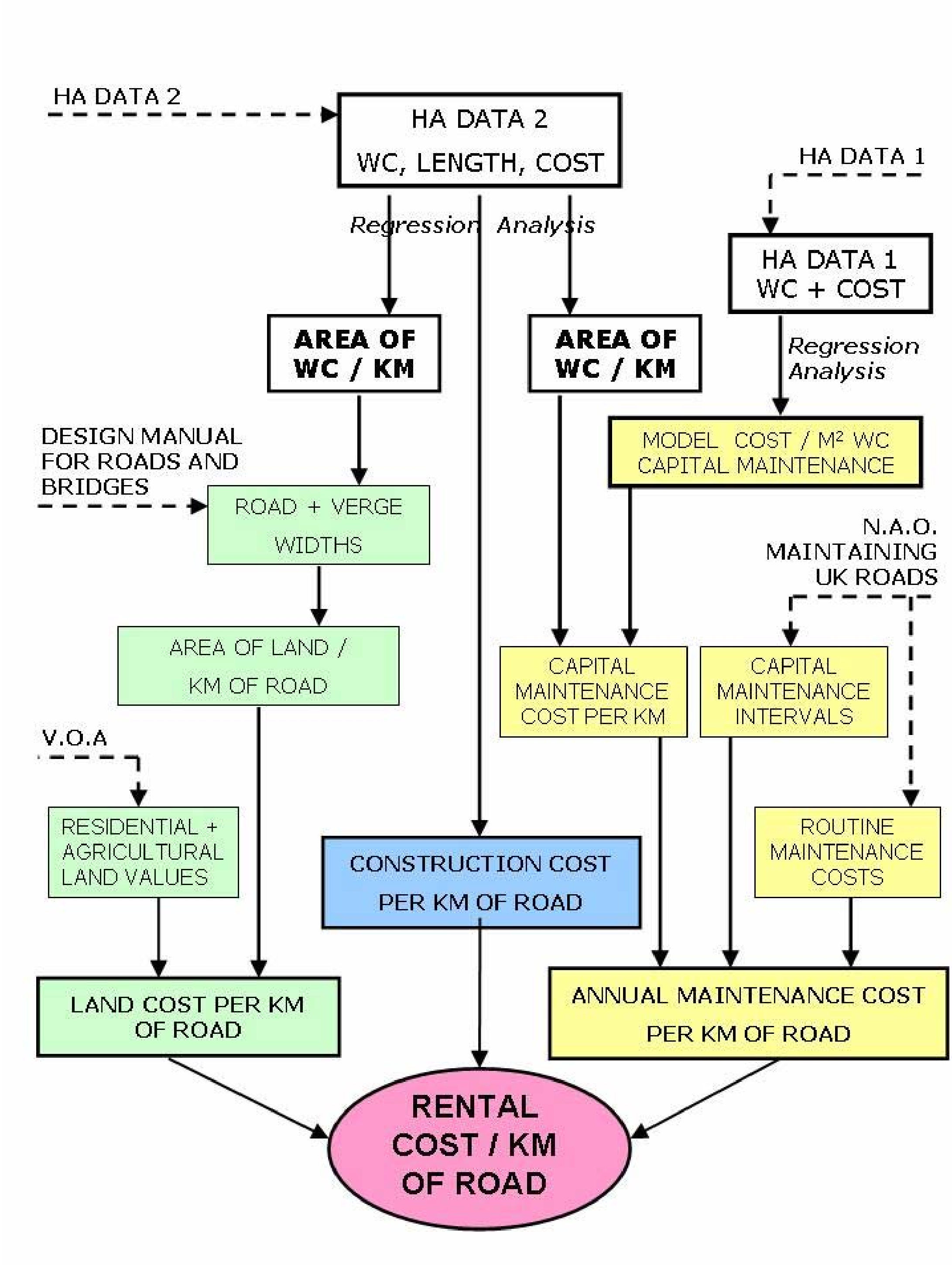
Cost Analysis

Figure 1 details the analysis process, including the hierarchy of the stages and data input points. It should be noted from the flow chart that the costs are broken down into maintenance costs, land costs and construction costs for analysis purposes before being combined in the final stage. This approach has become standard, as discussed in the literature review, and was adopted by a number of previous studies including Liedtke (2003), Small *et al* (1989) and Keeler & Small (1977).

This work differs from previous studies in its use of the data for the area of wearing course laid described in the Highways Agency data. The main difficulty and source of much uncertainty and disagreement in previous studies has been the problem of how properly to account for the various effects of junctions and structures on the cost per kilometre of road. These difficulties have led to varying estimates for returns to scale in highway construction noted in the literature and by Kenneth Small (1992) in his summary of empirical estimates of the capital cost of roads. By modelling the area of wearing course laid per kilometre of road and how it varies by road type and in rural or urban areas, an indication of size and frequency of junctions can be ascertained. This model for wearing course per km of road is used together with a regression model to find the costs of capital maintenance and to model area of land and hence land costs.

The following sections describe the methods by which the models for land, construction and capital maintenance costs are developed.

Figure 1: Calculation stages



Construction Costs

The second data set provided by the Highways Agency was analysed using linear least squares regression analysis in Limdep[1], to model the cost of construction per km. Regression Analysis was deemed to be the most suitable technique to analyse the data set for the following reasons:

- Previous studies have used linear regression to model construction costs to good effect. These studies are discussed in the literature review and include Hyman (1960) and Keeler & Small (1977).

- General literature on the subject of engineering cost analysis recommends the use of regression analysis, particularly "in cases where an appropriate cost estimating relationship can be identified," as is the case for highway construction costs, since "regression models have significant advantages in terms of accuracy, variability, model creation and model examination" (Smith, 1996)

- The use of regression analysis prevents the need for the data to be subdivided leading to problems of reduced sample sizes and therefore statistically insignificant results, such as those experienced by the consultants EC Harris when analysing data for the Highways Agency.

Limdep is used in preference to Excel because it is much more powerful. There is no limit to the number of independent variables which can be analysed. Furthermore, Limdep includes a more sophisticated array of modelling tools including weighting for hetroskedasticity.

Highways Agency data 2 is used to model the construction costs per km or road. Dummy variables are created for road type, scheme type (i.e. new road or road widening) and area type (i.e. rural or urban). To prevent patterns in the data

[1] Limdep econometric modelling software version 7.0

influencing the final model, the variables for road type are interacted with scheme type and area type.

Land Costs

The area of land required per kilometre of road is dependent upon the area of the road itself, i.e. the area of wearing course and the additional area required for verges and embankments either side of the road. The costs detailed in the two data sets provided by the Highways agency were only the tender prices of the schemes and therefore did not include land acquisition costs. Because of this shortage of data land acquisition costs cannot be directly modelled empirically.

The model of wearing course per kilometre developed in order to calculate maintenance costs is equally applicable to the corresponding land costs. In order to model how the total area of land required should vary with the area of wearing course, the ratio of road widths to road and verge widths are calculated, for the various road types in rural and urban areas, using data from the Design Manual for Roads and Bridges. Using these results together with the area of wearing course per kilometre model developed earlier, the areas of land required per km of road can modelled. This model uses recommended design values together with empirically derived data from the road network to estimate land areas. The model will account for the increased land required by junctions, using the results of the model for wearing course per kilometre.

Once the area of land required per kilometre of road is established, the cost of this land can be calculated using a suitable land price index. The Valuation Office Agency (VOA) produces such an index for both residential and agricultural land. The advantage of these externally produced indices is (assuming the veracity of the source) that they are continually updated, meaning that costing models derived in this project can be easily updated for use in the future. Furthermore, the Valuation Office Agency index gives future land price value predictions which, although inevitably suffering from problems of uncertainty inherent in any prediction of future trends, could allow the results of this report to be projected into the future.

Maintenance Costs

Highways Agency data 1 contains a number of major maintenance schemes. The inclusion of these schemes in the regression analysis performed to derive the cost per m^2 of construction together with a dummy variable for maintenance schemes returns a model of the cost of major maintenance projects per m^2 of wearing course laid. Combining this with the model of wearing course per kilometre of road, used in the land cost model, gives a model for the cost of performing major maintenance on a kilometre of road.

The second component of maintenance costs is the routine maintenance costs. The data from the highways agency does not include any routine maintenance costs. The best data available is that contained within the NAO report, *Maintaining England's Motorways and Trunk Roads* (2003). The costs of annual routine maintenance per lane kilometre are taken directly from these report and factored for year and location using RCTPI, under the assumption that maintenance costs vary in a similar way to construction costs.

Rental Cost per lane km

The three separate elements of road cost; construction, maintenance and land acquisition were calculated. However, since each of these costs is incurred at a specific point in time and will reoccur (not in the case of land acquisition) at certain intervals, finding the average annual "rental cost" of per kilometre of road is necessary. Keeler & Small (1977) assume the land acquisition is a one off payment, the road has a lifetime of thirty five years over which its cost must be recouped and maintenance costs are annual. By separating major maintenance costs from those for routine maintenance, it is possible to develop a more realistic model: land acquisition is kept as a one off payment. The lifetime of the road is extended to one hundred years, in keeping with other major civil engineering projects. However, major maintenance must be completed at intervals of approximately thirteen years[2], and routine maintenance is required annually. Keeler and Small's original formula is adapted as follows for the present work:

$$R(w) = \left(\frac{r}{1+e^{-rl}} \right) K(w) + r \cdot L(w) + i \cdot M(w) + m(w)$$

$$\begin{aligned}
\textit{Where}:\ & K(w) = \text{Construction Cost} \\
& L(w) = \text{Land Aquisition Cost} \\
& M(w) = \text{Major Maintenance Cost} \\
& m(w) = \text{Routine Maintenance Cost} \\
& r \quad = \text{Public Sector Discount Rate} \\
& i \quad = \text{Fraction of Network Undergoing Major Maintenance} \\
& l \quad = \text{Lifetime of Road}
\end{aligned}$$

Highways Agency Road Cost Data 1

The data kindly provided by the Highways Agency details 518 new road and major road maintenance projects for England and Wales which were put out to tender between 1987 and 1999. The data provided gives the following details for each scheme:

[2] The value of 13 years is derived from the report Maintaining England's Motorways and Trunk Roads which states that the Highways Agency aims to be carrying out capital maintenance on 7.5% of the network every year (NAO 2003).

Table 5: Highways Agency data 1 – breakdown of scheme descriptors

Year	Year of tender	
Name	Scheme name, including brief explanation	
Road Type 1	Detailed road type where:	
	S2	2 lane single carriageway
	WS2	Wide 2 lane road, usually with overtaking lane
	D2AP	4 lane dual carriageway
	D3AP	6 lane dual carriageway
	D2M	4 lane motorway
	D3M	6 lane motorway
	D4M	8 lane motorway
	HYBRID	Mixture of dual and single carriageway road
Road Type 1a	Simple road type where:	
	S	All single carriageway roads
	D	All dual carriageway roads
	M	All motorways
	H	Hybrid roads
Road Type 2	Whether road is rural (R) or urban (U)	
Region	Region of England e.g. N, W, SW, SE, Midlands or London	
Scheme Type	NR	New road
	L	Link: improvement to existing route Eg. construction of new junction
	M	Major maintenance / overhaul
Wearing Course	Area of road surface laid (m2)	
Total Tender (£)	The tender price agreed for the scheme	

Highways Agency data 1 does not include the length of road to be constructed for each scheme.

Highways Agency Data 2

A second set of data, henceforth referred as Highways Agency data 2, was provided by the Highways Agency, in response to queries regarding the length of the completed schemes detailed in the first Highways Agency data set. This second data set details 550 road projects. Highways Agency data 2 is very similar in format to Highways Agency data 1; however, there are a number of differences. The scheme types are now broken down as follows:

Table 6: Highways Agency data 2 – alternative scheme type descriptions.

Scheme Type	NR	New road construction
	NW	Road widening schemes
	IJ & IR	Junction and roundabout improvements respectively
	IO	Other improvement

The year and quarter of construction is now included, allowing all the information in the Road Construction Tender Price Index (RCTPI) to be used. Mixed type or Hybrid schemes are now listed explicitly, e.g. as S2/D2 or D2/D3. Local authority road schemes are included and differentiated from Highways Agency schemes. Most importantly in addition to the data provided in the first data set, the length of road was also given. However, the email (personal communication, 16/04/2006) accompanying the data set advised caution when using these lengths, particularly for schemes such as junction improvements where area of wearing course is a better benchmarking unit.

The two data sets are almost complete, comprehensive records of the tender prices of major road schemes planned or constructed within the last fifteen years. However, the data have been collected over a number of years from a variety of sources and have been recorded by different individuals. Consequently information has not always been recorded in the same way and there are a number of gaps in the record. In order to have confidence in the data and the results of the analysis it is necessary to identify errors, omissions or inconsistencies and to rectify them if possible.

The information in Highways Agency data 1 is complete - no errors or omissions were identified. Highways Agency data 2 on the other hand contains a large number of omissions; the majority of these concern the scheme type but some entries do not include scheme length, road type or area type. Work to rectify these omissions also highlighted a number of errors and inconsistencies in the data.

Where the column for scheme type has been left blank the relevant information can usually be found either within the scheme name or in the comments section of the scheme. There is also a degree of overlap between the two Highways Agency data sets and comparing entries for the same scheme in both data sets proved to be a convenient way of filling in the missing data. When a scheme is not included in Highways Agency data 1 and there are no clues contained within the entry, other sources must be utilised to rectify the omissions.

