WOLFSON ECONOMICS PRIZE MMXVII FINALIST

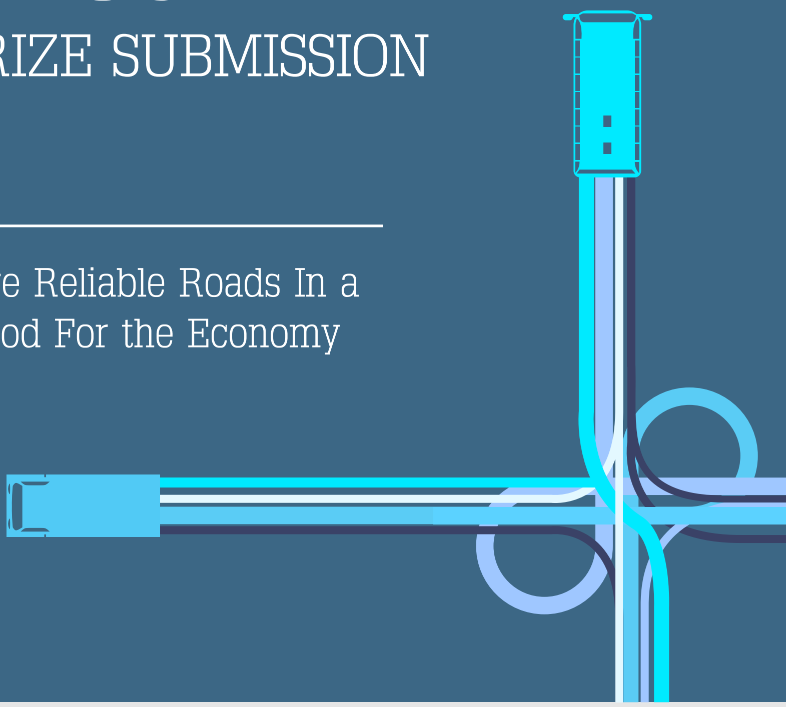
PRICING FOR PROSPERITY

WOLFSON ECONOMICS PRIZE SUBMISSION

2 March 2017 Primary Submission

Volterra Partners & Jacobs

How Can We Pay For Better, Safer, More Reliable Roads In a Way That is Fair To Road Users and Good For the Economy and the Environment?



WOLFSON ECONOMICS PRIZE MMXVII

Policy Exchange

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MMXVII

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Policy Exchange

Volterra Partners & Jacobs

Pricing For Prosperity

Paul, the spokesperson of Volterra and Jacobs', is an economist specialising in the transport sector. Paul has led many major project appraisals including Jubilee Line Extension and Crossrail. He has extensive overseas experience. Paul led the development of Wider Economic Benefits for Crossrail from 2002 to 2005, subsequently incorporated into DfT guidance. He is a Partner at Volterra.

The Wolfson Economic Prize invites entrants from around the world and all sorts of backgrounds to propose original, well-argued and informed solutions to big national challenges. The aim is to bring forward fresh thinking to help people, governments and businesses develop practical policies.

This year the prize addresses an issue at the heart of every country's economic future: road infrastructure, and

how can we pay for better, safer, more reliable roads in a way that is fair to road users and good for the economy and the environment?

The way cars are powered, driven and owned is being revolutionised. Soon a world of cleaner, automated vehicles will arrive and old annual charges and petrol taxes will no longer work. A new kind of driving will take a new kind of road and a new kind of funding – ideas needed not just in Britain but around the world.

The five shortlisted submissions – of which this is one – show that it is possible to come up with potential answers that can help road users, improve safety, protect the environment, and support our economy.

Prize Team

SIR JOHN KINGMAN

Chairman of the Judging Panel

BRIDGET ROSEWELL OBE

Judge

LORD DARLING

Judge

LORD WOLFSON

Founder

ISABEL DEDRING

Judge

JULIAN GLOVER OBE

Prize Director

LORD FINKELSTEIN

Judge

What Happens Next

Shortlisted entrants will be offered the chance to submit a revised and expanded submission. Shortlisted entrants are free at this stage to join up with others to help develop their proposals, including entrants whose submissions were not shortlisted.

These finalists will be given until June 2017 to expand their submissions before the Judges consider the winner. All shortlisted entrants who provide expanded submissions will receive £10,000. The winning entry, designated by the judges, will receive £250,000 in total. The Judges expect to announce the winner in July 2017.

The Judges also have the discretion to award further smaller prizes to recognise entrants whose submissions address aspects of the Prize Question in innovative, creative or otherwise outstanding ways, in particular giving weight to the use of technology. The winners of any such awards may not comprise a full entry for the £250,000 prize.

The Judges' decision is final.

CONTENTS

Non-technical Summary

The UK's roads are among the most congested in Europe. The UK is an island nation with high population density, high car ownership and a relatively low supply of road space. Road building has been limited for the last 30 years, perhaps a consequence of the anti-road campaigners in the 1980's. Now our roads are not only congested they are also in an increasingly poor state of repair as highway maintenance budgets are squeezed by local authority spending cuts.

Our proposal sets out a holistic solution for UK roads. This solution ensures that:

- The road network is self-sustaining, covering all of its costs (direct and indirect) from user charges, and generating a sustainable tax surplus for HM Treasury, although a lower surplus than exists today;
- The revenues flow direct from drivers to the appropriate authority and the appropriate purpose. Three separate "pots" of money are created for: road maintenance, mitigation of external impacts and investment in the network; and
- The combination creates a system which is sustainable, efficient, greener than at present and will generate new investment and mitigate the costs of road travel in a transparent and effective way.

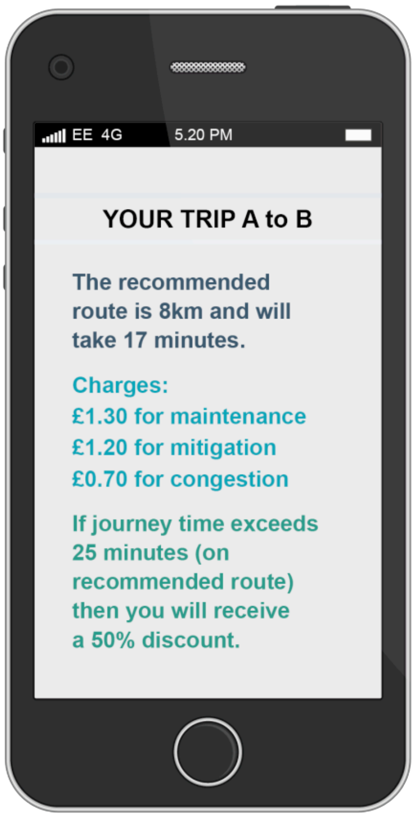
Our solution will change an inefficient charging system with almost no link between price and user behaviour, into one which provides full information to road users on journey costs, journey time, alternative routes, and modes available. It will also place pressure on highway authorities; failing to deliver on the agreed level of service which involves measures of expected speed and reliability, then drivers will pay lower charges and even receive refunds or compensation in the case of very poor performance. In short, our approach aims to internalise the external costs both to society (pollution, safety) and the internal costs to other drivers (congestion) as a result of the current inefficient way of charging for road use.

The marginal cost approach, whereby costs are made explicit to users before they start their journey is a powerful tool to drive behaviour change. When users perceive their costs as fixed irrespective of how much they drive, then they make very different choices. When costs are transparent people make better, more efficient choices.

Under this approach we are able to switch most of the cost of road usage to a Marginal Cost (MC) basis, enabling specific targeting of polluting vehicles, sensitive areas and congested roads. MC pricing not only delivers short term changes in user behaviour, it also drives long term decisions, encouraging the use of less polluting vehicles and switching travel to less congested routes or times. The proposals set out in this paper will be introduced gradually, to enable people to adjust and enable continuous feedback and improvement in how the overall system develops. We also envisage that our proposal will be accompanied by a comprehensive marketing and communication strategy to explain the benefits of the approach to the public.

Our proposal encompasses a pricing system which:

- Can price demand for congested parts of the network whilst also funding future investment so that road infrastructure can be improved and charges reduced in the future;
- Will be cheaper and faster for a very large majority of all road users (cars, bus, HGVs);
- Ensures that the road sector pays for itself, covering its maintenance, congestion and mitigation costs in a sustainable long term solution;



- Is infinitely flexible, cheap to implement and operate, generating enough funds to cover all road sector costs and pay a return to central government;
- Can adapt to technological change at different rates and scales of change, for example, accommodating driverless enterprise and Mobility as a Service concepts;
- Gives drivers effective performance related charges and automatic price reductions and/or compensation if thing go wrong; and
- To alleviate privacy concerns, users can opt in or out of personal data being stored on the cloud. If users opt-in for their data to be used (e.g. for transport modelling exercises in order to improve service) they are entitled to a small discount on their journeys.