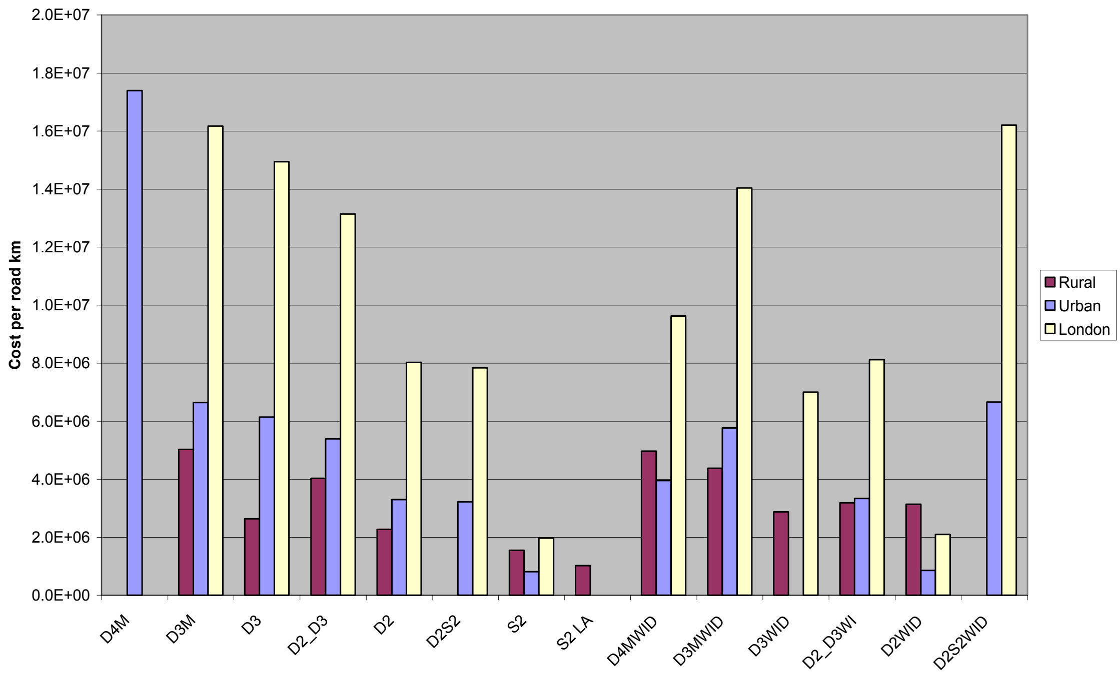
Google Maps (http://maps.google.co.uk) proved to be the best source of information. Using a combination of large and small scale maps and high resolution satellite and aerial photographs, a great deal of information can be found out about the road schemes in the data. The high resolution photographs are especially helpful when the road type has been omitted, as even large scale maps do not show the number of lanes. Searching for any place names contained within the scheme name will usually indicate in which area of the country the road is constructed and whether the area is rural or urban. Although, it should be noted, that "the urban reference relates to the design type rather than its location. Generally urban schemes are built to a slightly narrower cross section and usually have speed limits less than 30mph" (personal communication 16/04/2006). Where this column has been filled in using information from Google, roads passing through populated areas are assumed to be urban. The use of these images also allows the information in the data to be related to the actual roads constructed. This proves particularly useful during the analysis stages when attempting to identify whether projects which return high residuals should be removed from the data.

Unfortunately some of the missing information could not be found easily. This is particularly true for any entries in Highways Agency data 2 which do not contain a length for the completed scheme since Highways Agency data 1 does not include lengths, nor is there any sure way of determining the length of road constructed at a certain time from maps or photographs. In all 169 schemes were removed from the data before analysis because of missing lengths. For a small number of schemes, the number of lanes could not be determined for certain, due to the low resolution of images available of the area in question.

Close examination of the data begins to reveal errors and inconsistencies in the record. These range from minor inconsistencies, such as miss spelling of regions and roads consisting of both dual and single carriageway sections being listed as either S2/D2 or D2/S2 (important to consider when creating dummy variables), to more serious errors such as recording both a four lane section of the M62 motorway and an eight lane section of the M25 as D4 (an eight lane dual carriageway) rather than D2M and D4M respectively. Identifying these errors is more troublesome; however, once found they can be easily rectified using the techniques described.

Figure 2 displays some of the tender price data excluding land costs, as received, before analysis or adjustment for such things as price inflation and optimism bias.

Figure 2. Road construction tender prices, excluding land costs



Department for Transport Design Standards

The Design Manual for Roads and Bridges, Volume 9, Road Geometry (DMRB, 1996) details the advised widths of traffic lanes, hard shoulders, hard strips, central reservations, pavements and verges for rural and urban road types. The data are displayed in engineering drawings with associated tables and includes advised widths for slip roads and interchanges as well as mainlines. For this project only the advised widths of open carriageway sections of mainlines and associated verge widths have been used. The data allow the area of wearing course per kilometre of road built to design specifications, not including junctions to be calculated. The verge widths can be used to calculate the minimum area of lane required in addition to the area of wearing course of the road which is also expressed as a percentage.

Valuation Office Agency

The Valuation Office Agency Property Market Report (2005) gives tables of residential and agricultural land prices by financial quarter and region for England, Wales and Scotland. In addition the report gives future projections national trends in residential and agricultural prices.

Agricultural values are given by region and by type of land e.g. arable, dairy etc. For regions in which some land type is not available the relevant column is left blank. For the purpose of this report an average value was taken for each region from the values for the available land types for that region.

Residential values are given per hectare as an average of prices across the whole region. With the exception of London which is listed separately, no additional information is provided for land prices in major cities (average *house* prices are given by city; however, these are difficult to relate accurately to land price). The land prices given therefore will tend to underestimate prices in cities and overestimate prices in smaller towns. However, since the data for road construction costs only differentiates between rural and urban schemes and not the size of the conurbation or population density, average regional values for land prices will be suitable for the analysis.

National Audit Office and Audit Scotland

The report, *Maintaining England's Motorway's and Trunk Roads* (NAO 2003) and the corresponding report *Maintaining Scotland's Roads* (Audit Scotland 2003), give information on the costs of routine and capital maintenance as well as capital maintenance intervals for Britain's motorways and trunk roads.

The required data in both reports is contained both in graphs and tables and within the text. Annual routine maintenance and winter maintenance costs per lane kilometre are calculated from the total spent on routine maintenance and the number of lane kilometres in the network. The NAO report states that the Highways Agency target is for between 7% and 8% of the network to undergo capital maintenance each year (NAO, 2003). Taking a figure of 7.5% suggests that a section of road will require capital maintenance every 13.3 years; the value used for maintenance intervals. The reports do give figures for costs of capital maintenance, but these have not been used since these costs are included in schemes within Highways Agency data 1.

Maintaining Scotland's Roads (Audit Scotland 2003) details maintenance expenditure by both local authorities and the Scottish Executive (responsible for motorways and trunk roads). The problem with using the information, as the report makes clear, is that Scotland's roads are generally in poor condition due to a lack of funding during the mid 1990's. A backlog of maintenance has therefore built up requiring higher than normal spending on road maintenance (Audit Scotland, 2003). For the purpose of this report, these additional costs should not be considered as they will not affect the costs of maintaining new roads built in response to demand, identified through driver's willingness to pay road user charges. The costs for maintaining Scotland's roads are therefore taken from the NAO report and factored for Scottish prices using the RCTPI.

Statistical Analysis

The first set of highways agency data (Highways Agency data 1) was analysed using regression analysis to give a model for cost per metre squared of wearing course for capital maintenance projects. The second set of Highways agency data Highways Agency data 2 was analysed using regression analysis to give a model for area of wearing course per kilometre and a model for cost of construction per kilometre.

Highways Agency data 1 - Regression Analysis

The data were factored for year and location using the Road Construction Tender Price Index (RCTPI). Various combinations of independent variables were analysed with the aim of identifying the most powerful explanatory variables and finding anomalous schemes in the data. Fourteen schemes were excluded from the final analysis: The majority of excluded schemes were projects such as bridge and culvert construction or repair and advanced works, which had large cost for very little area of wearing course laid.

The regression coefficients corresponding to the best fit to the data were generally those for urban *versus* rural roads, certain regions (especially London), simple road type (Dual Motorway or single) and project type (e.g. link road, link road or major maintenance). Some previous studies of the subject have found a log-linear relationship for cost per unit length (Keeler and Small, 1977). Setting the dependent variable as ln(£/m^2) was found to give a significantly improved R^2. Furthermore if a factor of ln(m^2 wearing course) is included as a independent variable the R^2 coefficient is further improved and projects are found to have increasing returns to scale. This result is unsurprising since it considers cost per m^2 of wearing course laid and not capacity; therefore, scale economies are very likely.

The analysis for cost per m^2 of wearing course which gave the best fit to the data with the most statistically significant set of independent variables is shown in Table

7. The general fit to the data is good and the significance of the regression coefficients used in the final model is well over 99%, except for Widening.

Table 7: Regression analysis Highways Agency data 1, dependent variable ln(cost/m² WC) .

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7706
R Square	0.5938
Adjusted R Square	0.5852
Standard Error	0.5652
Observations	529

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	11	241.4255885	21.94778077	68.71632	9.87022E-94
Residual	517	165.1282138	0.319396932		
Total	528	406.5538023			

Sample Size		*Coefficients*	*Standard Error*	*t Stat*	*P-value*
	Intercept	7.1436	0.3077	23.2145	0.0000
181	**urban**	-0.2224	0.0306	-7.2786	0.0000
350	**rural**	-0.2409	0.0291	-8.2743	0.0000
178	**D2AP**	0.3185	0.0726	4.3878	0.0000
21	**D3AP**	0.4182	0.1404	2.9786	0.0030
49	**D2M**	0.6209	0.1036	5.9953	0.0000
118	**D3M**	0.4502	0.0946	4.7595	0.0000
26	**D4M**	0.7435	0.1422	5.2293	0.0000
11	**Hybrid**	-2.1633	0.3380	-6.4009	0.0000
249	**Maintenance**	-1.3117	0.0642	-20.4190	0.0000
61	**link road**	-0.4231	0.0896	-4.7224	0.0000
25	**Widening**	-0.2268	0.1306	-1.7372	0.0829

Highways Agency data 2 - Regression Analysis: cost per kilometre of road

The second set of data provided by the highways agency includes lengths of completed schemes, as discussed in the data section. As with the Highways Agency data 1, the costs in Highways Agency data 2 have been factored for year and location using RCTPI.

A number of iterations of the regression analysis were performed. The final data set analysed excluded schemes of type IO (other improvement) which generally consisted of improvements to lighting or earthworks etc. Schemes shorter than 0.2km were also excluded from the final analysis. Plots of residual values versus length of scheme indicated that the variance of the error may be related to the length of the scheme. Shorter schemes gave a poor fit to the model. Since the incidence of junctions and structures is a key factor in modelling the cost of a road and a longer scheme is more likely to have a representative frequency of junctions and structures than a shorter scheme, it would be expected that the variance in costs is larger for short schemes. To counter this effect the final model includes a weighting by length of scheme to deal with heteroskedasticity. Once anomalous results had been identified and errors in the data had been corrected, the best combination of independent variables was identified to model the cost/kilometre of road constructed directly from Highways Agency data 2.

Regression Analysis of area of wearing course per kilometre of road

Since the tender prices are not used in developing a model for m^2 wearing course/km, it is unimportant whether the costs of each scheme have been factored for year and location using RCTPI. The factors which are likely to affect the area of wearing course required per km of road are:

- Road type, the area of wearing course required will be proportional to the width of the road.

- Area type; i.e. urban or rural; in general the incidence of junctions in urban areas will be higher than in rural areas (Meyer, Kain and Wohl, 1965), a higher incidence of junctions will increase the area of wearing course required per kilometre of road Mohring (1976), Kraus (1979).

- Scheme type, the area of wearing course laid in a road widening scheme should be less than that laid in the construction of a new road.

- Other factors: any factor which influences the incidence of junctions along a route is likely to affect the area of wearing course required; for example, roads in locations such as London or the Midlands may be affected in such a way.

Twenty five regression analyses were performed using Highways Agency data 2. Initially the whole data set was analysed. However, the schemes of type OI (other improvement) were found to contain a huge variety of different project types including signalling improvements, lighting improvements and safety barrier enhancements. The incidence of these schemes in the data gave misleading results when attempting to analyse the area of wearing course/kilometre of road. The final analyses therefore excluded IO schemes, only analysing new roads, junctions and roundabouts and road widening schemes.

Locations such as London and the Midlands were analysed in early runs but did not return significant results. The Summary Output for the final analysis can be seen in Table 8.

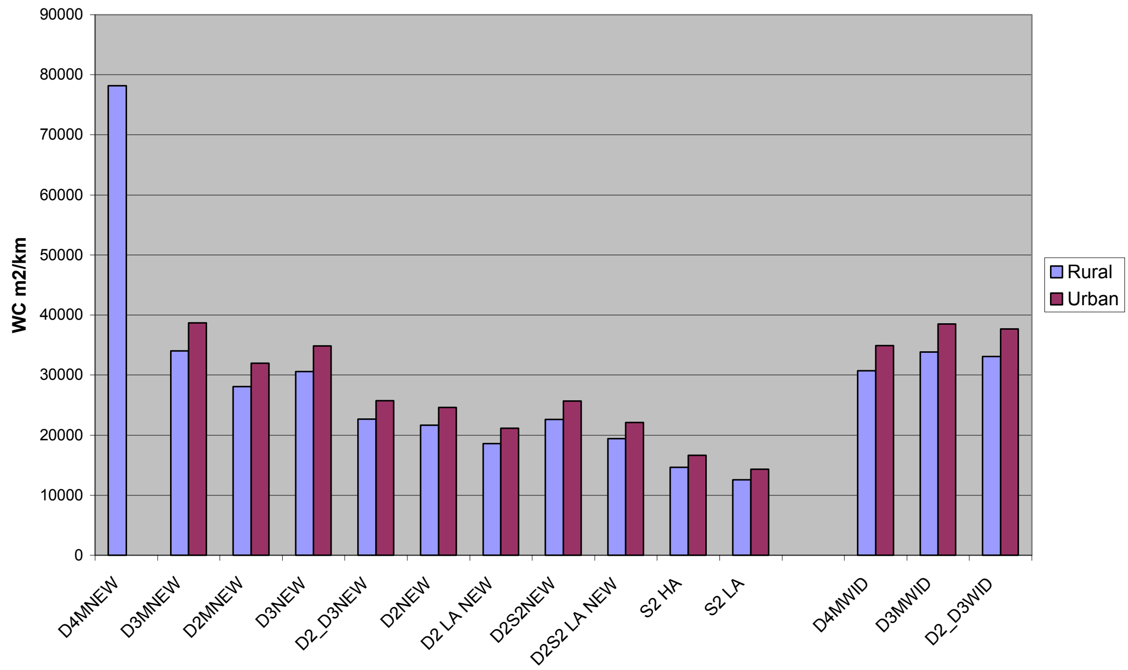
Table 8: Summary output, regression analysis Highways Agency data 2, dependent variable m²/km.

Variable	Coefficient	Standard Error	t-ratio	P[|T|>t	Mean of X
Constant	9.59054203	6.09E-02	157.608	0	
D2_D3NEW	0.437503224	0.2163483	2.022	0.0441	1.99E-02
D2_D3WID	0.817407325	0.19965265	4.094	0.0001	2.33E-02
D2MNEW	0.652156487	0.36186944	1.802	0.0726	6.64E-03
D2NEW	0.392636399	7.50E-02	5.232	0	0.2923588
D2S2NEW	0.434807552	0.16824565	2.584	0.0103	3.32E-02
D2S2WID	-0.244590064	0.29713993	-0.823	0.4111	9.97E-03
D2WID	0.131365105	0.12544891	1.047	0.2959	6.31E-02
D3MNEW	0.844471881	0.23144976	3.649	0.0003	1.66E-02
D3MWID	0.839383509	0.25896493	3.241	0.0013	1.33E-02
D3NEW	0.738710333	0.15841093	4.663	0	3.99E-02
D3WID	3.95E-02	0.23060849	0.171	0.8641	1.66E-02
D4MNEW	1.676281502	0.51019859	3.286	0.0011	3.32E-03
D4MWID	0.741116917	0.13077606	5.667	0	6.64E-02
SWID	-0.224699013	0.18846342	-1.192	0.2342	2.66E-02
URBAN	0.128906634	6.49E-02	1.986	0.048	0.38538206
LA	-0.151966363	7.28E-02	-2.088	0.0377	0.35215947

There is a reasonable overall fit to the data with R^2 of 0.34 and all but one of the coefficients for new road construction have greater than 95% significance with the coefficient for D2M roads having greater than 90% significance. All the coefficients behave as expected, with area of wearing course increasing with road width, as shown in Figure 3. The difference between the widths displayed in

Figure 3 corresponds to the area of wearing course required for junctions. This should indicate both the incidence of junctions and their elaborateness. The regression coefficients also show that widening schemes require less area than new construction and urban routes are found to have a greater area per kilometre than rural roads.

Figure 3: Area of wearing course per km of road for rural and urban schemes



The cost model

Analysis of the two Highways agency data sets has resulted in three empirical models: for cost per kilometre of road construction or maintenance, for the cost of capital maintenance per m² of wearing course and for the area of wearing course laid per kilometre of road constructed. Using these models together with information from government agency and non government organisation reports, costs of construction, maintenance and land acquisition per lane kilometre can be modelled.

The result is used to develop a model for rental cost of capacity by discounting capital expenditure and applying maintenance costs at suitable intervals.

Cost of Construction

Regression analysis of Highways Agency data 2 weighted for hetroskedasticiy with length gave the following log linear model for cost per km of construction:

$$C = EXP(14.25 + T + LAR + Lon)$$

The values of the coefficients are shown in Table 9:

Table 9. Coeficients for a log linear , weighted regression.

Dependent variable cost per km. of construction.

	Variable	Coefficient	P[|T|>t]
Road Type (*T*)	D4MU	2.41733737	0
	D3MU	1.454624134	0.0004
	D3MR	1.175915743	0.0001
	D2MR	1.49440022	0.0003
	D3U	1.375481803	0.0164
	D3R	0.531872417	0.0043
	D2_D3U	1.246928055	0.0493
	D2_D3R	0.955960713	0.0003
	D2U	0.753851274	0.0001
	D2R	0.380480169	0.0008
	D2S2U	0.730218811	0.027
	S2U	-0.650667412	0.0005
	D4MUWID	0.93539982	0
	D4MRWID	1.164068013	0
	D3MUWID	1.312786901	0.001
	D3MRWID	1.037920652	0
	D3RWID	0.616685905	0.0246
	D2_D3RWI	0.720843607	0.0708
	D2RWID	0.703490512	0.0089
Local Authority (Rural Only)	LAR	-0.418064652	0.0013
London Schemes	LON	0.889680769	0.0414

The road type displays the type of road and number of lanes, whether the road is in an urban (U) or rural (R) area and whether the cost refers to a new construction or a road widening scheme (WID). For urban Local Authority roads or roads constructed in London there are further coefficients to adjust cost. It should be noted that the London factor is in addition to the RCTPI factor for London. Further road types were included in this analysis; however, these coefficients did not have significant t-statistics. The current model is unable accurately to model the costs of these road types.

Maintenance Costs per lane kilometre

Maintenance costs are broken down into two parts, the routine maintenance costs incurred annually and the cost of capital/major maintenance required at regular intervals in the life of a road.

Capital maintenance costs derived from the model for maintenance costs per m^2 wearing course and the model for area of wearing course laid per km. The value for m^2 of wearing course per kilometre of road is input to the function for cost per m^2 using the coefficient for maintenance schemes. The analysis of Highways Agency data 2, described in the previous section, shows the area of wearing course per kilometre of road can be modelled by the following expression:

$$WC = I_{WC} + T_{WC} + S_{WC} + A + U_{WC}$$

The values of the coefficients together with their percentage error, taken from the summary output of the regression analysis shown in Table 10:

The resulting function the cost of capital maintenance per lane kilometre is

$$M(w) = \left(\frac{WC \cdot w}{n_T} \right)^{(1+U_c)} \cdot EXP\left(T_C + 5.832\right) \cdot Year \cdot Location$$

It is assumed that the cost of capital maintenance varies by year and location in line with road construction hence the relevant RCTPI coefficients are used.

Table 10: Coefficient values, model of m² wearing course/km of road.

Regression Coefficients		Coeff.	Error
I_{wc}	Intercept	16040.97	0.0000%
Road Type			
T_{wc}	D4M	35514.2	0.0000%
	D3M	24768.88	0.0000%
	D2M	20681.8	0.4445%
	D3	15424.76	0.0000%
	D2	7679.659	0.0006%
	D2/S2	6939.33	3.4391%
	S2	0	-
Scheme Type			
S_{wc}	Motorway Widening	-16750.1	0.5457%
	Other Road Widening	-6051.81	5.0204%
	Other	0	-
Authority			
A	Local Authority	-3172.06	7.4700%
	Highways Agency	0	-
Urbanisation			
U_{wc}	Urban	3813.33	1.6075%
	Rural	0	-

Regression Coefficients		Coeff.	Error
Road Type			
T_C	D4M	0.743459	0.0000%
	D3M	0.450212	0.0003%
	D2M	0.620883	0.0000%
	D3	0.418171	0.3032%
	D2	0.318537	0.0014%
	D2/S2	?	100%
	S2	0	-
Urbanisation			
U_C	Urban	-0.22244	0.0000%
	Rural	-0.24095	0.0000%

Routine Maintenance

The data provided by the highways agency did not included costs of routine maintenance costs. The problem of analysing these costs is not simple as the small sample of studies discussed in the literature review indicates. However, the cost of routine maintenance is relatively small in comparison to the other costs considered in this report. Thus, for the purpose of this project an estimate of the correct order of magnitude will be satisfactory. Using the data available in the reports *Maintaining England's Trunk Roads and Motorways* (NAO, 2003) and *Maintaining Scotland's Roads* (Audit Scotland, 2003) the routine maintenance costs shown in Table 11 have been developed. This gives routine maintenance costs varying by region. No information could be found giving a breakdown of values for regional winter maintenance costs in England and Wales and since these values are largely dependent on the climate and terrain of the area they cannot be estimated from the RCTPI. Therefore the average value for England has been applied to all regions except Scotland, for which a separate value could be calculated from the data in Maintaining Scotland's Roads (Audit Scotland, 2003).

Table 11: Routine and winter maintenance costs per lane kilometre by region (£ pa).

	Scotland	North	Wales	Midlands	East	South East	South West	London
Winter	1118	985	985	985	985	985	985	985
Routine	4472	4029	4528	4087	4092	4990	4432	5036
Total	**5513**	**4967**	**5582**	**5039**	**5045**	**6152**	**5464**	**6209**

Land Costs

The data supplied by the Highways Agency do not include land acquisition costs. The model for land cost is therefore developed in two stages: Firstly the area of land is found using the model for wearing course laid per kilometre in road construction together with an estimation of the area of land required per m^2 of wearing course, developed from the Design Manual for Roads and Bridges (DMRB, 1996). Secondly the cost of purchasing this land is found using a land price index (Valuation Office Agency, 2005).

Area of land per kilometre of road

Using the Design Manual for Roads and Bridges (DMRB, 1996) the design widths of wearing course and required land foot print can be calculated for sections of flat road without junctions. Table 12 and Table 13 display these design values together with the factor by which the area of land required exceeds the area of wearing course. It is these factors rather than the design widths which are used to model land area/kilometre.

Table 12: Width or road and land footprint, urban roads.

Road	WC (m)	LAND (m)	Factor Land/WC
D4M	39.1	41.1	1.051
D3M	31.9	33.9	1.063
D2M	24.5	26.5	1.082
D3	24.25	26.25	1.082
D2	16.85	18.85	1.119
S2 A	12	14	1.167
S2 B&C	9.3	11.3	1.215

Table 13: Width of road and land foot print, rural roads.

Road	WC (m)	LAND (m)	Factor Land/WC
D4M	39.8	42.8	1.075
D3M	32.6	35.6	1.092
D2M	26.6	29.6	1.113
D3	30.5	37.5	1.230
D2	23.1	30.1	1.303
S2 A	12	19	1.583
S2 B&C	9.3	16.3	1.753

Taking the previously developed model for m^2 wearing course/kilometre of road together with the relevant land factor from the above tables the area of land/kilometre of road can be modelled as follows:

$$A = \left(I_{wc} + T_{wc} + A + U_{wc}\right) \cdot Factor$$

Table 14: Coefficients, model land area/kilometre of road.

Regression Coefficients		Coeff.	Error
I_{wc}	Intercept	16040.97	0.0000%
Road Type			
T_{wc}	D4M	35514.2	0.0000%
	D3M	24768.88	0.0000%
	D2M	20681.8	0.4445%
	D3	15424.76	0.0000%
	D2	7679.659	0.0006%
	D2/S2	6939.33	3.4391%
	S2	0	-
Authority			
A	Local Authority	-3172.06	7.4700%
	Highways Agency	0	-
Area Type			
U	Urban	3813.33	1.6075%
	Rural	0	-

Land cost/km of road

Once the area of land per kilometre of road has been calculated, land cost can be found using the rural or urban land price indices from the Valuation Office Agency (2005). The land prices are given as (cost/m^2) according to year of purchase and region for rural and urban land. The cost of land is therefore given by:

$$L(x) = A \cdot x \cdot (\text{cost/m}^2)$$

Or in terms of number of lanes:

$$L(w) = \frac{A \cdot w \cdot (\text{cost/m}^2)}{n_T}$$

$w =$ length of lanes (km)

$\therefore\ w = x \cdot n_T$

Where:

$n_T =$ number of lanes of road type (T)

The cost of extra land for a road widening scheme is found from the difference between the cost of land for the widened road minus the cost of the land required for the original road.

The land prices given in the tables are average values within each region; the model for land price per kilometre of road will therefore only give an average land cost per kilometre of road. (Note that London has its own region and therefore its own land price.) While this will tend to underestimate the value of land in some large cities the level of detail is in keeping with the models for construction and maintenance costs. Furthermore, the source of the data is reliable and it is updated on regular basis, allowing this method to be used in the future.