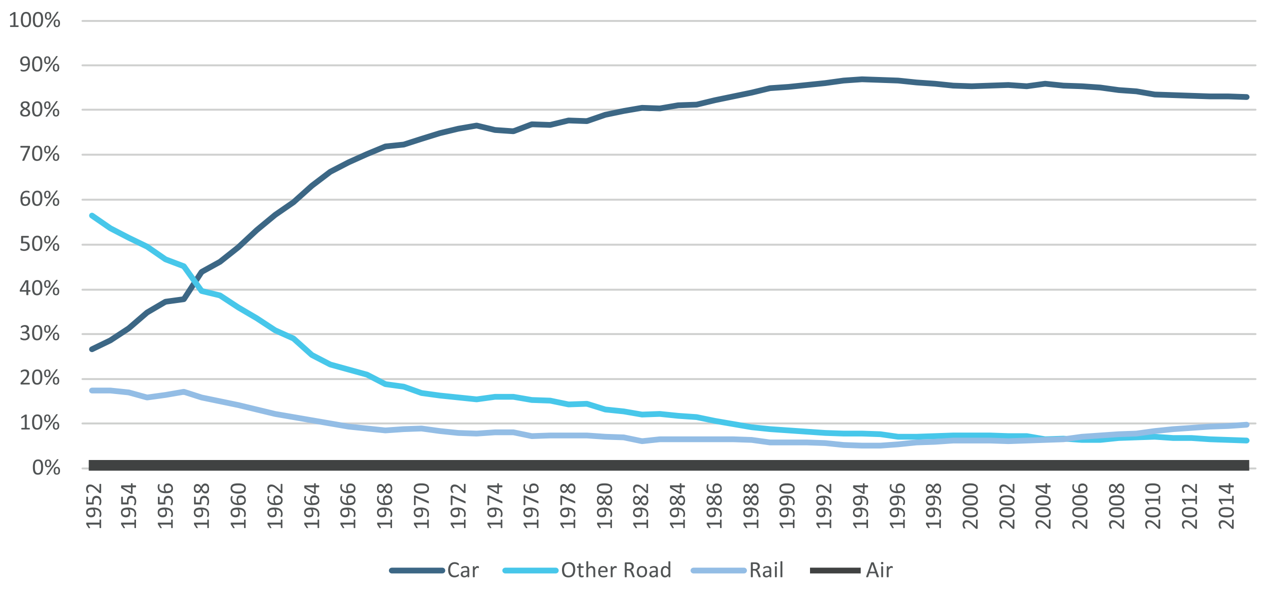
Our study shows that the government currently makes a £23Bn annual surplus on road user charges (largely via Vehicle Excise Duty and fuel tax) over highway maintenance and investment costs. That surplus is expected to fall rapidly, as fuel efficiency and the use of electric vehicles reduce future fuel tax revenues. Our proposal aims for a lower government surplus, in the region of £10-15B per annum, but one that is sustainable in the long term. The Government will reduce its net income in the short term but increase it in the long term.

The proposed approach sets up a contract between highway authorities and drivers for each journey. Drivers pay according to vehicle type, road location and level of congestion. Under such a system it is not possible to eliminate all congestion without high spikes in charges, which we know reduces public acceptability. Hence it is likely that low levels of congestion at peak times will remain in certain locations but it should never deteriorate into gridlock.

1. The state we are in

The car has been the dominant mode in UK transport since the late 1950's when it overtook other road users (largely bus), as the main mode of travel (Figure 1). Prior to this, rail had been the dominant mode since the second half of the 19th century, but the lower cost and greater flexibility of first buses and then cars provided a more attractive alternative. In 2010 rail overtook buses in terms of total passenger kilometres, for arguably the first time in a century.

Figure 1: UK transport mode shares since 1952 (%)



To understand how well UK roads perform, requires a comparison with other countries. Figure 2 shows the total highway provision in lane kilometres across selected countries per square kilometre of land and per 1 million people. Size of country is a key determinant of highway provision, but population, wealth and car ownership are also important. Overall, the UK scores poorly compared to the European countries shown.

The main determinants of the road density measure are population density and car mode share. In general the larger countries tend to have lower road kilometres per square kilometre because their population densities are lower. Thus Australia and Canada have low results for this measure despite having high car mode shares.

Figure 3 displays total road kilometres in the UK from 1951 to 2014 alongside total vehicle kilometres over the same period. Since 1951 vehicle kilometres have increased by 765%, an average annual increase of 3.4%, but lane kilometres has risen by only 33%. The difference between those two numbers is the primary reason for higher congestion.

In more recent years demand growth has been lower. Between 1995 and 2005 the average annual increase was only 1.4%, an overall increase of 15%. Since 2005 vehicle kilometres have only increased by 3.2%, with an average annual increase of 0.2%. However, there has been an upturn in growth as the economy has come out of the recent recession. Road kilometre provision has plateaued since 1995, the increase in lane kilometres from 1995 - 2015 was only 2.4% compared to 17.1% in the period between 1975 and 1995 but still lower than the growth in vehicle kilometres.

Figure 2: Total road provision per sq kilometre of land and per million of population, per country

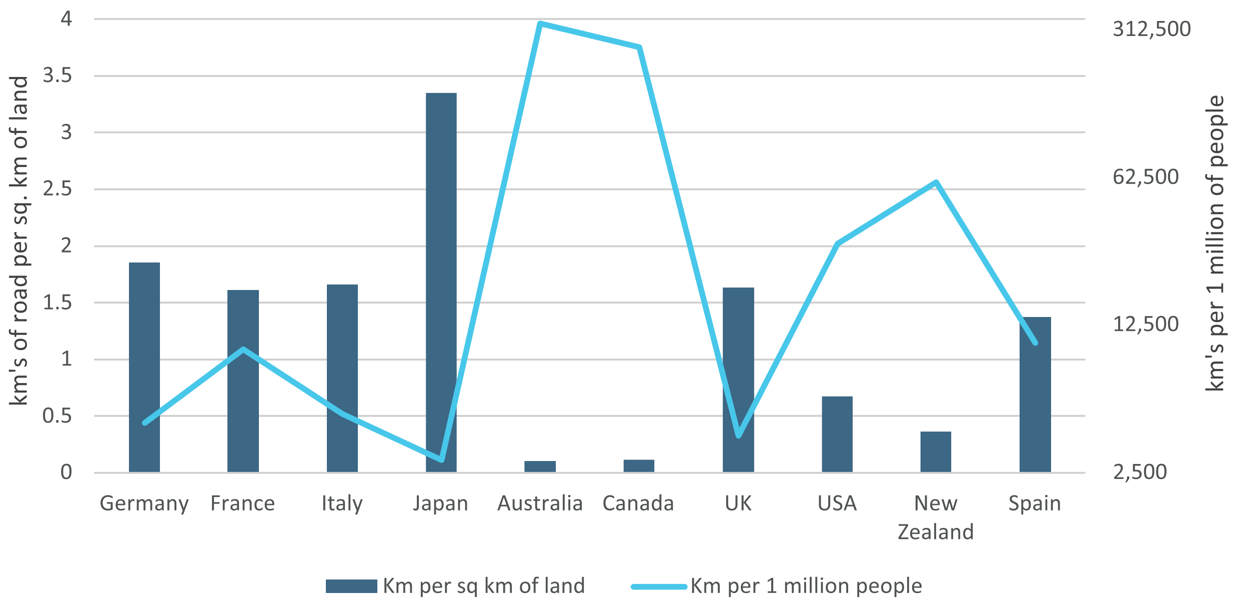
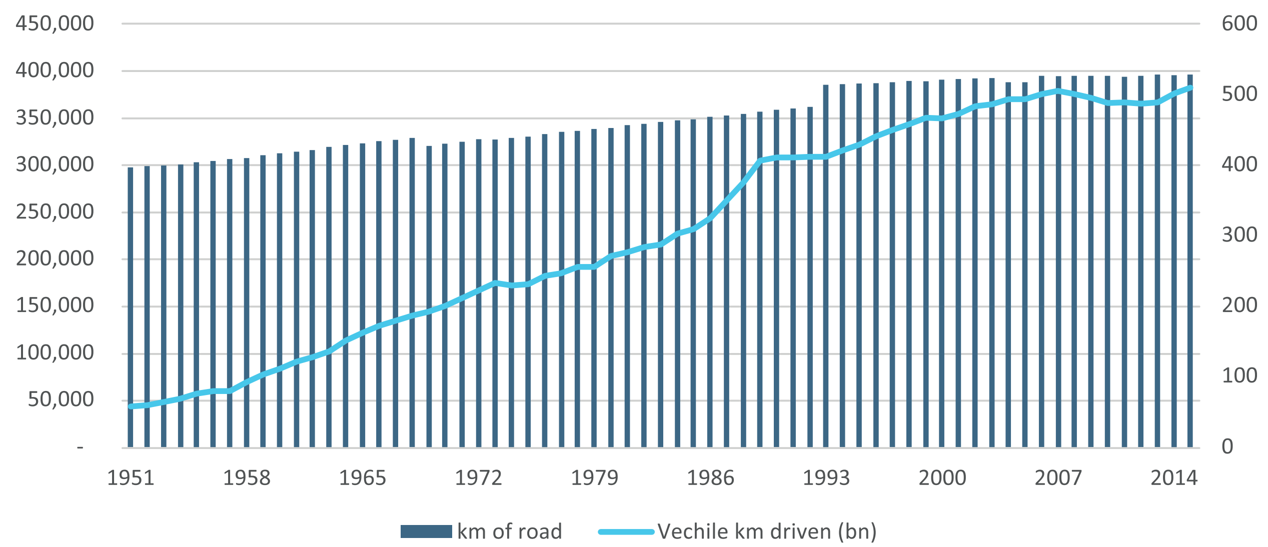


Figure 3: UK trends in road provision (lane kilometres) and vehicle kilometres - 1951 to 2014



As highlighted above demand growth has reduced in recent years. The "peak car" phenomenon suggests that this is largely down to behavioural change among the Millennials, but it may be much simpler than that. There has clearly been a large increase in the costs of driving with higher fuel prices (and fuel taxes) and more expensive insurance, especially for young people. At the same time the increase in congestion caused by the mismatch between demand and supply has made driving slower and more unreliable. The two would be expected to reduce the growth in highway demand.

Combine this with stagnating wages in the post-crash era and the drop in car use appears less of a behavioural shift and more like a response to market forces.

As figure 4 shows, total motoring costs (i.e. including vehicle purchasing costs) have fallen in real terms but the increase in marginal costs (i.e. car operating/running costs) have risen. It would appear therefore that even though the overall cost of motoring has fallen, the increase in marginal costs has led to a change in behaviour reinforcing the importance of marginal cost pricing.