Rental Cost

With values of cost per kilometre and per lane kilometre for road construction or widening, major maintenance and land acquisition it is now possible to calculate the rental cost per lane kilometre. In order to do so, a suitable choice of the discount rate must be made. In the UK, the Treasury's Green Book (HM Treasury, 2006) provides detailed advice for economic analysis of public projects including appropriate discount rates. Prior to 2003 the discount rate was set at 6% real, while public projects funded using the Private Finance Initiative (PFI) or by Public-Private Partnership (PPP) could be discounted at up to 8% (Grout, 2003). However, such a high discount rate not only accounts for the change in economic costs or benefits over time, but also factored for optimism bias. "Optimism bias is the demonstrated systematic tendency for appraisers to be over-optimistic about key project parameters" (HM Treasury, 2006). Therefore, the latest Treasury guideline states that a 3.5% discount rate should be applied to all projects and proper account should be taken of optimism bias.

The model for construction costs in this project is based upon tender costs. Optimism bias must be accounted for by factoring the typical "mark up" between tender prices and construction out-turn costs. The rental cost will therefore take account of optimism bias. A value of 30.5%[3] is used as the mark up from tender to out-turn costs, calculated from information provided by the Highways Agency.

[3] Sample weighted average of 28% pre 1995 and 40%, resulting from a more aggressive approach by contractors to bid process, post 1995 (personal communication, 10/04/2006)

Results

Construction and maintenance costs

In the following cost tables we assume a real discount rate of 3.5% pa, a scheme life of 100 years, an optimism bias factor of 1.3 and a capital maintenance interval of 0.075 (i.e. 7.5% of the network is undergoing capital maintenance each year).

Tables 15 and 16 display the capital costs *per lane km*, excluding land costs. They show the differences between rural and urban roads—implicitly incorporating the typical variation in the frequency of junctions—and the variation across the Regions. They are the main component of the estimates of the costs of constructing and widening roads, including the land costs, *per road km*. shown in Tables 17 and 18. Note that only one, generic land cost is used for London which will understate costs in Central London but overstate them in outer London.

Note that these results are, of necessity, a reflection of the particular schemes in the data from which they are derived. They are not a scientifically selected representative sample of schemes. Therefore, they cannot be assumed to be typical of all schemes to be undertaken in the future. There are some "peculiarities" in the estimates shown in these tables and some of these will be due to the fact that the particular schemes in the sample were atypical for some, unknown reason.

These Tables contain more detail by road type and location than the previous studies known to us, reported above. This makes direct comparison complicated. Broadly speaking they are similar to, but somewhat higher than the estimates by Starkie in Table 1. They are somewhat lower than the costs used by Bayliss and Muir Wood shown in Table 2, but (unsurprisingly, since the source of the data were the same) not dissimilar to the Highways Agency estimates that they based their own figures on in Table 3. However, Bayliss and Muir Wood did not distinguish between rural and urban, or between the Regions. Note how our estimates show higher urban costs in the South East and, particularly London as one would expect.

Tables 19 and 20 translate these capital costs into an annual cash flow by amortising the initial capital costs and periodic capital maintenance costs over the one hundred year life of the road, and adding annual maintenance costs.

Revenues

The final stage of our analysis is to compare these unit costs of capacity expansion with the revenues from road pricing. These revenues are as estimated in Glaister and Graham (2006a) in which two scenarios were considered: either the revenue is all held for general local or national expenditure purposes (we call this "revenue additional") or it is all returned to the *national* community of charged road users by rebating fuel duties ("revenue neutral").

The tax revenue neutrality is calculated from a national Exchequer viewpoint. The charges would not be neutral from the point of view of most individuals or groups of individuals. For instance, it would change the balance between cars and commercial vehicles. With the revenue additional policy some of the money would undoubtedly be used for transport purposes such as public transport and road improvements but we assume that the benefits are general. They are taken to be £1 per £1 of revenue. Under the revenue neutral policy there is, by definition, no new money available. Under both policies we are neglecting the important issues of exemptions and of the cost of implementing and operating the charging system.

Table 15. Costs of constructing and widening roads, excluding land costs (£m per lane km, 2005 prices).

RURAL

Road Type	Lanes per direction	Scotland	Wales	North East	North West & Merseyside	Yorkshire & The Humber	Eastern	South West	South East	London	East Midlands	West Midlands
D4MNEW	4											
D3MNEW	3	1.2	1.1	1.4	1.4	1.4	1.4	1.5	1.5		1.2	1.2
D2MNEW												
D3NEW	3	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8		0.6	0.6
D2 D3NEW	2.5	1.5	1.5	1.8	1.8	1.8	1.8	1.9	2.0		1.5	1.5
D2NEW	2	0.8	0.8	1.0	1.0	1.0	0.9	1.0	1.0		0.8	0.8
D2S2NEW	1.5											
S2 HA	1	1.1	1.1	1.3	1.3	1.3	1.3	1.4	1.4		1.1	1.1
S2 LA	1	0.7	0.7	0.9	0.9	0.9	0.8	0.9	0.9		0.7	0.7
D4MWID	1											
D3MWID	1	3.1	3.0	3.7	3.7	3.7	3.6	3.9	4.0		3.1	3.1
D3 WID	1											

Table 16. Costs of constructing and widening roads, excluding land costs (£m per lane km, 2005 prices).

URBAN

Road Type	Scotland	Wales	North East	North West & Merseyside	Yorkshire & The Humber	Eastern	South West	South East	London	East Midlands	West Midlands
D4MNEW	3.1	3.0	3.6	3.6	3.6	3.5	3.9	4.0		3.1	3.1
D3MNEW	1.6	1.5	1.9	1.9	1.9	1.8	2.0	2.0	5.7	1.6	1.6
D2MNEW											
D3NEW	1.5	1.4	1.7	1.7	1.7	1.7	1.8	1.9	5.2	1.5	1.5
D2 D3NEW	1.2	1.1	1.4	1.4	1.4	1.3	1.4	1.5	5.5	1.2	1.2
D2NEW	1.2	1.1	1.4	1.4	1.4	1.3	1.5	1.5	4.2	1.2	1.2
D2S2NEW	1.5	1.5	1.8	1.8	1.8	1.7	1.9	2.0	5.5	1.5	1.5
S2 HA *	0.6	0.5	0.7	0.7	0.7	0.7	0.7	0.7	2.1	0.6	0.6
S2 LA *	0.6	0.5	0.7	0.7	0.7	0.7	0.7	0.7	2.1	0.6	0.6
* no significant difference found											
D4MWID	3.5	3.4	4.2	4.2	4.2	4.0	4.4	4.6	10.1	3.5	3.5
D3MWID	4.1	3.9	4.8	4.8	4.8	4.7	5.1	5.3	14.7	4.1	4.1
D3 WID	2.0	2.0	2.4	2.4	2.4	2.3	2.6	2.7	7.3	2.0	2.0

Table 17. Costs of constructing and widening rural roads including land costs (£m per road km, 2005 prices).

RURAL

Road Type	Lanes per direction	Scotland	Wales	North East	North West & Merseyside	Yorkshire & The Humber	Eastern	South West	South East	London	East Midlands	West Midlands
D4MNEW	4											
D3MNEW	3	7.2	6.9	8.4	8.5	8.5	8.2	9.0	9.3		7.2	7.2
D2MNEW	0											
D3NEW	3	3.8	3.6	4.4	4.5	4.5	4.3	4.7	4.9		3.8	3.8
D2 D3NEW	2.5	7.7	7.4	9.1	9.1	9.1	8.8	9.6	10.0		7.7	7.7
D2NEW	2	3.2	3.1	3.8	3.8	3.8	3.7	4.1	4.2		3.3	3.3
D2S2NEW	1.5											
S2 HA	1	2.2	2.1	2.6	2.6	2.6	2.5	2.8	2.9		2.2	2.2
S2 LA	1	1.5	1.4	1.7	1.7	1.7	1.7	1.8	1.9		1.5	1.5
D4MWID	1											
D3MWID	1	6.2	6.0	7.3	7.3	7.3	7.1	7.8	8.1		6.2	6.2
D3 WID	1											

Table 18. Costs of constructing and widening urban roads including land costs (£m per road km, 2005 prices).

URBAN

Road Type	Scotland	Wales	North East	North West & Merseyside	Yorkshire & The Humber	Eastern	South West	South East	London	East Midlands	West Midlands
D4MNEW	25.1	24.1	29.4	29.4	29.4	28.7	31.3	32.4		25.1	25.1
D3MNEW	9.6	9.2	11.2	11.3	11.2	11.0	12.0	12.4	34.1	9.6	9.6
D2MNEW											
D3NEW	8.9	8.5	10.4	10.4	10.4	10.1	11.1	11.5	31.5	8.9	8.9
D2 D3NEW	5.8	5.6	6.8	6.9	6.8	6.7	7.3	7.5	27.7	5.9	5.8
D2NEW	4.8	4.6	5.6	5.6	5.6	5.5	6.0	6.2	16.9	4.8	4.8
D2S2NEW	4.7	4.5	5.5	5.5	5.5	5.4	5.9	6.0	16.5	4.7	4.7
S2 HA *	1.2	1.2	1.4	1.4	1.4	1.4	1.5	1.6	4.2	1.2	1.2
S2 LA *	1.2	1.2	1.4	1.4	1.4	1.4	1.5	1.6	4.2	1.2	1.2
* no significant difference found											
D4MWID	7.2	7.0	8.4	8.4	8.4	8.3	9.0	9.3	20.3	7.2	7.2
D3MWID	8.2	7.9	9.7	9.7	9.7	9.4	10.3	10.7	29.4	8.2	8.2
D3 WID	4.1	4.0	4.8	4.8	4.8	4.7	5.2	5.3	14.7	4.1	4.1

Table 19. Annual rental costs of rural roads, including land and maintenance costs

(£ thousands per lane km, 2005 prices)

RURAL

Road Type	Lanes per direction	Scotland	Wales	North East	North West & Merseyside	Yorkshire & The Humber	Eastern	South West	South East	London	East Midlands	West Midlands
D4MNEW	4											
D3MNEW	3	72.3	69.1	84.3	84.3	84.3	81.9	89.5	93.2		72.1	72.2
D2MNEW												
D3NEW	3	49.0	46.9	56.9	56.9	57.0	55.4	60.5	63.1		48.8	48.9
D2 D3NEW	2.5	79.9	76.3	93.2	93.2	93.3	90.6	99.0	103.0		79.7	79.8
D2NEW	2	54.3	52.0	63.1	63.2	63.2	61.4	67.1	69.9		54.2	54.3
D2S2NEW	1.5	31.6	30.3	36.3	36.4	36.4	35.5	38.7	40.5		31.4	31.6
S2 HA	1	63.2	60.5	73.6	73.7	73.7	71.6	78.2	81.5		63.1	63.2
S2 LA	1	47.3	45.4	54.9	55.0	55.0	53.5	58.4	61.0		47.2	47.4
D4MWID	1											
D3MWID	1	131.6	125.6	154.0	154.1	154.1	149.6	163.4	169.8		131.4	131.4
D3 WID	1											

Table 20. Annual rental costs of urban roads, including land and maintenance costs

(£ thousands per lane km, 2005 prices)

URBAN

Road Type	Scotland	Wales	North East	North West & Merseyside	Yorkshire & The Humber	Eastern	South West	South East	London	East Midlands	West Midlands
D4MNEW	179.9	172.3	210.3	210.5	210.3	204.8	223.7	232.0		179.9	179.6
D3MNEW	95.1	91.3	110.8	110.9	110.7	108.0	118.0	122.4	258.8	95.1	94.8
D2MNEW											
D3NEW	87.0	83.5	101.2	101.3	101.2	98.7	107.8	111.9	237.7	86.9	86.7
D2 D3NEW	73.1	70.2	84.9	85.0	84.9	82.8	90.5	93.9	244.0	73.0	72.8
D2NEW	75.2	72.3	87.4	87.5	87.3	85.3	93.2	96.7	198.8	75.2	74.9
D2S2NEW	96.9	93.2	112.7	112.9	112.7	110.1	120.2	124.7	257.6	96.9	96.6
S2 HA	51.6	50.0	59.4	59.6	59.4	58.4	63.7	66.0	118.4	51.6	51.3
S2 LA	48.5	47.0	55.8	56.0	55.8	54.8	59.8	62.0	113.9	48.5	48.2
D4MWID	243.5	233.6	284.6	285.0	284.6	277.5	303.1	314.1	532.4	243.8	243.1
D3MWID	172.4	164.7	201.9	201.9	201.9	196.2	214.3	222.5	565.2	172.2	172.1
D3 WID	111.4	106.7	130.0	130.1	130.0	126.6	138.3	143.6	318.6	111.3	111.1

Table 21 summarises the results of the two “polar” policies.

Table 21. Economic performance of revenue additional and revenue neutral policies (£ billion per annum)

	Change in traveller benefit	Saving in environmental costs	Change in tax & charge revenue	Net benefit
Revenue additional	-8.18	2.10	15.77	9.68
Revenue neutral	6.32	0.46	0	6.77

Source: Glaister and Graham (2006a)

Both policies produce overall net benefits, the revenue additional policy rather more. They both produce a saving in environmental costs, the revenue additional policy substantially more because, in addition to achieving a more efficient (that is, lower environmental cost) pattern of usage of the road network, it reduces total national traffic.