Figure 4: Changes in motoring running costs (source: DfT Statistics, Table TSGB1307)

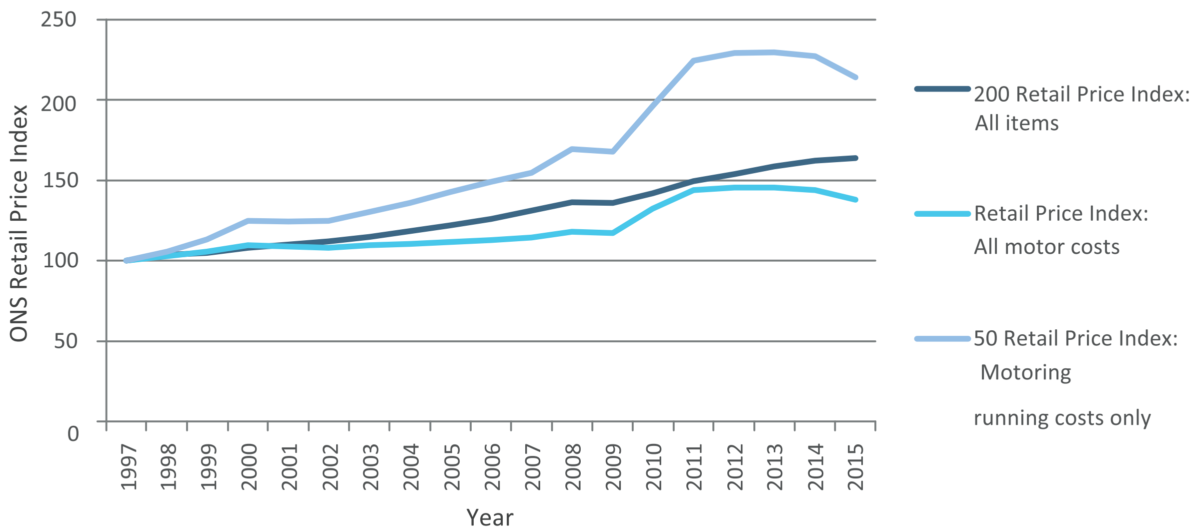
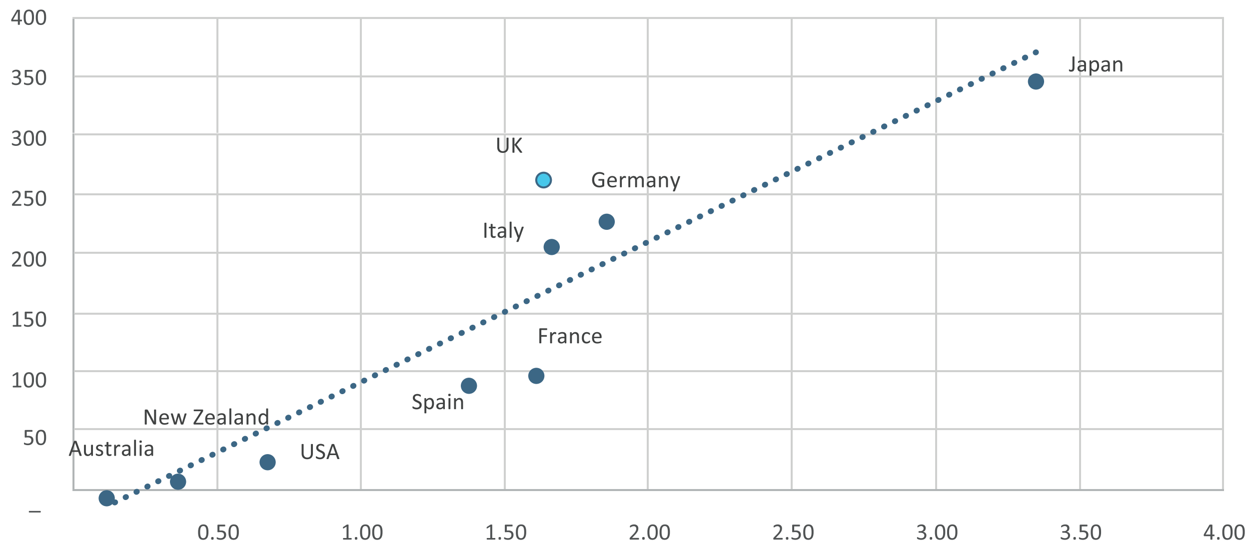


Figure 5 shows that kilometre of road per square kilometre of land, is heavily dependent upon population density. It also suggests that the UK (red dot in Figure 5) is under supplied with roads for a country with its level of population density.

Figure 5: Road provision by country (source: CIA World FactBook, 2017)

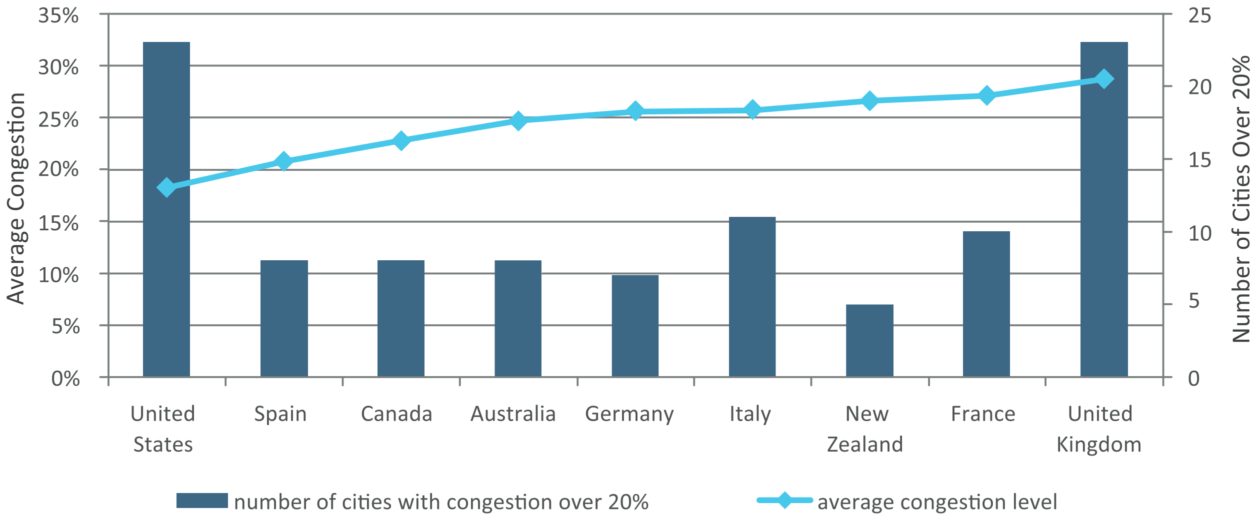


It is difficult to obtain comparable congestion information between countries, but TomTom and INRIX, provide some useful data. TomTom data is focussed on congestion levels in cities, and uses its database to determine levels of congestion in 295 cities around the world. Here, congestion is measured using the percentage increase in travel time compared to travel at free flow speeds. As this is based on publicly available data from the TomTom website, there may be an element of sample bias.

Using data from the TomTom Traffic Index[1], Figure 6 shows that the UK performs relatively poorly in terms of congestion, compared to other countries. For example, in the UK the number of cities with congestion over 20% is 23, the same as in the United States, a much larger country. In terms of average congestion levels the UK tops the list below at 29%, while the United States has the lowest average congestion level at 18%.

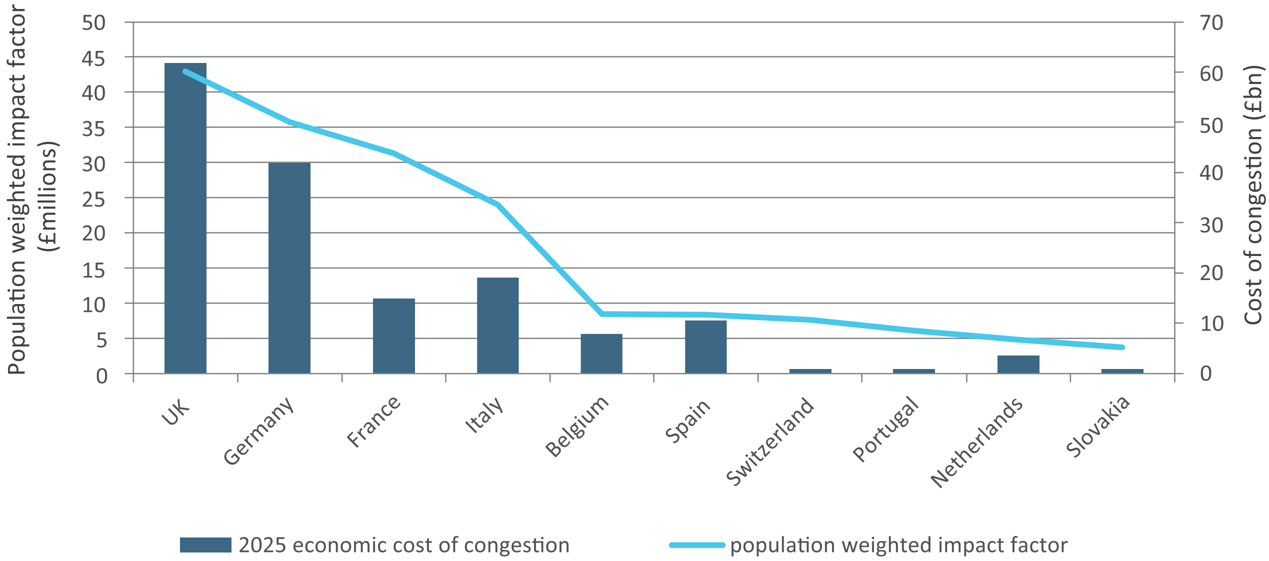
[1] http://www.tomtom.com/en_gb/trafficindex/list?citySize=LARGE&continent=ALL&country=ALL

Figure 6: Congestion, by country



The INRIX[2] (2016) congestion analysis takes a similar city-focussed approach, shown in Figure 7. This analysis looks at European cities with populations over 250,000. An impact factor is used as the measure of congestion (e.g. how large is the impact on traffic). This impact is weighted by population so that countries that have more cities are not over represented. INRIX also provides forecasts of the predicted economic cost of congestion over a 10-year period, based on time lost due to traffic. Once again, the UK came out as the most congested, with the highest absolute and population weighted impact factor, as well as the highest economic cost of congestion.

Figure 7: Impact and cost of congestion, by country

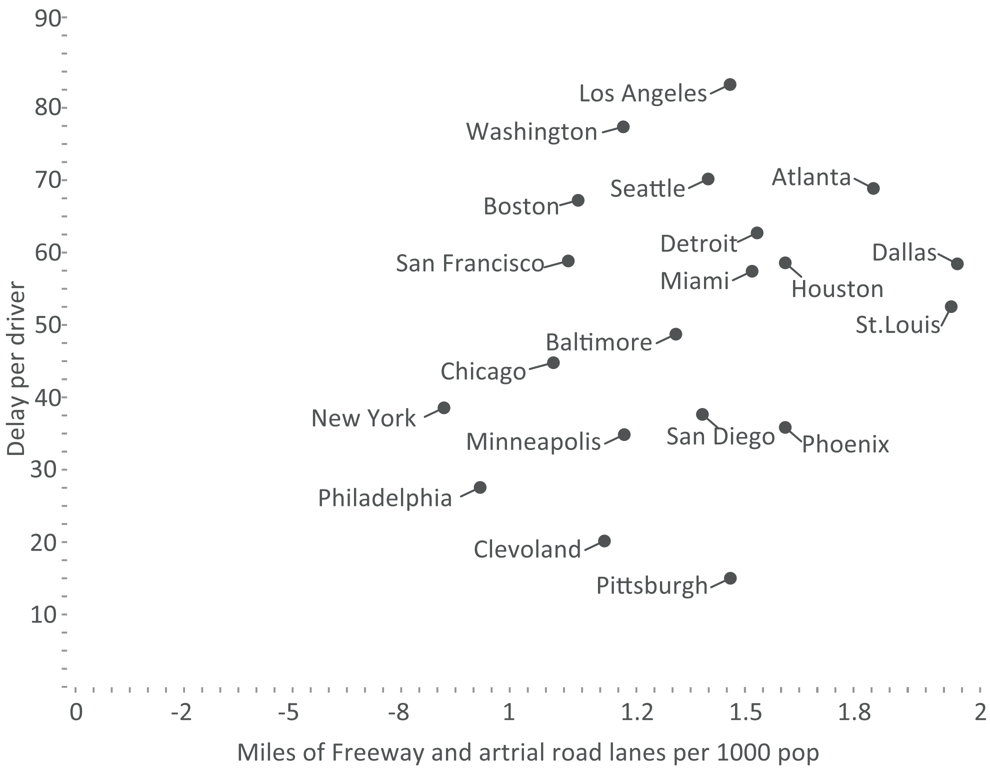


[2] Europe's Traffic Hotspots – measuring the impact of congestion in Europe (2016)

Conclusion

The UK is a densely populated island with lower road provision than most European comparators. International comparisons suggest that our roads are more congested than those in comparable countries. The direction of causation can be difficult to determine. Figure 8 shows that comparing US cities, the more traffic lane kilometres are provided (per capita) the higher the level of delay experienced by users. Building more roads is therefore no guarantee of faster travel.

Figure 8: 20 biggest US cities - do more roads reduce delays? (source: Urban Transport Monitor, 1999)



2. Potential solutions and barriers

2.1 Road pricing policy options

The UK either needs to expand road supply without generating too much of an increase in demand, or to restrict demand in ways which do not harm the economy or the environment. The main policy options for doing this are included in Table 1.

Table 1: Balancing demand and supply policy options

Option	Description
Raise fuel tax to restrict demand	This is a blunt tool, as fuel tax cannot be location specific. It does however have the advantage of being an existing tax with low collection costs and is difficult to avoid.
Rationing car use	In this option, every person gets an allowance of driving kilometres a year. This is seen as a “fair” or equitable system, in that everyone receives the same allowance. People who don’t use their allowance might be able to sell the unused portion to other drivers resulting in some income redistribution impacts. However, the system is ineffective as it will not resolve congestion; indeed it might make congestion worse. Similar problems arise from the use of odd / even number plates on alternate days. Some people can get around that through owning multiple cars.
Pricing parking	Parking charges are a good way of managing traffic demand to particular locations, but they are not effective at dealing with general congestion, for example, on motorways.
Increase road building	It is possible for the UK to build new roads and add to the existing road supply. However, this is generally expensive, unpopular and exacerbates environmental concerns. The mass protests of the 1980s have made large scale road building increasingly difficult. Importantly, building more roads may still not deliver the desired outcome of alleviating congestion. On the other hand it is possible to expand the road network and those network improvements can significantly reduce journey times and journey time unreliability, but it is not a quick, cheap or popular solution.
Technological change	Much hope is placed on the role of technology in delivering higher capacity on roads. Connected and/or Autonomous Vehicles (CAVs) operating closer together can certainly increase capacity and reduce accidents. It is difficult currently to have any real insights about the scale of those impacts. A specific section on CAVs is included in a later chapter of this paper.
Road pricing	A form of pricing can potentially be a policy option for: • financing the network; • ensuring that the external costs of road use are mitigated; and • managing the network, especially dealing with congestion arising from peak demand levels and congestion arising from accidents or other incidents.
In this study, we have chosen to present a strategy based on pricing – we consider this to be the only mechanism that can deliver the desired outcome. Pricing is infinitely flexible and can adjust to deal with any scenario. That is particularly useful in an era where technological change is fundamentally altering the way we use cars and the costs of using them.	

2.2 What are the barriers towards policy change?

It is always easier to maintain the status quo than to change something, no matter how bad the status quo or how effective the proposed solution. Road pricing has been proposed many times in the UK only to fall at the hurdle of public support. The main barriers are likely to include:

- A huge number of car drivers will be affected. Some (although only a small minority) will no doubt be adversely affected, most will see a much better service for a lower price;
- HM Treasury (probably) will not welcome a system which hypothecates funds, even to a sector as important as transport;
- The public don't like charging, especially for something that is currently 'free'. It is very easy to see the costs of charging and much less so the benefits. We also believe that referenda are not an appropriate way to introduce such a system;
- There are distributional impacts of a pricing policy, although often not the ones that people perceive. The biggest beneficiaries tend to be lower income travellers already on public transport (especially buses). They get better journeys at no change in cost. The other main winners are the high income travellers (business trips and leisure trips by wealthy individuals) who value their time savings much higher than the additional costs. The "losers" tend to be the middle income

group where the higher price may push them onto public transport or require them to pay to drive when both those options are worse than the status quo;

- Vested interests in maintaining the status quo prevent policy change towards charging; and
- The road management system and/or operator will know where vehicles are located, where they are heading and when. This will generate enormous amount of trip data containing potentially sensitive and personal information. That raises issues of privacy, but no more so than the ability to track people's movements via mobile phones, apps, CCTV, etc. The issue of privacy is a wider, societal issue, one.

Against this backdrop of policy inertia, there are also positive reasons to think that the barriers to change are lower now than previously:

- People are more used to treating car use as a service. Car clubs, trip sharing apps, UBER pool, are all examples of mobility and people are much more amenable to those systems in the new "sharing economy";
- UBER has demonstrated the attraction of a system that not only picks you up quickly, but informs you of the price and journey time in advance. Moving to a similar user-friendly system for road travel would put it on a par with rail and air transport modes;
- Government tax revenues from road use will decline significantly in the future as fuel efficiency and electricity powered vehicles reduce petrol and diesel consumption. Government will need to find additional revenue sources from somewhere; and
- Passenger cars and in particular Heavy Goods Vehicles (HGVs) usually get a bad press. It is easy to target road transport with stories all about accidents, pollution and delays. The transport industry as a whole suffers from negative press therefore we should aim to make roads safer and greener as well as more efficient.

3. Our solution to the Wolfson Prize Question

3.1 What is our proposal?

The proposal set out in this chapter is the end state implementation of a scheme that will be rolled out gradually in phases. There is some level of uncertainty, especially regarding users' reaction in terms of demand changes. However, as a result of fast advancing technology our system has built-in flexibility (prices can be centrally changed with relative ease) so a certain amount of experimentation could occur to show viability and to optimise charging levels. This experimentation can occur also in order to balance the price with public acceptability, demands and concerns.

Our proposal encompasses a holistic system which:

- Can price demand for congested parts of the network whilst also funding future investment so that road infrastructure can be improved and charges potentially reduced in the future;
- Will be cheaper and faster for a very large majority of all road users;
- Ensures that the road sector pays for itself, covering its maintenance, congestion and mitigation costs in a sustainable long term solution;
- Is infinitely flexible, cheap to implement and operate, generating enough funds to cover all road sector costs and pay a return to central government;
- Can adapt to technological change at different rates and scales of change, for example accommodating driverless enterprise and Mobility as a Service concepts;
- Gives drivers effective performance related charges and automatic price reductions and/or compensation if thing go wrong; and
- To alleviate privacy concerns, users can opt in or out of personal data being stored on the cloud. If users opt-in for the data to be used (e.g. for transport modelling exercises in order to improve services) they are entitled to a small discount on their journeys.

3.2 How does it work?

Our solution involves transferring most of the costs of car use from Average Cost (AC) to Marginal Costs (MC). This is how it will work for a typical trip:

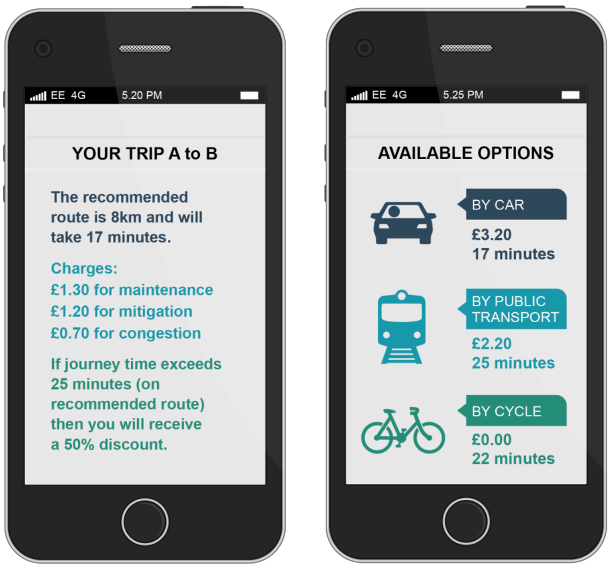
- Driver departs from their home either in their own car or having ordered one via their smartphone;
- Driver is given the price and time that the journey will take and information on alternative routes (with varying charges) and modes (public transport, walk, cycle);
- Driver selects the private car option via the fastest route (cheapest route also available). For example, in a private car the journey will take an expected time 30 minutes with a fare of £4.40.
- Driver arrives on time, payment is deductedautomatically deducted upon arrival and a receipt emailed to the driver;
- If driver arrives 15 minutes late to their destination, then no fare levied because of poor time performance;
- If driver arrives 30 minutes late, receives £4.40 compensation; and
- Social media friendly: the intuitive smartphone app enables the driver or passengers to easily rate the journey experience and feedback on the condition of the network on social media outlets.