There is a crucial difference between the two policies: with revenue additional policy motor vehicle users as a group are definitely worse off. The environmental cost savings and the tax revenues both represent benefits to others (and to road users in the other aspects of their lives) and they are more than sufficient to outweigh the disbenefits to road users. With revenue neutrality road users as a group are made better off. In effect the compensation is made.

Note that in the illustrative maps in Figures 4 and 5 there has been considerable averaging, particularly by time of day: the changes displayed relate to a weighted average across the week. The changes are substantially greater at peak times.

Figure 4 displays an estimate of the average traffic volume changes experienced in each census ward in Great Britain under a revenue additional policy. Figure 5 displays the corresponding revenue neutral policy.

Under either policy there is a marked difference between the impact on urban areas and the much larger rural areas. The busy urban areas experience similar traffic reductions—congestion is treated aggressively in both cases. With the revenue additional policy the rural areas experience a small reduction in traffic: there is no congestion charge but a relatively small charge reflecting the environmental damages. But with the revenue neutral policy the rural areas experience a 22 to 26 percent increases in traffic. This is because the revenues earned in the urban areas are used to reduce the cost of fuel.

Tables 22 to 26 display summaries of the revenues by Region under the various bases for calculation.

Table 22. Gross revenues from charges by region. Revenue additional (£m pa)

E Ang	E Mids	London	North East	North West	South East	South West	West Mids	Yorks & Humber	Scotland	Wales	Total
1303	1094	4767	834	1479	1886	1044	1314	1155	883	505	16262

Table 23. Gross revenues from charges by region net of environmental charges. Revenue additional (£m pa)

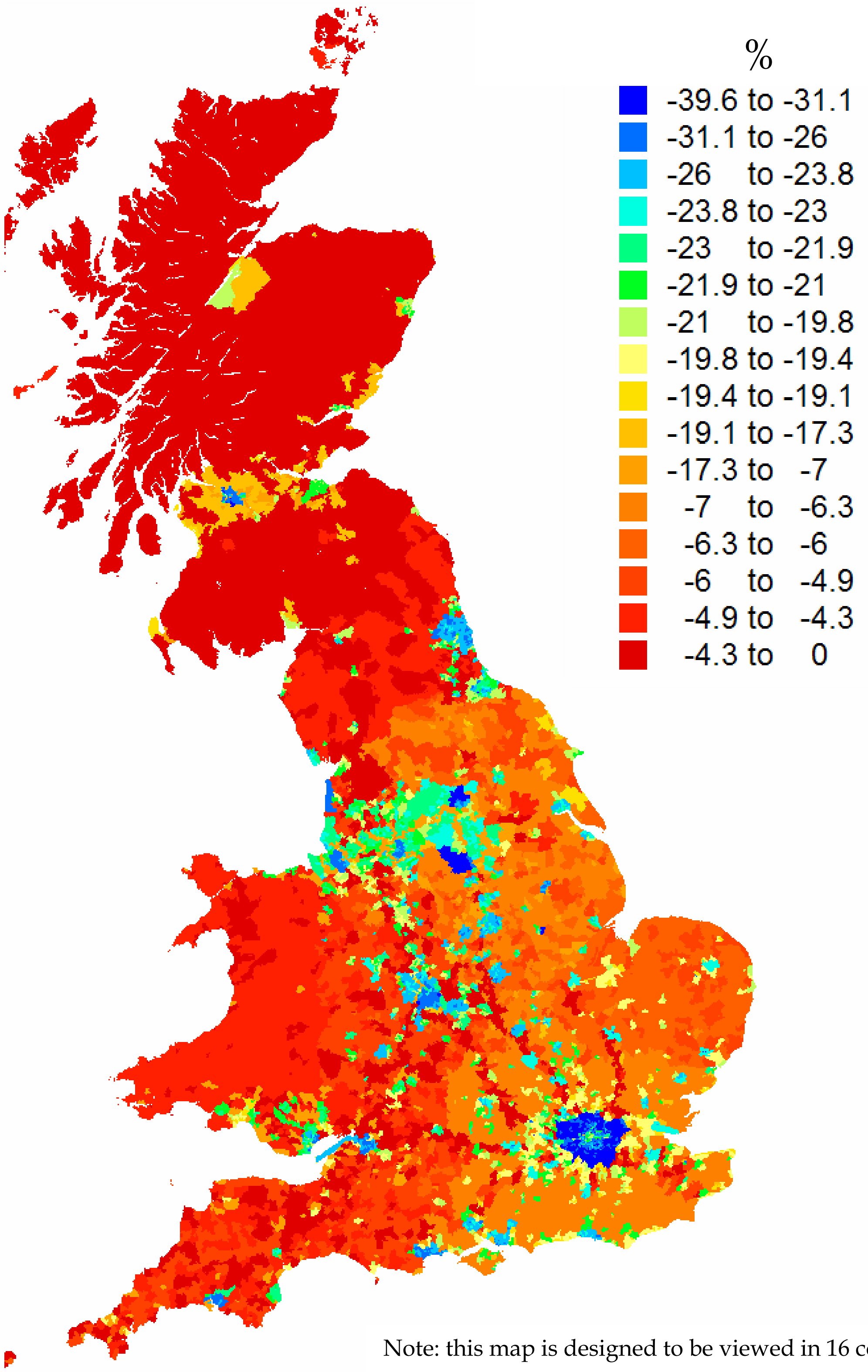
E Ang	E Mids	London	North East	North West	South East	South West	West Mids	Yorks & Humber	Scotland	Wales	Total
209	234	3723	388	167	335	114	272	159	35	53	5689

Table 24. Gross revenues from charges by region net of environmental charges and fuel duty adjustment. Revenue additional (£m pa)

E Ang	E Mids	London	North East	North West	South East	South West	West Mids	Yorks & Humber	Scotland	Wales	Total
1221	1012	4207	650	1251	1812	972	1191	951	709	458	14433

Figure 4. Average percentage traffic changes by census ward, GB, 2010

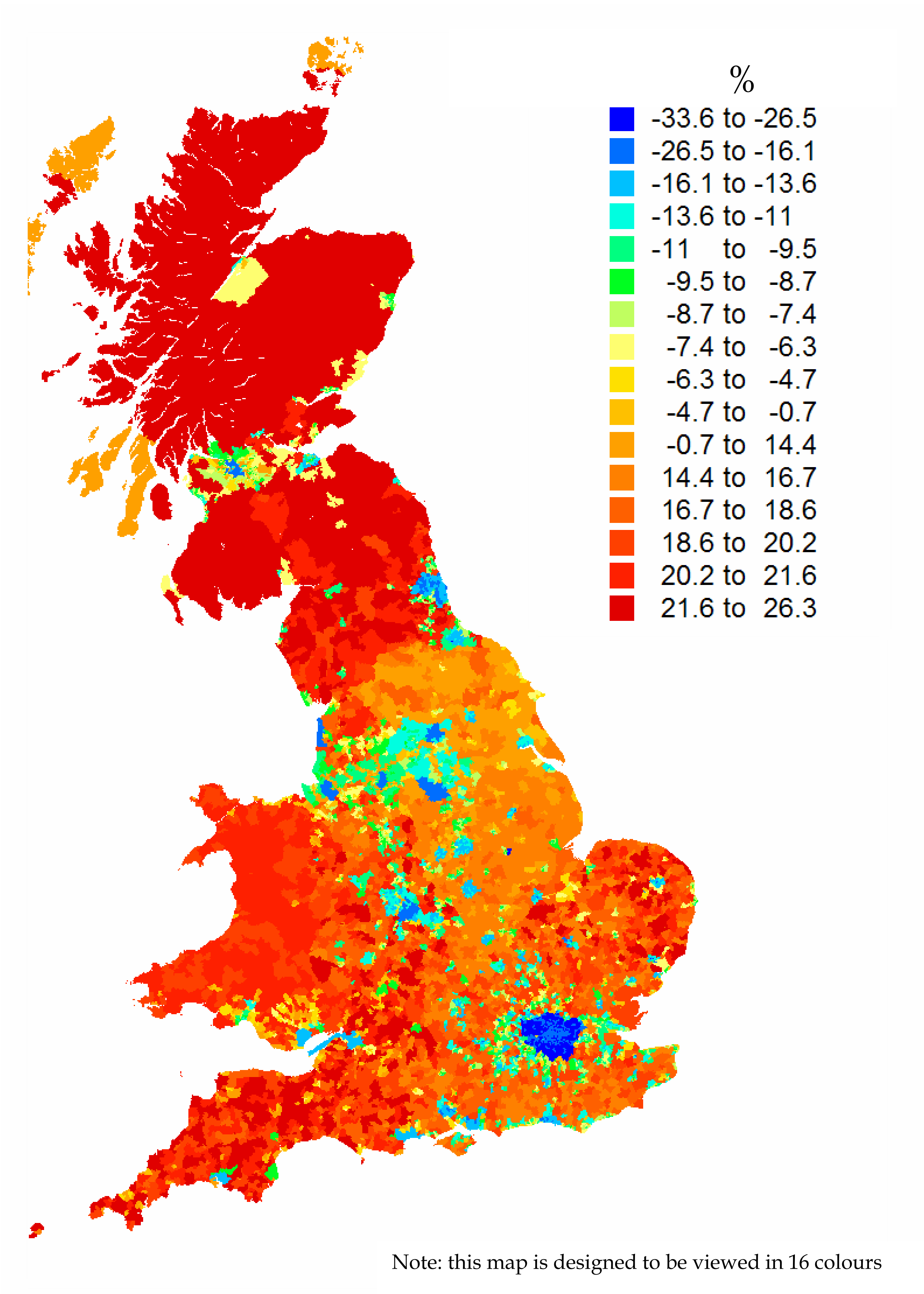
Additional revenue: £16 billion per annum



Note: this map is designed to be viewed in 16 colours

Figure 5. Average percentage traffic changes by census ward, GB, 2010

Revenue neutral



Source for Figures 4 and 5: Glaister and Graham (2006a)

Table 25. Gross revenues from charges by region. Revenue neutral (£m pa)

E Anglia	E Mids	London	North East	North West	South East	South West	West Mids	Yorks & Humber	Scotland	Wales	Total
-675	-314	4297	347	-278	-1167	-879	-285	-62	-529	-456	-1

Table 26 Gross revenues from charges by region net of environmental charges. Revenue neutral (£m pa)

E Anglia	E Mids	London	North East	North West	South East	South West	West Mids	Yorks & Humber	Scotland	Wales	Total
-1949	-1317	3167	-168	-1793	-2986	-1984	-1498	-1217	-1519	-997	-12260

Widening versus building new

Our cost tables above offer some estimates of costs per lane kilometre for widening as well as for new roads. As Tables 19 and 20 show widening tends to be more expensive than building new. The following analysis is entirely in terms of building new. However, where it is proposed to increase capacity by widening the analysis would have the same revenues and higher costs – so the case for expansion would be weaker.

Revenues in relation to costs: the revenue neutral case

We now display the detailed results, by Region and by area type. We first discuss the Revenue Neutral case, net of environmental costs. That is probably the closest of our scenarios to an economically efficient pricing regime, especially in the congested areas. Table 27 shows, for each Region, the ratio of revenue to cost, by degree of urbanisation and road type. In cases where the ratio is greater than unity—where revenues exceed costs—the entries are shaded and shown in bold type. The respective lengths of road in the base data are also shown in the right hand half of each panel as an indication of how much there is of the road type corresponding to each respective ratio. The urban areas where Table 27 suggests there may be a strong case for building more roads can be related to the area marked in blue in Figure 5.

It is important to note that each cell in the left hand panel of Table 27 is an average figure. Within that there will be particular instances where the ratio is much lower and others where it is much higher. Therefore, just because a particular cell is less than unity it does not follow that there would be no schemes at all in that category that would meet the criteria. Similarly, if it is greater than unity it does not follow that all individual schemes in that category would be worthwhile.

In no case in Table 27 is there an indication that there should be a capacity expansion in the rural areas.

In the urban areas there is a wide range of outcomes. In the East of England Region there are 336 km. of major roads in towns with a population over 100,000 where revenues are more than five times the costs. The map indicates that these places include Cambridge, Colchester, Ipswich, Norwich and Peterborough.

In East Midlands the ratios between 2.5 and 4.5 for 243 km. of roads in towns with a population above 250,000. These include Derby, Leicester and Nottingham. There is a more severe problem with a ratio of 8.2 for 114 km. of major road in towns with a population over 100,00 which the map in Figure 5 indicates includes Grantham and Lincoln.

In London, for the major roads the ratios range from 5.8 to 10.6 on a total of 812 km. of major roads. In Outer London the revenues are nearly ten times the costs on 235 km. of major roads. This indicates that there are serious problems of road capacity shortage in London. Costs could, in practice, turn out to be much higher than our estimates and still leave plenty of revenue "coverage".

The North East Region shows a highest excess of revenue over cost: a ratio of 21.5 on 17 km. of Inner Conurbation major roads in Newcastle upon Tyne and 11.3 on a further 56 km. of Outer Conurbation major roads. There are a further 25 km. of major roads with a ratio of 8.3 in town with a population exceeding 250,000; Sunderland is one urban area falling into this category. The more extreme figures for this Region may look a little odd in relation to common experience in the area. However, officials working in the area confirm to us that the traffic and congestion data have suggested problems for a long time. It could be because the boundaries of Tyne and Wear are drawn more tightly around the built up area than is the case with other conurbations, all of which enclose larger hinterlands and the trunk road network is dominated by a couple of roads which combine to form the "Newcastle Western Bypass".