One of the great advantages of this solution is that the trade-off between time and money is explicit. There will be trip sharing options to reduce the price and increase vehicle occupancy (thereby reducing demand).

The system will also be able to accommodate more advanced travel demand functions, such as paying regular user not to make trips at particular busy times when there is a risk the highway authority will not meets its desired performance targets. In essence, this is similar to airlines paying people when flights are overbooked to travel on an alternative flight.

Key elements in the system are:

- The "booking" system – the user can type or talk (voice recognition) to the phone app about where they want to go and automatically receive a "quote" for the time taken and the price charged. At the same time walk/cycle and public transport alternatives will be shown, offering the opportunity to switch to other modes.
- If the user "accepts" that quote, then the emphasis is on the road authority to deliver. If there are significant delays to the car journey then the authority will need to recompense the user for the increase in journey time. If there are very long delays then the payment may reverse direction with the authority not just refunding the fare but paying additional compensation to the user due to the failure to deliver the agreed Level of Service.
- This contractual relationship between the highway authorities and individual users is a much more efficient outcome for both parties and for network performance as a whole.
- All user charges are allocated into an appropriate pot (for maintenance, congestion, mitigation) and then diverted to the appropriate authority:
    - Strategic: e.g. Highways England;
    - Urban: main city authorities; and
    - Other: Local Authorities.
- Thus money is spent where it is earned, all the maintenance and congestion charges are spent by the local highway authority on maintaining and investing in roads.



3.3 What are driver costs now and proposed?

Under our proposed system both the make-up of costs and the total paid would change from the current system described in the previous section. Over a period of years we propose to reduce VED and fuel tax eventually removing them entirely. Whilst this transition is taking place, we would also introduce a mitigation charge, maintenance charge and congestion charge. These would vary depending upon vehicle type, location and level of congestion.

The transition of VED (a fixed cost) and fuel tax (an average cost), to marginal costs is important because marginal charging has a much bigger impact upon behaviour, in economic terms it has a higher price elasticity.

The essence of this proposal is to shift driver costs from fixed and average costs to marginal cost. That change will mean that the marginal costs will be more transparent to drivers and will have a greater impact on behaviour. Using data from the Automobile Association[3], Table 2 shows the breakdown of the different costs for fixed, average and marginal costs and the proportion each type of charge makes up of the total user cost.

Currently the average spent on a car per year is £4,220. This is based on there being approximately 36 million registered vehicles at the start of 2015 and the total vehicle kilometres driven being approximately 510 billion kilometre giving an average of 14,000 kilometres driven per car per year.

Table 2: Current User Costs split by Fixed, Average & Marginal costs

Fixed cost		Average cost		Marginal cost		Total cost	
VED	£154	Fuel tax	£768	Tolls & parking	£177		
Insurance	£352	Tyres	£121				
Cost of capital	£198	Service labour costs	£ 186				
Depreciation	£1,163	Replacement parts	£198				
Breakdown cover	£49	Fuel cost	£854				
Total (£)	£1,916	Total	£2,127	Total	£177	Total	£4,220
Proportion (%)	45%	50%		4%			100%

Therefore, in the current pricing situation drivers are faced with relatively negligible marginal costs (4% of total user cost). Some 96% of their costs are fixed or average. However, the allocation of costs to categories is neither clear nor transparent.

[3] The AA, Car running costs, 2015, http://www.theaa.com/motoring_advice/running_costs/advice_rcosts_guide.html

Fuel costs for example might be thought to be fixed on very short trips (no impact at all on behaviour) they might be considered as average costs for trips of less than 20 kilometres when there is little chance of having to fill up with petrol, but on long trips of several hundred kilometre then we would expect fuel costs to be better taken into account – maybe even as marginal costs.

A benefit of the marginal costing system would be that journeys along different road types would incur different costs. This would mean maintenance and mitigation revenue could be made to be place or region specific..

Table 3 shows how much an average user would be charged for a journey of 50 kilometres along the motorway. This is done under the current charging system (VED and fuel tax) and under our charging system (marginal cost approach).

Table 3: User Costs for a typical motorway journey of 50 kilometres with proposed charging mechanisms

Present system					
Fixed cost		Average cost		Marginal cost	
				Congestion revenue	£0
VED	£0.54	Fuel tax	£2.70	Maintenance revenue	£0
				Mitigation revenue	£0
VED(%)	17%	Fuel tax(%)	83%	0%	
Total	£3.24			£0	
Marginal cost charging					
				Congestion revenue	£0.91
VED	£-	Fuel tax	£-	Maintenance revenue	£0.05
				Mitigation revenue	£1.01
VED(%)	0%	Fuel tax(%)	0%		100%
Total	£0				£1.97

Table 3 shows that users are better off with the proposed charging system. That is true even though they are paying for costs currently ignored such as mitigation. In addition, users will also enjoy a better level of service by benefitting from a faster and more reliable service. Other costs, which were included in Table 2 would be incurred by the user but they are private costs not charged by the state and will not change with an introduction of marginal pricing.

Table 4 sets out the total revenue by charge type from 2015 to 2050 and gives a breakdown of the revenue generated by each road type and vehicle type. It is shown under a system whereby full marginal pricing would be introduced from 2015 onwards. Total costs paid by road users reduce over time even though demand grows and price is used to manage that demand. Total costs fall because a higher share of costs are priced marginally and hence have a greater impact on driver behaviour and choices.

Table 4 Full Marginal Cost Pricing Approach (£billions)

Full Marginal Cost Pricing Approach (£billions)				
Year	Motorway	Urban	Rural	Total
2015	£ 5.3	£ 9.3	£ 12.7	£ 27.3
2025	£ 5.2	£ 8.7	£ 11.5	£ 25.3
2050	£ 5.5	£ 8.2	£ 9.9	£ 23.6
Year	Car	LGV	HGV	
2015	£ 18.3	£ 6.5	£ 2.4	£ 27.2
2025	£ 17.5	£ 5.7	£ 2.1	£ 25.3
2050	£ 17.2	£ 4.7	£ 1.7	£ 23.6
Year	Mitigation	Maintenance	Congestion	
2015	£ 13.5	£ 2.9	£ 10.8	£ 27.2
2025	£ 10.6	£ 3.0	£ 11.7	£ 25.3
2050	£ 5.9	£ 3.3	£ 14.3	£ 23.5

3.4 Charging calculations

The following paragraphs set out the calculations of charging separate for congestion, maintenance and mitigation.

Congestion Charge – is directly related to the level of congestion. Under our approach, we recommend starting to charge at a low price when demand exceeds 75% of supply. Our analysis uses a price elasticity of -0.1 for fixed prices, -0.3 for average prices and -0.45 for marginal prices. The target is to maintain all roads operating near capacity with vehicles achieving the maximum legal speed on each section..

Maintenance Charge – this should be applied as an average cost per vehicle kilometre varying for cars, LGV, HGV, bus/coach. Heavier vehicles will pay higher rates proportional to the damage (wear and tear) they cause to road assets. Different charges will apply for motorway, urban and rural roads. All vehicles will pay the maintenance charge at all times.

Mitigation Charge – there are significant negative externalities resulting from road use. Accidents, noise and air pollution are particularly issues, all three would be covered by the proposed system. Healthcare costs depend on accident rates and severity, DfT guidance can inform authorities on what the associated medical care and human costs are, for different types of accidents and enabling a charge to be set by road type to cover these. Environmental mitigation depends both on the vehicle (noise pollution) and on the location (low/med/high density of population). We believe that driving a large truck on an elevated road in a high density city centre should be more expensive than driving an electric car through the countryside.

3.5 Spending mechanisms

In our proposed solution, all charges are to be paid directly into the relevant highway authority coffers. The mechanisms for spending these revenues are set out below.

Congestion Charge – paid into an investment fund for each highway authority. Drivers that pay the congestion charge will know that the money will be invested in improved highway infrastructure, although they will need to either wait for funds to build up to the required total or borrow on the basis of expected future revenues. Highway authorities will be able to invest those funds:

- In a co-ordinated way with neighbouring authorities to address strategic issues;
- Directly on specific junction improvements; and
- In non-highway solutions where it is appropriate. In large cities, for example, it might include investment in pedestrian, cycling and bus priority facilities, which in turn will have a greater effect on urban traffic speeds and reliability, than investing directly in highways.

Maintenance Charge - paid directly into the appropriate highway authority responsible for road maintenance. The highway authority should have the responsibility to spend that money as they see fit. Sometimes it may be sensible to invest in a series of smaller projects, in other situations it may make sense to save the money for a few years (or borrow) and invest it in a larger scale solution.

The Maintenance Charge will improve highway quality across all roads, bringing significant benefits from reduced accidents and vehicle operating and maintenance costs. It will be a requirement that roads are maintained to a specific standard by the relevant highway authority.