The North West Region contains both the Merseyside and Greater Manchester conurbations. The map in Figure 5 indicates that there are congestion problems in both of these. However, Table 27 indicates that generally the road pricing revenues in relation to costs would be low compared to most other Regions.

The South East Region shows a ratio of 18.5 for 32 km. of major roads in towns with a population over 250,000., between 4.0 and 7.5 for 152 km. of major roads in towns with a population over 100,000 and 13.9 for 20 km of major roads in smaller towns. The locations are widely spread but will probably include Reading and several locations on the South Coast such as Brighton, Portsmouth, and Southampton.

In the South West there is a case for expansion in the case of 272 km of major roads in towns with a population exceeding 250,000. These probably include Bournemouth, Bristol and Plymouth.

The most severe problems in the West Midlands appear to relate to 36 km. of major roads in towns with population above 250,000 where revenues exceed costs by a ratio of 6.3: possibly places such as Coventry. The ratio is 3.1 for 184 km of major roads in the West Midlands inner conurbation. It is 1.5 for 387 km. of major roads in the outer conurbation and 45 km in medium sized settlements such as Stafford and Newcastle under Lyme.

In Yorkshire and the Humber the ratio exceeds 3 for 200 km. of major roads in the inner conurbations and it is 4.9 for a further 19 km. of major roads in the largest towns. This may include Bradford, Leeds and Sheffield.

Scotland seems to have a particularly severe problem with shortage of major roads in very large cities with a population exceeding 250,000 where, for 12 km. revenues exceed costs by a factor of 29.7: this may be Edinburgh. Also there is a ration of 7.5 for 65 km. of outer conurbation road, in Glasgow. Wales displays some severe shortages over 78 km. of major roads in the Cardiff area.

In most of the Regions there is an indication that it would be worthwhile building major new roads in urban areas. Building new roads in built up areas is clearly disruptive and particularly unpopular, but this is the kind of situation in which tunnelling could be an economic and acceptable solution. As noted from Table 2, tunnelling can increase construction costs by a factor of up to six, operating costs tend to be greater but land costs would be lower. In many of the urban cases in Table 27 the ratio of revenues to costs is above six to one, often substantially so. That suggests that tunnelling may be a viable solution in a significant number of cases. It can be done for the Channel Tunnel Link and Crossrail and many other places on the railways so it is worth investigation for roads.

The revenue additional cases

Table 28 repeats this analysis for the Revenue Additional case. Within the accuracy of our analysis there is no difference from the Revenue Neutral case just discussed: the situation is similar in the congested, urban circumstances and, as one would expect, there is no need for more rural roads under either scenario.

Table 29 repeats again, for the Revenue Additional case but with the correction for the fact that in this case there would be a smaller call on the taxpayer than with the Revenue Neutral case. Other things being equal there is a saving in the economic cost associated with having to collect taxes and this saving is credited to the road pricing revenues. In the urban areas, whilst revenues are raised somewhat relative to the (unchanged) costs the results are not qualitatively very different to the previous two cases. But there is a substantial difference in the rural areas of all the Regions: in every Region it now becomes strongly worthwhile building new rural Motorways. In some cases dual lane Trunk roads also show as worthwhile.

Sensitivities

The annual costs of new road capacities are sensitive to several assumptions we have made. In particular, a higher cost of capital (or discount rate, presently set at 3.5 % pa real) or a higher mark up for optimism bias (currently set at 30.5%) or a shorter maintenance interval (currently 7.5 % of the network is assumed to be undergoing capital maintenance each year) would all increase annual costs, and *vice versa*. Changing the assumed life of a new road (currently 100 years) makes little difference, so long as the change is not unreasonably dramatic.

Of course, there are important items of cost that we have not accounted for in our work. For instance, costs associated with loss of landscape or amenity. Also, we have used a particular environmental cost for carbon dioxide emissions which some would argue to be too low.

In considering a "snapshot" in 2010 we have ignored the growth in benefits that will occur as traffic demand grows with real incomes into the future. In practice that would increase future road pricing revenues for two reasons, partly because of increasing traffic volume and partly because the charges themselves would rise in increasingly congested conditions. This is an important factor causing us to underestimate the benefits of new roads.

Our software makes it easy to restate our results after changing any or all of the assumptions. We have not presented results in this document because of the considerable space they would consume.

Table 27. Ratio of revenues to costs and km. of road, by road type and Region. Revenue neutral, net of environmental cost

E Ang — Ratio revenue:cost

E Ang		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Area	Central Lon							
	Inner Lon							
	Outer Lon							
	Inner Conurb							
	Outer Conurb							
	>250k							
	>100k				7.2	5.5	-0.3	-0.2
	>25k				0.7	-0.7	-0.4	-0.2
	>10k				0.0	-0.9	-0.2	-0.3
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
	Rural	-13.3	-8.3	-5.0	-2.5	-0.4	-0.7	-0.2

E Ang — Kilometres of road

E Ang		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon								0
	Inner Lon								0
	Outer Lon								0
	Inner Conurb								0
	Outer Conurb								0
	>250k								0
	>100k				28	307	384	2,296	**3,015**
	>25k				125	496	747	4,729	**6,098**
	>10k				45	133	351	978	**1,507**
		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	
	Rural	264	477	68	463	1,738	2,930	22,222	**28,162**
		264	**477**	**68**	**661**	**2,674**	**4,412**	**30,226**	**38,782**

E Mids — Ratio revenue:cost

E Mids		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Area	Central Lon							
	Inner Lon							
	Outer Lon							
	Inner Conurb							
	Outer Conurb							
	>250k				2.6	4.5	-0.1	-0.3
	>100k				-0.4	8.2	-0.2	-0.2
	>25k				-1.5	-1.4	-0.2	-0.3
	>10k				-0.9	-0.6	-0.3	-0.2
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
	Rural	-13.4	-7.4	-5.0	-1.5	-1.0	-0.4	-0.1

E Mids — Kilometres of road

E Mids		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon								0
	Inner Lon								0
	Outer Lon								0
	Inner Conurb								0
	Outer Conurb								0
	>250k				36	206	292	2,332	**2,867**
	>100k				37	114	155	1,348	**1,654**
	>25k				111	271	509	1,912	**2,804**
	>10k				70	129	425	1,180	**1,804**
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	194	367	89	596	1,799	1,677	18,154	**22,875**
		194	**367**	**89**	**850**	**2,519**	**3,059**	**24,926**	**32,003**

Table 27 (cont) Ratio of revenues to costs and km. of road, by road type and Region.
Revenue neutral, net of environmental cost

London	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon	0.0			9.9	6.2	6.8	0.1				8	87	62	392	**549**
Inner Lon	-1.8			10.6	5.8	1.8	0.1	6			77	405	454	2,980	**3,923**
Outer Lon	-5.3			9.8	0.7	0.4		61			235	914	842	8,210	**10,262**
Inner Conurb															**0**
Outer Conurb															**0**
>250k															**0**
>100k															**0**
>25k															**0**
>10k															**0**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural															**0**
								67	**0**	**0**	**319**	**1,407**	**1,358**	**11,583**	**14,733**

North E	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	Total
Central Lon															**0**
Inner Lon															**0**
Outer Lon															**0**
Inner Conurb	-5.6			21.5	1.6	-0.1	-0.1	4			17	85	138	933	**1,178**
Outer Conurb	-4.3			11.3	0.2	-0.1	-0.1	8			56	252	367	1,968	**2,650**
>250k				8.3	1.0	-0.1	-0.2				25	114	85	1,116	**1,340**
>100k															**0**
>25k				-0.7	-1.0	-0.3	-0.2				26	233	192	1,540	**1,991**
>10k				-0.4	-0.4	-0.2	-0.1				10	31	56	160	**256**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	-7.0	-4.5	-3.6	-1.5	-0.6	-0.3	-0.1	46	132	37	171	568	975	6,704	**8,633**
								58	**132**	**37**	**306**	**1,284**	**1,812**	**12,421**	**16,048**

Table 27 (cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue neutral, net of environmental cost

North W	**Ratio revenue:cost**							**Kilometres of road**							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	**Total**
Central Lon															**0**
Inner Lon															**0**
Outer Lon															**0**
Inner Conurb	-6.6			**3.7**	**1.7**	**1.8**	-0.1	31			1	327	250	3,130	**3,739**
Outer Conurb	-8.3			-0.5	-0.1	-0.2	-0.2	198			103	872	1,272	8,133	**10,579**
>250k				-1.4	-0.1	0.6	-0.2				9	71	82	722	**884**
>100k				-1.8	0.4	-0.3	-0.2				3	183	155	916	**1,258**
>25k				-0.6	-1.0	-0.3	-0.2				71	370	491	3,286	**4,218**
>10k				-1.0	-0.3	-0.3	-0.1				27	64	34	702	**827**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	-9.7	-4.7	-3.2	-0.6	-0.4	-0.6	-0.1	396	106	31	507	1,250	1,064	11,674	**15,027**
								625	**106**	**31**	**721**	**3,137**	**3,349**	**28,563**	**36,531**

South E	Ratio revenue:cost							**Kilometres of road**							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	**Total**
Central Lon															**0**
Inner Lon															**0**
Outer Lon															**0**
Inner Conurb															**0**
Outer Conurb															**0**
>250k				**18.5**	**2.1**		-0.2				32	213	361	2,190	**2,795**
>100k				**7.5**	**4.0**	-0.3	-0.3				22	130	312	1,329	**1,792**
>25k				**1.3**	-0.7	-0.3	-0.2				143	1,059	1,691	8,628	**11,520**
>10k				**13.9**	-0.3	-0.3	-0.2				20	255	444	1,318	**2,037**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	-11.5	-7.5	-4.3	-1.7	-0.7	-0.6	-0.2	655	388	238	253	2,333	2,259	22,841	**28,966**
								655	**388**	**238**	**470**	**3,989**	**5,066**	**36,305**	**47,110**

Table 27 (cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue neutral, net of environmental cost

South W	Ratio revenue:cost							Kilometres of road							
	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area: Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb															0
Outer Conurb															0
>250k				-0.7	4.5	0.1	-0.1				37	272	373	3,526	4,208
>100k				-1.0	0.1	-0.4	-0.2				29	112	222	1,668	2,030
>25k				-1.0	-0.6	-0.3	-0.2				24	256	785	1,909	2,974
>10k				-0.9	-0.8	-0.2	-0.4				17	192	318	1,101	1,628
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	-9.2	-4.6	-4.5	-1.2	-0.6	-0.5	-0.2	327	363	63	530	3,159	2,914	31,678	39,032
								327	363	63	636	3,990	4,612	39,882	49,872

W Mids	Ratio revenue:cost							Kilometres of road							
	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area: Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb	-10.4				3.1	1.4	-0.1	20				184	146	2,095	2,446
Outer Conurb	-11.0			-0.9	1.5		-0.3	57			59	387	682	4,460	5,645
>250k				6.3	-0.7	-0.2	-0.2				36	105	188	1,198	1,526
>100k					1.5	-0.4	-0.1					45	195	126	366
>25k				-1.2	-2.2	-0.3	-0.1				52	275	471	2,306	3,103
>10k				-0.6	-1.0	-0.1	-0.2				29	70	96	392	587
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	-13.1	-6.8	-4.2	-2.0	-0.7	-0.4	-0.1	309	214	31	449	1,597	1,892	14,108	18,599
								386	214	31	625	2,661	3,670	24,685	32,272

Table 27 (cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue neutral, net of environmental cost

Yorks & Humber		Ratio revenue:cost							Kilometres of road							
		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon															0
	Inner Lon															0
	Outer Lon															0
	Inner Conurb	-7.2			**4.1**	**3.1**	0.6	-0.1	18			6	194	128	2,498	**2,844**
	Outer Conurb	-9.2				-0.2	-0.2	-0.1	232			191	1,135	2,163	8,431	**12,152**
	>250k				**4.9**	**1.2**	-0.2	-0.2				19	41	67	706	**833**
	>100k															**0**
	>25k				-0.9	-0.7	-0.2	-0.2				14	140	221	1,027	**1,402**
	>10k				-0.7	-0.3	-0.2	-0.2				5	56	63	195	**318**
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	-5.8	-5.0	-2.4	-1.9	-0.7	-0.2	-0.1	116	199	13	276	1,029	1,099	10,395	**13,126**
									365	**199**	**13**	**509**	**2,595**	**3,742**	**23,252**	**30,675**

Scotland		Ratio revenue:cost							Kilometres of road							
		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon															0
	Inner Lon															0
	Outer Lon															0
	Inner Conurb	-9.3					0.1	-0.1	43				146	110	2,465	**2,764**
	Outer Conurb	-5.9			**7.5**	-1.1	-0.2	-0.1	71			65	344	741	2,812	**4,033**
	>250k				**29.7**	**1.2**	-0.3	-0.2				12	97	132	898	**1,139**
	>100k				-0.6	-0.3	-0.4	-0.1				37	68	147	572	**824**
	>25k				-0.1	-0.5	-0.4	-0.1				60	196	437	1,798	**2,490**
	>10k				-0.7	-0.7	-0.2	-0.1				49	169	162	1,009	**1,390**
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	-4.7	-5.0	-5.9	-1.2	-0.4	-0.2	-0.1	272	305	42	2,285	6,419	6,487	30,757	**46,566**
									386	**305**	**42**	**2,508**	**7,440**	**8,216**	**40,310**	**59,207**

Table 27 (cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue neutral, net of environmental cost

	Wales	Ratio revenue:cost							Kilometres of road							
		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon															0
	Inner Lon															0
	Outer Lon															0
	Inner Conurb															0
	Outer Conurb															0
	>250k				**35.5**	**9.3**		-0.2				2	76	88	557	**723**
	>100k					**1.7**	-0.3	-0.2					97	82	683	**862**
	>25k				-0.7	-1.2	-0.3	-0.3				47	208	207	1,284	**1,746**
	>10k				-1.3	-0.6	-0.2	-0.3				47	61	592	759	**1,459**
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	-8.6	-6.8	-4.4	-1.5	-0.7	-0.3	-0.1	141	247	80	1,179	2,104	2,771	21,643	**28,164**
									141	**247**	**80**	**1,276**	**2,545**	**3,739**	**24,926**	**32,954**

Table 28 Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost

E Ang	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon															**0**
Inner Lon															**0**
Outer Lon															**0**
Inner Conurb															**0**
Outer Conurb															**0**
>250k															**0**
>100k				**8.0**	**6.5**	0.3	-0.1				28	307	384	2,296	**3,015**
>25k				**1.6**	-0.2	0.1	0.0				125	496	747	4,729	**6,098**
>10k				**1.0**	0.2	0.0	-0.1				45	133	351	978	**1,507**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	
Rural	-1.8	-1.4	-0.6	0.1	0.2	0.0	0.0	264	477	68	463	1,738	2,930	22,222	**28,162**
								264	**477**	**68**	**661**	**2,674**	**4,412**	**30,226**	**38,782**

E Mids	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon															**0**
Inner Lon															**0**
Outer Lon															**0**
Inner Conurb															**0**
Outer Conurb															**0**
>250k				**4.7**	**5.4**	0.6	0.0				36	206	292	2,332	**2,867**
>100k				**1.3**	**9.2**	0.7	0.0				37	114	155	1,348	**1,654**
>25k				-0.2	-0.1	0.5	-0.1				111	271	509	1,912	**2,804**
>10k				-0.4	0.0	0.0	-0.1				70	129	425	1,180	**1,804**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	-1.9	-1.3	-0.7	0.6	-0.1	-0.1	0.0	194	367	89	596	1,799	1,677	18,154	**22,875**
								194	**367**	**89**	**850**	**2,519**	**3,059**	**24,926**	**32,003**

Table 28 (Cont) Ratio of revenues to costs and km. of road, by road type and Region.
Revenue additional, net of environmental cost

London		Ratio revenue:cost							Kilometres of road							
		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon	0.0			10.4	6.4	6.7	0.2				8	87	62	392	549
	Inner Lon	-0.3			10.9	6.1	2.0	0.1	6			77	405	454	2,980	3,923
	Outer Lon	-1.0			10.4	0.9	0.5		61			235	914	842	8,210	10,262
	Inner Conurb															0
	Outer Conurb															0
	>250k															0
	>100k															0
	>25k															0
	>10k															0
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural															0
									67	0	0	319	1,407	1,358	11,583	14,733

North E		Ratio revenue:cost							Kilometres of road							
		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	Total
Area	Central Lon															0
	Inner Lon															0
	Outer Lon															0
	Inner Conurb	-0.7			27.0	2.3	0.2	0.1	4			17	85	138	933	1,178
	Outer Conurb	-0.8			12.1	1.1	0.4	0.0	8			56	252	367	1,968	2,650
	>250k				9.9	1.6	0.4	0.0				25	114	85	1,116	1,340
	>100k															0
	>25k				-0.1	0.0	0.2	0.0				26	233	192	1,540	1,991
	>10k				-0.2	0.0	0.0	0.0				10	31	56	160	256
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	-0.9	-0.9	-0.5	0.0	0.0	0.0	0.0	46	132	37	171	568	975	6,704	8,633
									58	132	37	306	1,284	1,812	12,421	16,048

Table 28 (Cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost

North W — Ratio revenue:cost

Area		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Area	Central Lon							
	Inner Lon							
	Outer Lon							
	Inner Conurb	-1.0			**4.5**	**2.4**	**2.4**	0.1
	Outer Conurb	-1.5			0.7	0.5	0.2	0.0
	>250k				-0.1	0.4	**1.2**	0.0
	>100k				-0.2	**1.1**	0.1	-0.1
	>25k				0.0	-0.2	0.1	0.0
	>10k				-0.2	0.1	0.3	0.0
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
	Rural	-1.7	-1.0	-0.3	0.5	0.1	-0.1	0.0

North W — Kilometres of road

Area		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon								**0**
	Inner Lon								**0**
	Outer Lon								**0**
	Inner Conurb	31			1	327	250	3,130	**3,739**
	Outer Conurb	198			103	872	1,272	8,133	**10,579**
	>250k				9	71	82	722	**884**
	>100k				3	183	155	916	**1,258**
	>25k				71	370	491	3,286	**4,218**
	>10k				27	64	34	702	**827**
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	396	106	31	507	1,250	1,064	11,674	**15,027**
		625	**106**	**31**	**721**	**3,137**	**3,349**	**28,563**	**36,531**

South E — Ratio revenue:cost

Area		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Area	Central Lon							
	Inner Lon							
	Outer Lon							
	Inner Conurb							
	Outer Conurb							
	>250k				**19.6**	**2.9**		0.0
	>100k				**8.6**	**4.8**	0.3	-0.1
	>25k				**2.2**	0.0	0.0	0.0
	>10k				**15.0**	0.4	0.0	0.0
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
	Rural	-1.3	-1.3	-0.5	1.0	0.2	-0.1	0.0

South E — Kilometres of road

Area		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon								**0**
	Inner Lon								**0**
	Outer Lon								**0**
	Inner Conurb								**0**
	Outer Conurb								**0**
	>250k				32	213	361	2,190	**2,795**
	>100k				22	130	312	1,329	**1,792**
	>25k				143	1,059	1,691	8,628	**11,520**
	>10k				20	255	444	1,318	**2,037**
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	655	388	238	253	2,333	2,259	22,841	**28,966**
		655	**388**	**238**	**470**	**3,989**	**5,066**	**36,305**	**47,110**

Table 28 (Cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost

South W

Area	Ratio revenue:cost M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.	Kilometres of road M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.	Total
Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb															0
Outer Conurb															0
>250k				1.2	5.0	0.7	0.0				37	272	373	3,526	4,208
>100k				0.2	1.1	0.3	0.0				29	112	222	1,668	2,030
>25k				-0.1	0.0	0.1	0.0				24	256	785	1,909	2,974
>10k				-0.2	-0.1	0.0	-0.1				17	192	318	1,101	1,628
Rural	-1.4	-1.0	-0.8	0.7	0.0	-0.1	0.0	327	363	63	530	3,159	2,914	31,678	39,032
								327	**363**	**63**	**636**	**3,990**	**4,612**	**39,882**	**49,872**

W Mids

Area	Ratio revenue:cost M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.	Kilometres of road M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.	Total
Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb	-2.4				4.3	1.9	0.1	20			0	184	146	2,095	2,446
Outer Conurb	-1.1			0.9	2.2	0.6	0.0	57			59	387	682	4,460	5,645
>250k				7.7	0.6	0.0	0.0				36	105	188	1,198	1,526
>100k				0.0	2.3	0.2	0.0				0	45	195	126	366
>25k				0.6	-0.6	0.2	-0.1				52	275	471	2,306	3,103
>10k				-0.1	0.0	0.5	-0.1				29	70	96	392	587
Rural	-1.6	-1.3	-0.8	0.6	0.0	-0.1	0.0	309	214	31	449	1,597	1,892	14,108	18,599
								386	**214**	**31**	**625**	**2,661**	**3,670**	**24,685**	**32,272**

Table 28 (Cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost

Yorks & Humber

Ratio revenue:cost

Area	M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.
Central Lon							
Inner Lon							
Outer Lon							
Inner Conurb	-1.2			**5.3**	**4.0**	1.0	0.0
Outer Conurb	-1.9				0.6	0.0	0.0
>250k				**6.5**	**1.9**	0.3	0.0
>100k							
>25k				0.0	0.0	0.0	0.0
>10k				-0.2	0.1	0.0	0.0
Rural	-1.1	-1.6	-0.4	0.4	0.0	0.0	0.0

Kilometres of road

Area	M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.	Total
Central Lon								**0**
Inner Lon								**0**
Outer Lon								**0**
Inner Conurb	18			6	194	128	2,498	**2,844**
Outer Conurb	232			191	1,135	2,163	8,431	**12,152**
>250k				19	41	67	706	**833**
>100k								**0**
>25k				14	140	221	1,027	**1,402**
>10k				5	56	63	195	**318**
Rural	116	199	13	276	1,029	1,099	10,395	**13,126**
	365	**199**	**13**	**509**	**2,595**	**3,742**	**23,252**	**30,675**

Scotland

Ratio revenue:cost

Area	M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.
Central Lon							
Inner Lon							
Outer Lon							
Inner Conurb	-1.3					0.4	0.1
Outer Conurb	-1.2			**8.5**	-0.1	0.0	0.0
>250k				**30.6**	**2.1**	0.0	0.0
>100k				0.0	0.3	0.2	0.0
>25k				0.6	-0.1	0.1	0.0
>10k				-0.2	-0.2	0.0	0.0
Rural	-0.9	-0.9	-0.7	-0.1	0.0	0.0	0.0

Kilometres of road

Area	M Way	Trunk Dual A	Principal Dual A	Trunk D & S / Trunk Single A	Principal D & S / Principal Single A	B rds	C & Unclass.	Total
Central Lon								**0**
Inner Lon								**0**
Outer Lon								**0**
Inner Conurb	43				146	110	2,465	**2,764**
Outer Conurb	71			65	344	741	2,812	**4,033**
>250k				12	97	132	898	**1,139**
>100k				37	68	147	572	**824**
>25k				60	196	437	1,798	**2,490**
>10k				49	169	162	1,009	**1,390**
Rural	272	305	42	2,285	6,419	6,487	30,757	**46,566**
	386	**305**	**42**	**2,508**	**7,440**	**8,216**	**40,310**	**59,207**

Table 28 (Cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost

Wales		Ratio revenue:cost							Kilometres of road							
		M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Area	Central Lon															**0**
	Inner Lon															**0**
	Outer Lon															**0**
	Inner Conurb															**0**
	Outer Conurb															**0**
	>250k				**37.9**	**10.6**		0.0				2	76	88	557	**723**
	>100k					**2.6**	0.0	-0.1					97	82	683	**862**
	>25k				0.9	-0.1	0.1	0.0				47	208	207	1,284	**1,746**
	>10k				-0.3	0.3	0.0	-0.1				47	61	592	759	**1,459**
		M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
	Rural	-1.3	-1.3	-0.7	-0.1	0.0	0.0	0.0	141	247	80	1,179	2,104	2,771	21,643	**28,164**
									141	**247**	**80**	**1,276**	**2,545**	**3,739**	**24,926**	**32,954**

Table 29 Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost, with tax correction.

E Ang — Ratio revenue:cost

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Central Lon							
Inner Lon							
Outer Lon							
Inner Conurb							
Outer Conurb							
>250k							
>100k				9.4	7.2	0.5	0.0
>25k				2.6	0.3	0.3	0.0
>10k				2.1	0.6	0.1	0.0
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
Rural	5.3	2.2	1.1	1.4	0.5	0.1	0.0

E Ang — Kilometres of road

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon								0
Inner Lon								0
Outer Lon								0
Inner Conurb								0
Outer Conurb								0
>250k								0
>100k				28	307	384	2,296	3,015
>25k				125	496	747	4,729	6,098
>10k				45	133	351	978	1,507
	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	
Rural	264	477	68	463	1,738	2,930	22,222	28,162
	264	**477**	**68**	**661**	**2,674**	**4,412**	**30,226**	**38,782**

E Mids — Ratio revenue:cost

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Central Lon							
Inner Lon							
Outer Lon							
Inner Conurb							
Outer Conurb							
>250k				5.9	6.1	0.9	0.1
>100k				2.4	10.1	1.0	0.0
>25k				0.8	0.4	0.8	0.0
>10k				0.2	0.3	0.0	0.0
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
Rural	6.8	2.7	0.9	1.8	0.2	0.1	0.0

E Mids — Kilometres of road

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon								0
Inner Lon								0
Outer Lon								0
Inner Conurb								0
Outer Conurb								0
>250k				36	206	292	2,332	2,867
>100k				37	114	155	1,348	1,654
>25k				111	271	509	1,912	2,804
>10k				70	129	425	1,180	1,804
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	194	367	89	596	1,799	1,677	18,154	22,875
	194	**367**	**89**	**850**	**2,519**	**3,059**	**24,926**	**32,003**

Table 29 (Cont) Ratio of revenues to costs and km. of road, by road type and Region.
Revenue additional, net of environmental cost, with tax correction.