Mitigation Charge – this is a different type of charge. It is widely acknowledged that road use imposes substantial external costs on the rest of society. The Mitigation Charge will specifically address these external costs. It will provide funds which can be used by the relevant highways authority or community to either:

Mitigate the negative impacts, for example, by providing the revenues to install noise barriers;

- Charge higher price to more polluting vehicles whether noise or air pollution, thereby encouraging them to avoid environmentally sensitive routes; or
- Cover the health care costs associated with road accidents. Dangerous sections of roads which have higher accident costs will be paid for by the highway authority giving them a financial incentive to improve safety. This will also reduce national government health care spending as some will be paid for by drivers and highway authorities.

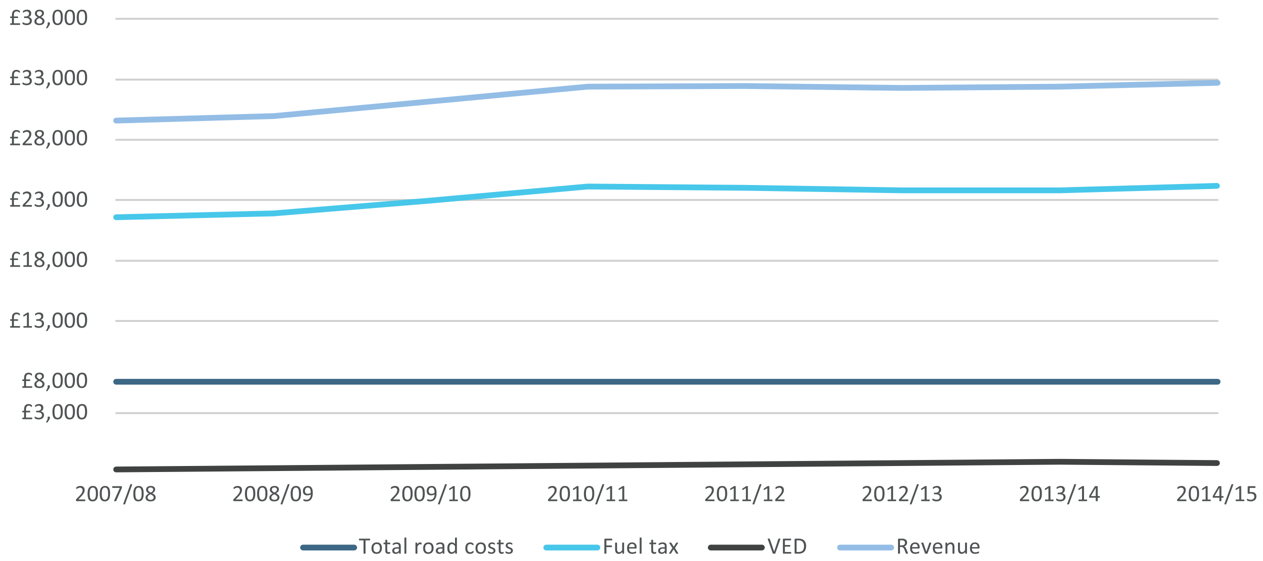
Our proposed pricing structures are flexible and can be varied according to regional or national policies or other considerations. This means it is ideally suited and easily adapted to accommodate disruptive technology such as CAVs, electric vehicle technology and Mobility as a Service.

4. Charges, revenues and road performance

4.1 Current costs and revenues and how they will change?

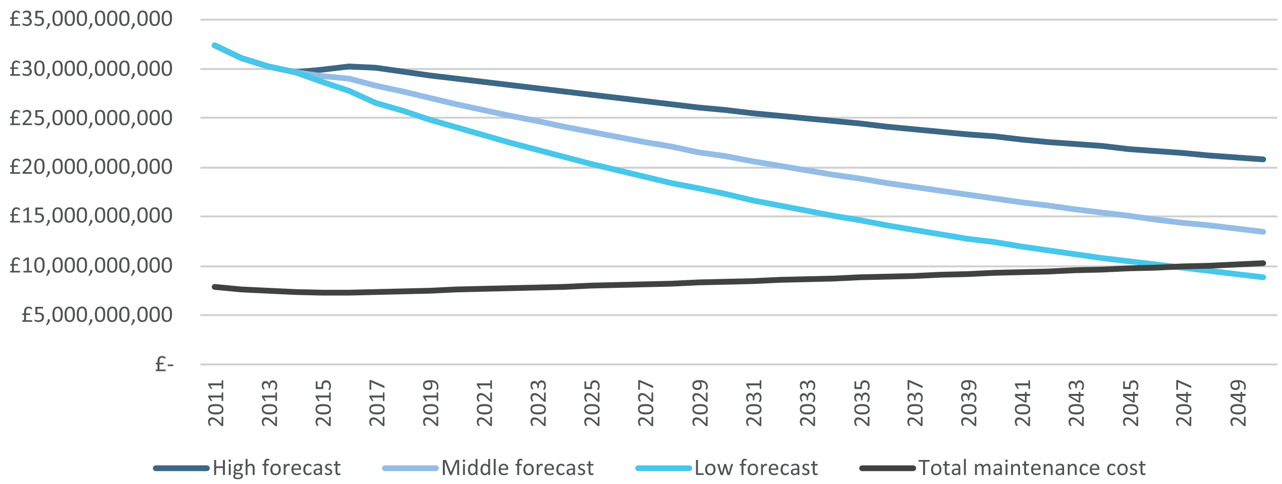
Figure 9 shows both revenues and direct costs of the road system for the past eight years. The surplus is approximately £25 billion since only £8 billion of the £33 billion in revenue, is actually reinvested back into the road system. Fuel tax makes up the vast majority (£27 billion) of the £33 billion revenue. However, fuel tax is not a sustainable form of revenue, especially considering that electric vehicles are becoming more efficient and are sold in greater volumes.

Figure 9: Road revenue by type and road expenditure for 2007/08 to 2014/15



In terms of future road revenues, Figure 10 displays fuel tax and VED revenue alongside maintenance costs under three different do minimum (DM) scenarios. Each scenario operates under a different assumption of fuel tax revenue change with VED annual change remaining at 2.1% (based on CBRE 2015 prediction of VED revenue[4]) for all scenarios.

Figure 10: Expected decline in government revenues from roads



[4] CBRE, 2015, The future of motoring taxation, A report for the Society of Motor Manufacturers & Traders (SMMT).

Table 5 gives a breakdown of each scenario. All scenarios are in 2011 prices.

Table 5: Fuel tax and VED revenue forecast scenarios (based on CBRE, 2015)

Forecast type	Details
High forecast	• Fuel tax based on average growth per annum from 1990 to 2014 (4%). • VED -2.1%. 2011 prices.
Middle forecast	• Fuel tax based on average growth per annum from 2004-2014 (1.5%). • VED -2.1%. 2011 prices.
Low forecast	• Fuel tax based on reduction of 1% per annum as a result of significant change in fuel efficiency/consumption. • VED -2.1%. 2011 prices.

Figure 10 shows that government revenue will decrease in real terms under all scenarios. The high forecast scenario is considered unlikely, as the rate of increase in fuel use is decreasing each year and vehicles are become more fuel efficient. The middle scenario is based on recent trends in fuel tax revenue; between 2004 and 2014 there was an increase of 1.5% per annum – a trend that is assumed to continue. This forecast does not allow for any increase in fuel efficiency or switch to electric power. The low scenario assumes a steady 1% reduction in fuel usage.

In order to examine the financial impact of our proposed system, we have made a set of assumptions about the appropriate level of changes and how that compares to average vehicle usage costs at present, largely based on published data.

4.1.1 Maintenance charge assumptions

According to data from the DfT, road maintenance costs in 2015 were around £4.5bn. Allocating this between motorways, urban and rural roads and dividing by the total number of vehicle kilometres on each road type suggests an appropriate maintenance charge would be as shown in Table 6 below.

Over time, we envisage that the average maintenance charge would gradually decline as electric cars and AVs are expected to be lighter and do less damage to the road. A decrease in the maintenance charge of 1% a year has been assumed.

Table 6: Maintenance charge (pence per kilometre, 2015 prices)

	Motorway	Rural	Urban
2015 (car)	0.10	0.30	0.90
2030 (car)	0.08	0.25	0.75
2015 (LGV)	0.20	0.60	1.81
2030 (LGV)	0.17	0.50	1.51
2015 (HGV)	0.27	0.82	2.47
2030 (HGV)	0.23	0.68	2.05

4.1.2 Mitigation charge assumptions

The mitigation charge accounts for a number of externalities imposed by vehicle users on others:

- Noise - taken from the DfT's transport appraisal guidance, WebTAG;
- Emissions of greenhouse gases - WebTAG;
- Local air quality - WebTAG;
- Accidents - the total cost of accidents in 2015 has been estimated and valued using published DfT data, and converted into a cost per kilometre by using total vehicle kilometres by road type.

Again, the costs per kilometre are envisaged to decline over time with the introduction of electric vehicles and/or CAVs. The Table 7 below shows the cost per kilometre as of 2015, and how this might have changed by 2030.

Table 7: Mitigation charge (pence per kilometre, 2015 prices)

	Motorway	Rural	Urban
2015 (car)	2.02	1.76	1.95
2030 (car)	1.48	1.29	1.43
2015 (LGV)	6.66	4.23	6.38
2030 (LGV)	4.90	3.11	4.69
2015 (HGV)	5.29	5.86	10.16
2030 (HGV)	3.89	4.31	7.47

4.1.3 Congestion charge assumptions

Table 8 below shows that 75% of vehicle kilometres would not be subject to any congestion charge, and for those that are charged on average it would be around 3.0 pence per kilometre for urban roads, less for others. At extremely high levels of congestion the charge could be up to £0.8 to £1 per kilometre.

Changes to the congestion charge over time would be directly linked to a) changes in the number of vehicles over time and b) changes to capacity. For example the introduction of CAVs would increase capacity since they can safely travel closer together and hence would reduce the congestion charge.

The congestion charge should be set so it is zero at low levels of congestion, increasing as the level of traffic relative to road capacity increases. For simplicity we have used five congestion bands (where congestion =volume / capacity) in line with the DfT's published figures:

- Less than 25%;
- Between 25% and 50%;
- Between 50% and 75%;
- Between 75% and 100%; and
- Greater than 100%

Table 8: Congestion charge (pence per kilometre, 2015 prices)

		Congestion charge (pence per kilometre)			
Congestion band	% of traffic	Average road (pence/kilometre)	Motorway (pence/kilometre)	Rural (pence/ kilometre)	Urban (pence/ kilometre)
<25%	43%	0.0	0.0	0.0	0.0
25% - 50%	32%	0.0	0.0	0.0	0.0
50% - 75%	17%	0.6	0.4	0.3	0.6
75% - 100%	8%	26.6	16.0	13.3	26.6
>100%	1%	77.1	46.3	38.6	77.1
Weighted Average		3.0	1.8	1.5	3.0

In the example in table 7 for the first two categories of congestion, there would be no charge. With congestion above 50%, the charge that we have assumed is in line with the external costs of congestion from WebTAG, with uplifts applied at higher levels of congestion to reflect the charge that we believe would be required to reduce congestion to the desired level of free movement of traffic at the speed limit for that road.

Those costs are higher for certain road types / times of day, so although Table 8 shows the average congestion charges per kilometre, there would be a range around this in practice. In addition, Table 8 also shows:

- The proportion of traffic travelling at each congestion level as of 2015;
- Our proposed congestion charge per road type such that the charge is lower for motorways and rural roads relative to urban roads.

These charges are then used to estimate a weighted average congestion charge for each road type, shown at the bottom of the Table 8.

4.1.4 Net financial position

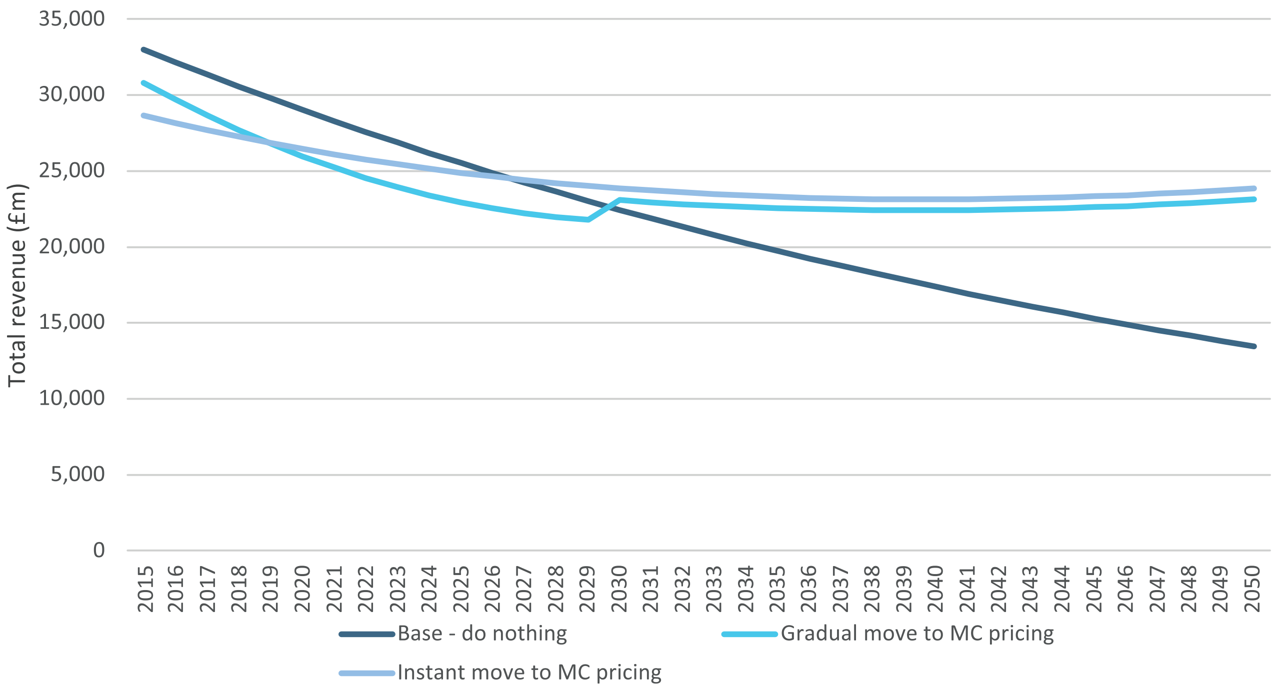
The introduction of this new pricing system would naturally have huge implications for the government's net financial position with regards to road infrastructure.

Figure 11 shows the net financial position for the government under three different scenarios. Each scenario is explained in Table 9 (below).

Table 9: Financial scenarios

Scenario	Explanation
Scenario 1	Do nothing and roads continue to be funded by VED and fuel tax
Scenario 2	VED and fuel tax are slowly phased out and there is a gradual move to marginal cost pricing
Scenario 3	VED and fuel tax are removed instantly and marginal cost pricing is imposed immediately

Figure 11: Government highway revenue under different scenarios



As can be seen the do-nothing option leads to the worst position for both the road user (congestion remains) and the government (in terms of declining revenue). The difference between the immediate or gradual move to marginal cost pricing lead to very similar outcomes so given concerns over public acceptability we would favour the gradual introduction of our proposal.

4.2 Case Study

A high level modelling exercise was undertaken to explore how the use of a distance based charging mechanism would impact traffic flows, compared to a baseline and an alternative flat London-style 'congestion charge'. The goal of this was to analyse the pricing scheme in an urban context. We have used real data extracted from a transport model for a typical small city in the East of England.

The results show that the distance based toll and the flat toll both would raise roughly the same amount of revenue. However, the distance based charge appeared to reduce congestion in the city centre more than the flat toll (congestion was measured as average vehicle speeds compared to the baseline). This may indicate that a flat toll is a blunter instrument and less suited for tackling widespread urban congestion. This is evident in London where congestion outside the congestion charge is widespread and therefore difficult to address with area specific cordon based charging systems..

A more sophisticated modelling assessment with variable charging levels will be undertaken if our study is shortlisted.

5. Impact of Connected and Autonomous Vehicles

5.1 Benefits of Connected and Autonomous Vehicles

We are proposing a system designed to deliver long term sustainable outcomes. That means that at the very least it needs to take account of the potential impacts of technological change, especially disruptive technology. Connected and Autonomous Vehicles (CAVs) and associated transport technology are advancing fast and will impact how roads are used, the costs associated with driving, and urban spatial structure.

A proactive approach is required to anticipate the effects of this technology and implement policy that will maximise its benefits and mitigate any potential harms. The following, are impacts which we consider realistic and directly relevant to this study; it is not an exhaustive list:

- Technology could potentially increase highway capacity (without building new infrastructure) such that capital investment in the network is not required or that congestion charging revenues fall to zero over a greater proportion of the network.
- AVs/CAVs will be much safer than human drivers - over 90% of all accidents are attributable to human error. Eliminating accidents would reduce mitigation payments considerably and reduce the congestion caused by accidents.
- There are many attractions to future users of CAVs in particular, removing the need to drive. That alone would be expected to generate a large increase in demand as people will be prepared to make much longer trips if they can use that time to do something other than driving

History has shown that increases in road capacity will be met by increases in demand. While higher speeds will be offset by driving further. Left unchecked, sprawling urban areas would expand ever outwards. Examples of potential negative effects from CAV proliferation include congestion returning to previous levels as people travel more and further and air and noise pollution, and loss of open spaces and agricultural land to greenfield development.

However, we consider that dynamic road pricing technology, the switch to electric vehicles and CAVs are highly complementary. CAVs will replace low frequency buses and trains (mostly rural and evening or weekend services) with a much more efficient and attractive alternatives.

5.2 CAVs – a new urban management tool

The proposed pricing approach will leverage the benefits of CAV technology to make sure that the UK road network improves, rather than just maintains the status quo. Depending on the road pricing philosophy chosen, traffic volumes, car parking and car ownership patterns can be partially managed through pricing. In short, the price set for using or accessing a CAV will have a direct impact on how cities experience the benefits (or disbenefits) of CAVs, as shown in Table 10 below. In essence, CAVs combined with our proposal, can offer a new urban management tool to local authorities or cities.

Table 10: Charging for CAVs

Impact on	Low Price Scenario	High Price Scenario
Traffic Volumes	Large increase in demand (Vehicle kilometres travelled), offset by increase in capacity of road network in the short term. In the long term demand likely to exceed capacity	Price used to reduce the increase in demand and as an incentive to change time of travel. MC pricing is critical with CAVs
Public Transport	CAVs to replace low capacity bus services but also to feed rail stations	Same
Car Ownership Patterns	Variety of car ownership models: outright ownership, on-demand hire (from a private or public operator), car sharing	Few people own an AV outright, most hire on-demand.
Urban Structure	People may be more inclined to travel farther distances. Geographical decoupling of home / work location, resulting in urban sprawl and higher energy consumption	Concentration of homes / workplaces leading to urban containment which may also constrain energy consumption

5.3 Timeline of CAV technology

The scheme proposed in this paper is viable to be implemented today, rolled out on existing mobile phone technology or using vehicle-mounted transceivers. However, increased connectivity is poised to transform traffic infrastructure. Connected and later on Autonomous Vehicles could replace the use of mobile phones to manage the system by having dedicated short-range communication (DSRC) technology on-board the cars and allowing GPS to give coordinates at all times. The national roll out of 5G is seen as an enabler for the mass roll out of Connected Vehicles (see Stage 1, in Table 10). In combination, new technologies will provide an opportunity to inexpensively charge road users, reducing concerns of a costly collection system.

What exactly will a world with CAVs look like, and when will it happen? In this paper we have made some assumptions based on previous research and determined a timeline with three stages, which we think represents a likely progression of CAV technology. Table 11 below describes some key elements of each.

Currently over 81% of the population of the UK owns a smartphone[5] and though this figure is expected to increase, the rate is slowing down and it may nearly have peaked. In its early stages, road pricing is expected to rely on a combination of smartphones with GPS technology and vehicle based transceivers when smartphones are not available. From today, increases in vehicle connectivity will make the management and implementation of a pricing scheme cheaper and easier, with all new cars having connectivity features such as a SIM card by 2025.