London	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon	0.0			11.1	6.9	7.3	0.2				8	87	62	392	549
Inner Lon	0.4			11.6	6.5	2.2	0.2	6			77	405	454	2,980	3,923
Outer Lon	1.4			11.2	1.2	0.7		61			235	914	842	8,210	10,262
Inner Conurb															0
Outer Conurb															0
>250k															0
>100k															0
>25k															0
>10k															0
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural															0
								67	0	0	319	1,407	1,358	11,583	14,733

North E	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	Total
Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb	0.4			30.8	2.8	0.3	0.2	4			17	85	138	933	1,178
Outer Conurb	1.5			13.4	1.5	0.6	0.0	8			56	252	367	1,968	2,650
>250k				11.3	2.1	0.6	0.1				25	114	85	1,116	1,340
>100k															0
>25k				0.6	0.3	0.4	0.0				26	233	192	1,540	1,991
>10k				0.3	0.3	0.1	0.0				10	31	56	160	256
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	3.3	1.0	0.5	0.7	0.2	0.0	0.0	46	132	37	171	568	975	6,704	8,633
								58	132	37	306	1,284	1,812	12,421	16,048

Table 29 (Cont) Ratio of revenues to costs and km. of road, by road type and Region.
Revenue additional, net of environmental cost, with tax correction.

North W

Area	Ratio revenue:cost							Kilometres of road							
	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb	2.2			5.2	2.9	2.8	0.2	31			1	327	250	3,130	3,739
Outer Conurb	2.5			1.5	0.9	0.3	0.1	198			103	872	1,272	8,133	10,579
>250k				0.4	0.7	1.5	0.1				9	71	82	722	884
>100k				0.3	1.5	0.3	0.0				3	183	155	916	1,258
>25k				0.7	0.3	0.2	0.0				71	370	491	3,286	4,218
>10k				0.1	0.4	0.5	0.0				27	64	34	702	827
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	4.1	1.1	0.5	1.3	0.3	0.0	0.0	396	106	31	507	1,250	1,064	11,674	15,027
								625	106	31	721	3,137	3,349	28,563	36,531

South E

Area	Ratio revenue:cost							Kilometres of road							
	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb															0
Outer Conurb															0
>250k				21.2	3.4		0.1				32	213	361	2,190	2,795
>100k				9.8	5.4	0.5	0.0				22	130	312	1,329	1,792
>25k				3.1	0.4	0.1	0.0				143	1,059	1,691	8,628	11,520
>10k				16.5	0.7	0.2	0.0				20	255	444	1,318	2,037
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	4.1	1.7	0.6	1.9	0.5	0.1	0.0	655	388	238	253	2,333	2,259	22,841	28,966
								655	388	238	470	3,989	5,066	36,305	47,110

Table 29 (Cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost, with tax correction.

South W	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb															0
Outer Conurb															0
>250k				**2.0**	**5.6**	0.9	0.1				37	272	373	3,526	**4,208**
>100k				0.9	**1.5**	0.5	0.0				29	112	222	1,668	**2,030**
>25k				0.6	0.3	0.2	0.0				24	256	785	1,909	**2,974**
>10k				0.2	0.2	0.1	0.0				17	192	318	1,101	**1,628**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	**3.6**	0.9	0.6	**1.6**	0.2	0.0	0.0	327	363	63	530	3,159	2,914	31,678	**39,032**
								327	**363**	**63**	**636**	**3,990**	**4,612**	**39,882**	**49,872**

W Mids	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon															0
Inner Lon															0
Outer Lon															0
Inner Conurb	**2.0**				**5.1**	**2.2**	0.2	20			0	184	146	2,095	**2,446**
Outer Conurb	**5.4**			**1.7**	**2.9**	0.9	0.1	57			59	387	682	4,460	**5,645**
>250k				**9.3**	**1.0**	0.1	0.0				36	105	188	1,198	**1,526**
>100k				0.0	**3.0**	0.4	0.0				0	45	195	126	**366**
>25k				**1.6**	0.0	0.4	0.0				52	275	471	2,306	**3,103**
>10k				0.8	0.3	0.8	0.0				29	70	96	392	**587**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	**6.8**	**1.4**	0.9	**1.7**	0.3	0.0	0.0	309	214	31	449	1,597	1,892	14,108	**18,599**
								386	**214**	**31**	**625**	**2,661**	**3,670**	**24,685**	**32,272**

Table 29 (Cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost, with tax correction.

Yorks & Humber — Ratio revenue:cost

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Central Lon							
Inner Lon							
Outer Lon							
Inner Conurb	0.9			**6.0**	**4.6**	**1.2**	0.1
Outer Conurb	**3.2**				0.9	0.1	0.0
>250k				**8.0**	**2.3**	0.4	0.1
>100k							
>25k				0.8	0.3	0.1	0.0
>10k				0.1	0.3	0.1	0.0
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
Rural	**3.7**	**1.9**	0.4	**1.3**	0.2	0.0	0.0

Yorks & Humber — Kilometres of road

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon								**0**
Inner Lon								**0**
Outer Lon								**0**
Inner Conurb	18			6	194	128	2,498	**2,844**
Outer Conurb	232			191	1,135	2,163	8,431	**12,152**
>250k				19	41	67	706	**833**
>100k								**0**
>25k				14	140	221	1,027	**1,402**
>10k				5	56	63	195	**318**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	116	199	13	276	1,029	1,099	10,395	**13,126**
	365	**199**	**13**	**509**	**2,595**	**3,742**	**23,252**	**30,675**

Scotland — Ratio revenue:cost

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.
Central Lon							
Inner Lon							
Outer Lon							
Inner Conurb	**1.1**					0.6	0.2
Outer Conurb	**2.0**			**10.0**	0.3	0.1	0.0
>250k				**33.1**	**2.6**	0.1	0.1
>100k				0.9	0.8	0.3	0.0
>25k				**1.5**	0.3	0.2	0.0
>10k				0.4	0.1	0.2	0.0
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.
Rural	**2.4**	1.0	0.9	0.4	0.1	0.0	0.0

Scotland — Kilometres of road

Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon								**0**
Inner Lon								**0**
Outer Lon								**0**
Inner Conurb	43				146	110	2,465	**2,764**
Outer Conurb	71			65	344	741	2,812	**4,033**
>250k				12	97	132	898	**1,139**
>100k				37	68	147	572	**824**
>25k				60	196	437	1,798	**2,490**
>10k				49	169	162	1,009	**1,390**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	272	305	42	2,285	6,419	6,487	30,757	**46,566**
	386	**305**	**42**	**2,508**	**7,440**	**8,216**	**40,310**	**59,207**

Table 29 (Cont) Ratio of revenues to costs and km. of road, by road type and Region. Revenue additional, net of environmental cost, with tax correction.

Wales	Ratio revenue:cost							Kilometres of road							
Area	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	M Way			Trunk D & S	Principal D & S	B rds	C & Unclass.	Total
Central Lon															**0**
Inner Lon															**0**
Outer Lon															**0**
Inner Conurb															**0**
Outer Conurb															**0**
>250k				**41.1**	**11.4**		0.1				2	76	88	557	**723**
>100k					**3.3**	0.1	0.0					97	82	683	**862**
>25k				**1.8**	0.3	0.3	0.0				47	208	207	1,284	**1,746**
>10k				0.1	0.8	0.0	0.0				47	61	592	759	**1,459**
	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	M Way	Trunk Dual A	Principal Dual A	Trunk Single A	Principal Single A	B rds	C & Unclass.	
Rural	**3.7**	**1.2**	0.6	0.4	0.2	0.0	0.0	141	247	80	1,179	2,104	2,771	21,643	**28,164**
								141	**247**	**80**	**1,276**	**2,545**	**3,739**	**24,926**	**32,954**

Conclusion

We set out to test the proposition that if road pricing were introduced then there would no longer be a case for building new roads. We conclude that this proposition is false.

Using actual scheme cost data supplied by the Highways Agency we have constructed a new and detailed model of how the annualised, whole-life costs of building and maintaining new roads varies by road type, region and degree of urbanisation.

We have compared these costs with the revenues that would be generated by road pricing.

Unsurprisingly, what are classified in our model as "rural" roads would generally be adequate. But there would remain a strong case for new capacity in many other places where congestion conditions would indicate higher charges. In particular, there appears to be a case for more major roads in and around some of the larger towns and conurbations, including London. The case is considerably strengthened in the revenue additional case if allowance is made for the fact that the revenues would remove the need to raise the same funds through taxation (that is, allowing for the "shadow cost of public funds"). With that allowance it becomes worthwhile building some new rural motorways. Building new road capacity is unpopular and disruptive, particularly in built-up areas, but in some cases the revenues are so high that it is worthwhile considering going to the expense of building new urban roads in tunnel so as to mitigate these problems—as we routinely do for railways. The additional cost of road tunnels may also be justified in some suburban and rural locations.

We recognise that there are many important considerations that we have not included: "worthwhile" in terms of this study simply means that average revenues per road kilometre would cover expansion costs per road kilometre. We have given a technical argument setting out the circumstances under which this is a valid criterion. But we have not included some important costs, such as landscape costs and some authorities would argue for higher costs to be imputed to non-users of the charged roads, such as the cost of carbon dioxide emissions. Against this, we have significantly under-stated the benefits, as reflected in the charge revenues because we have treated 2010 as if it were typical of the 100 year life of the road. In reality, it is likely that traffic, and therefore revenues, will increase in the future. So revenues in 2010 are likely to be substantially less than the average annual revenues over the life of the road.

Although we have identified those general kinds of circumstance where roads expansion is likely to be justified together with the length of the respective roads, we have not been able to estimate by how many kilometres they should be expanded, or how much extra should be spent in total. Each time capacity is increased road charges fall so the case for yet further expansion must be re-considered. Expansion would continue to the point where revenues fall to match the costs of expansion. This calculation would be possible in principle but it outside the scope of this study.

We fully acknowledge that policy on how much new road capacity to build in the future is difficult and involves many considerations beyond those we have considered. Further, although we think that road pricing has a great deal to offer as a means of managing demand and providing public funds, we are under no illusions as to how difficult it will be to introduce in practice (see Glaister and Graham, 2006b). What this research does suggest is that if national road pricing were introduced and if no new capacity were built, then in some circumstances it would be as if public authorities were deliberately choosing not to provide roads that it would be economic to provide in order to earn excessive profits—in other words to abuse a dominant position. This might be judged to be against the public by the economic criteria applied in competition cases.

References

Audit Scotland (2004) *Maintaining Scotland's Roads,* Prepared for the Auditor General for Scotland and the Accounts Commission, November 2004.

Bayliss, D and Muir Wood, A. (2002), *Means to mitigate effects of increasing strategic road capacity*, RAC Foundation, London, November.

Department of Environment Transport and the Regions (1998) *A New Deal for Trunk Roads in England: understanding the new approach*

Glaister S & Graham D (2003) *Transport Pricing and Investment in England, Technical Report, Independent Transport Commission*.

Glaister S & Graham D (2004), *Pricing Our Roads: Vision and Reality,* Institute of Economic Affairs, London.

Glaister S & Graham D (2005) *An evaluation of national road user charging in England*, in: Transportation Research Part A, 39, p 632

Glaister S & Graham D (2006a) *Road pricing in Great Britain: Winners and Losers, Technical report.* Independent Transport Commission

Glaister, S & Graham, D (2006b) *National Road Pricing: is it Practical and Fair?*, Social Market Foundation, October.

Gomez-Ibanez J, Tye WB, & Winston C (1999), *Essays in Transportation Economics and Policy,* The Brookings Institution, Washington DC

Grout PA (2003), *Public and Private Sector Discount Rates in Public-Private Partnerships,* The Economic Journal, 113:486 March 2003

Highways Agency UK, DMRB (1996) *Design Manual for Roads and Bridges, Volume 6, Road Geometry,*.

HM Treasury (2006) *The Green Book*, online at http://greenbook.treasury.gov.uk/ (accessed 06/2006)

Hyman J (1960) *Construction Costs of Urban Expressways.* C.A.T.S. Research News, Chicago Area Transportation Study, Vol 4:1

Keeler TE & Small KA (1977) *Optimal Peak-Load Pricing, Investment, and Service Levels on Urban Expressways,* The Journal Of Political Economy. Vol 85:1.

Kraus M (1981) *Scale Economies Analysis for Urban Highway Networks,* Journal of Urban Economics, Vol 9

Liedtke G & Ott A (2003), *A new European Directive for Road Pricing, Discussion and Consequences,* 2nd Workshop Applied Infrastructure Research, Berlin University of Technology, Online: http://wip.tu-berlin.de/workshop/2003/papers/ (accessed 30/05/06)

Meyer JR, Kain JF & Wohl M (1965), *The Urban Transportation Problem,* Oxford University Press

Mohring, H. (1976) *Transportation Economics.* Cambridge, Mass., Ballinger P140-145

National Audit Office (2003) *Maintaining England's Motorways and Trunk Roads,* Report by the Controller and Auditor General HC 431, March 2003

Small KA (1992) *Urban Transportation Economics,* Hardwood

Small KA, Winston C & Evans CA (1989), *Road Work – A new highway pricing and investment policy,* The Brookings Institution, Washington DC

Valuation Office Agency (2005), *Property Market Report July 200,* HM Revenues and Customs