Real-time data from connected vehicles and a good understanding of how people respond to pricing (based on data analysis and experiments) will result in moves towards network optimisation. Machine learning/artificial intelligence will be relied on to manage the system and alter incentives as appropriate to keep traffic flowing at optimum speeds, all the time. It is yet unclear how automation of vehicles will impact pricing, as this in part depends on how users react to this change in technology.

[5] https://www.deloitte.co.uk/mobileuk/

Table 11: Future Connected and/or Automated Car scenarios

Scenario	Scenario Description	Time Frames	Area
Stage 1	Connected Vehicles (SAE Level 3 conditionally automated vehicles) on Motorways, continuation of the automation trend on cars whereby driver's input is reduced by use of adaptive cruise control, lane control, improved safety, marginal reduction in use of fossil fuels (from smoother driving). Marginal capacity increases in urban areas, as cars will be able to 'connect' with other vehicles and/or infrastructure which will enable them to follow each other closer in slow moving traffic conditions. Platooning on motorways will be the major source of benefits in this scenario.	From today, with connectivity increasing. No car will be sold without some basic form of connectivity (e.g. a SIM card) in the very near future.	Motorway only
Stage 2	Connected and Autonomous Vehicles (SAE Level 4) on motorways - closer, more aggressive platooning (thus further increase in capacity), more advanced connectivity between vehicles and/or infrastructure. CAVs enhance road capacity by optimizing driving behaviour with respect to time gaps, speed and lane changes. In addition, if CAVs are operated centrally as part of a network, the vehicles will be able to collectively calculate the most efficient route in real time.	2025 +	Motorway only
Stage 3	Fully automated CAVs (SAE Level 5) - no human input required. Vehicles summoned on demand, with minimum waiting times. Lower car ownership but higher car use. Vehicles are operated as part of a network which improves efficiency.	Penetration will begin in 2030 with >50% penetration expected in 2050	Urban

6. Acceptability

There is no point in developing a system which cannot be implemented because it is unacceptable to either the public or politicians. It doesn't matter how good the technical solution is if it cannot win the popular argument as well as the technical one. We envisage that our proposal will be accompanied by a comprehensive marketing and communication strategy to explain the benefits of the approach to the public and improve acceptability.

Public – the public will get the road network it deserves. Fast reliable, lots of cheap options available by varying the time of day and route but fast, reliable and direct when you need it (and are prepared to pay for it). In addition, for the people who are negatively affected by road noise and pollution there will be a significant investment in mitigation of those effects.

Government – the national government stands to lose most of its revenues from the highway sector over the next decade or two. Our proposed approach delivers a better road network, requiring less investment because of price demand management, whilst covering not just its direct operation and maintenance and capital investment costs but also its health and environmental impacts. Some of the mitigation charges will directly replace what are currently NHS costs.

Cost - The road pricing scheme will be cheaper for consumers, it is designed to generate less revenue than the government is raising currently. The issue of cost will be key to selling it to the public. Except for a small minority of users driving in heavily congested areas in peak periods, the majority of users will find their annual cost of vehicle ownership decreasing.

At this point it is not clear what groups will be negatively affected. Logic points towards poorer people who spend a large proportion of their income on their vehicles, and for whom driving on congested urban roads is the only option as a group that may be adversely affected. For this reason, in early stages of the implementation it will be a major goal to identify users/groups that are disproportionately impacted in terms of distribution, and to come up with mitigation policies where appropriate.

Phasing - We expect that initial public reaction to pricing schemes may be negative. A voluntary phasing approach would help users see the benefits of the system and the lower costs will win them over.

A trial in a particular county (or counties) could be the first step, where motorists are asked to volunteer, perhaps in exchange for some credit initially. They will find that lower costs and improved network performance are well worth making the switch and public trust in the scheme will grow. This will also be the beginning stages of data gathering so that the scheme management will learn about how users react to pricing incentives.

Wider connectivity improvements – This is not a narrow road focused system. It is explicitly designed to promote walking, cycling and public transport use as well as producing a much more efficient road network. At the trip booking stage alternative modes will be presented on a comparable basis enabling well-informed decisions. A significant positive effect will be a boost to public transport, both from the switch of demand from car to public transport and from the faster journey times delivered by the reduction in congestion. Those lead to significant operating cost savings and revenue gains on buses. Short trips will have a clear financial incentive to use free soft modes.

7. Conclusion

The UK's roads are among the most congested in Europe. The UK is an island nation with high population density, high car ownership and a relatively low supply of road space. Road building has been limited for the last 30 years, perhaps a consequence of the anti-road campaigners in the 1980's. Now our roads are not only congested they are also in an increasingly poor state of repair as highway maintenance budgets are squeezed by local authority spending cuts.

Our proposal sets out a holistic solution for UK roads. This solution ensures that:

- The road network is self-sustaining, covering all of its costs (direct and indirect) from user charges, and generating a sustainable tax surplus for HM Treasury, although a lower surplus than exists today;
- The revenues flow direct from drivers to the appropriate authority and the appropriate purpose. Three separate "pots" of money are created for: road maintenance, mitigation of external impacts and investment in the network; and
- The combination creates a system which is sustainable, efficient, greener than at present and will generate new investment and mitigate the costs of road travel in a transparent and effective way.

Our solution will change an inefficient charging system with almost no link between price and user behaviour, into one which provides full information to road users on journey costs, journey time, alternative routes, and modes available. It will also place pressure on highway authorities; failing to deliver on the agreed level of service which involves measures of expected speed and reliability, then drivers will pay lower charges and even receive refunds or compensation in the case of very poor performance. In short, our approach aims to internalise the external costs both to society (pollution, safety) and the internal costs to other drivers (congestion) as a result of the current inefficient way of charging for road use.

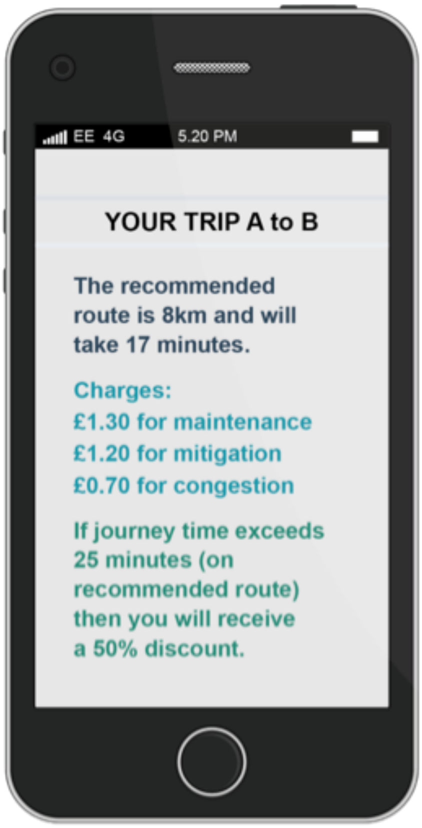
The marginal cost approach, whereby costs are made explicit to users before they start their journey is a powerful tool to drive behaviour change. When users perceive their costs as fixed irrespective of how much they drive, then they make very different choices. When costs are transparent people make better, more efficient choices.

Under this approach we are able to switch most of the cost of road usage to a Marginal Cost (MC) basis, enabling specific targeting of polluting vehicles, sensitive areas and congested roads. MC pricing not only delivers short term changes in user behaviour, it also drives long term decisions, encouraging the use of less polluting vehicles and switching travel to less congested routes or times. The proposals set out in this paper will be introduced gradually, to enable people to adjust and enable continuous feedback and improvement in how the overall system develops.

We also envisage that our proposal will be accompanied by a comprehensive marketing and communication strategy to explain the benefits of the approach to the public.

Our proposal encompasses a pricing system which:

- Can price demand for congested parts of the network whilst also funding future investment so that road infrastructure can be improved and charges reduced in the future;
- Will be cheaper and faster for a very large majority of all road users (cars, bus, HGVs);
- Ensures that the road sector pays for itself, covering its maintenance, congestion and mitigation costs in a sustainable long term solution;
- Is infinitely flexible, cheap to implement and operate, generating enough funds to cover all road sector costs and pay a return to central government;
- Can adapt to technological change at different rates and scales of change, for example, accommodating driverless enterprise and Mobility as a Service concepts;
- Gives drivers effective performance related charges and automatic price reductions and/or compensation if thing go wrong; and
- To alleviate privacy concerns, users can opt in or out of personal data being stored on the cloud. If users opt-in for their data to be used (e.g. for transport modelling exercises in order to improve service) they are entitled to a small discount on their journeys.



Our study shows that the government currently makes a £23Bn annual surplus on road user charges (largely via Vehicle Excise Duty and fuel tax) over highway maintenance and investment costs. That surplus is expected to fall rapidly, as fuel efficiency and the use of electric vehicles reduce future fuel tax revenues. Our proposal aims for a lower government surplus, in the region of £10-15B per annum, but one that is sustainable in the long term. The Government will reduce its net income in the short term but increase it in the long term.

The proposed approach sets up a contract between highway authorities and drivers for each journey. Drivers pay according to vehicle type, road location and level of congestion. Under such a system it is not possible to eliminate all congestion without high spikes in charges, which we know reduces public acceptability. Hence it is likely that low levels of congestion at peak times will remain in certain locations but it should never deteriorate into gridlock.

7.1 Next steps

In addition to developing in more detail the themes explored in the primary submission, we propose to carry out the following, if our team of is shortlisted for the secondary Wolfson Prize submission:

- Develop further our case 'typical East of England' case study, in order to determine optimum pricing strategies by hour of day, including scenarios in 2030 with and without CAVs;
- Carry out detailed analysis of the Singapore congestion charge scheme, including effectiveness and lessons learnt that can be applied to the UK. Our team can draw resources and data from colleagues in Singapore, but also has links with the Singaporean Land Transport Authority who are responsible from the scheme; and
- Elaborate on the technology aspect of our proposal and how the integrated phone app will work in practice.

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