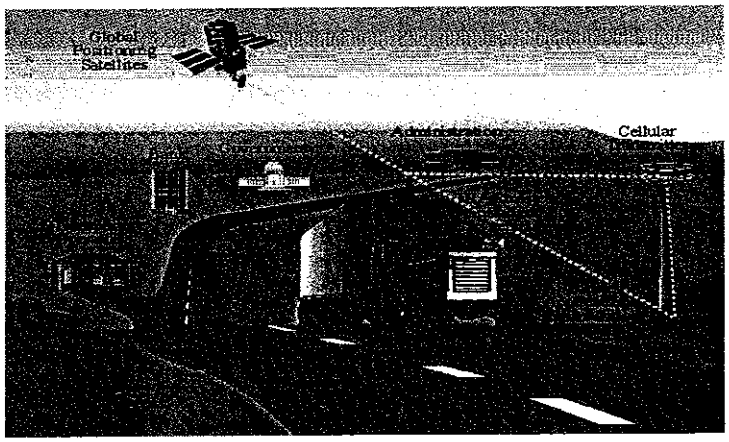
23rd Australasian Transport Research Forum
Perth, Western Australia. 29 September – 1 October 1999

Network Wide Road Pricing Using Global Positioning System Information

Paul Salter
Department of Infrastructure, Energy and Resources, Tasmania

Abstract



The Department of Infrastructure, Energy and Resources (TAS) has trialed the use of the Global Positioning System (GPS) as an aid to better management of road networks. This paper considers how information from the system could be used to implement network wide road user charging. It scopes out some of the economic efficiency issues that need to be considered if this type of reform proposition were to be realistically evaluated. It finds that the trade-off between the transaction costs and pricing complexity (differentiation) is a crucial consideration associated with analysis of the proposition The uncertainty regarding the value of cross-price elasticity is a major impediment to solving this optimisation problem.

Contact Author

Paul Salter
Department of Infrastructure, Energy and Resources
9th Floor
10Murray Street
Hobart Tas 7000

Phone: +61 3 6233 4110 Fax: +61 3 6233 4978 e-mail: p-salter@dot tas.gov.au

Introduction

The Department of Infrastructure, Energy and Resources (IAS) has trialed the use of the Global Positioning System (GPS) as an aid to better management of road networks. The trial has the financial support of the National Road Transport Commission (NRTC) and the Federal Office of Road Safety (FORS).

The first stage of the "Intelligent Vehicle Trial (IVT)" involved a trial of a GPS location system and the digital mobile network (GSM-as a means of data transmission) over a period of three months in late 1998.

The second stage of the trial is dedicated to addressing the policy issues associated with implementing initiatives that are facilitated by the technology. This paper considers how information from the system could be used to implement network wide road user charging. It scopes out some of the economic efficiency issues that need to be considered if this type of reform proposition were to be realistically evaluated.

Context

The Department of Infrastructure, Energy and Resources experiences problems that are encountered by all road authorities and faces some challenges which are unique to the State. Like most other road authorities, the department has struggled to deal with the issues associated with increasing axle mass limits, escalating congestion, air pollution and road safety. The department has also had to deal with a road budget that has been steadily decreasing over the last decade. This has put the onus on getting the most out of our existing transport infrastructure.

As a response the department is looking at opportunities to manage the demand for its facilities by encouraging more efficient utilisation of the road network and a more equitable distribution of benefits and costs. GPS technology provides us with an information tool that can be used to meet this objective.

The Information Problem

The current system of taxation, and the outcomes that are associated with it, reflects the underlying problem with the management of road networks – the absence of good road use information.

Government imposts in the transport sector

The transport sector may or may not be overtaxed but it is certainly undercharged. Explanation:

- Generally, there are no "charges" in the road transport sector as government imposts are not a payment for services rendered. Government imposts are purely taxes and are set to raise general revenue for government
- There is little evidence of a link between the costs of providing and maintaining infrastructure, the "external" social costs caused by using the road network, and the taxes currently administered.

The flat rate nature of current taxes means that some travel is overpriced and some travel is under priced. These incentives continue to distort the quantity, location and timing of individual's use of the road network. This has implications for road maintenance expenditure, investment programs, the environment and the efficiency of our cities.

In Australia, road maintenance and investment expenditures amount to over 6 billion dollars per annum (BTE 1998). Estimates relating to congestion costs in cities throughout Australia are around 5 billion a year (Cox 1994). If other social and environmental costs are included the total costs of urban road congestion throughout Australia may be as high as $10 Billion per year and rising (Cotgrove 1998). Environmental costs are also significant. Estimates reported by the NZ Transport Ministry, the UK royal commission and the Australian Government indicate that the cost the community faces could range from $4 billion to $9 Billion per annum (Marschall 1998).

No government imposts clearly attempt to reflect these costs of road use. Indeed, no taxation instrument that is available, and in use, is able to accurately perform this function. The main failing of current instruments relates to the inability to differentiate imposts on road users according to roads used and time of day travelled.

The critical issue

In all markets the important issue is whether or not the supplier of the product has the capacity to enforce property rights over what they have expended effort to produce (Coase 1960). Where property rights exist, a supplier may enforce them by seeking compensation from an individual who uses the product without permission or payment. If it is not possible to prevent 'free riders' from consuming a service (or the cost involved in doing so would be prohibitive), it is not possible to effectively charge a price for the service (Campbell 1997). The capacity to cost effectively monitor the use of the asset is therefore the crucial consideration

The information problem solved

Intelligent Transport System (ITS) applications have a key role to play in solving the information problem for roads. GPS information when combined with Geographic Information Systems is able to identifying actual road use by individual vehicles over the entire network. The Tasmanian trial has shown this.

If units were fitted in vehicles and road owners where able to access this information it could permit network charging similar to that adopted for other network infrastructure such as electricity, telecommunications, water and gas. Road networks could (should) be treated like any other public utility.

The case for road pricing

The long experiment with the socialist mode of production and delivery through taxation, and public sector operation, could be argued to have yielded less than satisfactory results. If road pricing where to be implemented this tool could be used to

integrate road transport with the rest of the market economy. It would put charging for roads on a similar basis to most other goods and services, including for example, electricity and telephones.

The main benefit of pricing derives from the use of information. The service provider (the road owner) uses the price signal to communicate public information about the costs associated with providing the service of travel. The individual road user then combines this public information with his/her private information regarding private costs of travel and how much he/she benefits from consumption (taking the journey at that time, using that route or mode). Through this process the price mechanism facilitates efficient decisions being made by the individual.

Road pricing is unlikely to be a solution to resource allocation issues if used in an isolated fashion. There is clearly a need for an integrated approach to investment and regulation.

The availability of public transport services, walking and cycling infrastructure, the flexibility of work place arrangements, the ability of road freight and rail freight operators to work together; and the time and resources needed to improve land use decisions will all require an integrated development of government policy. Equally, governments will need to develop the intellectual framework surrounding the road pricing concept. Who to charge and what to charge, that is the question.

A pricing model

Decisions made by people with respect to their choice of mode, their location and investments are to a large extent based on prices. In principle, prices paid for individual journeys should be aligned with the real costs of these journeys. As costs differ across, time, space and modes, this implies that there is a need for a high degree of price differentiation (EC 1995).

The pricing model that is being considered as part of the Intelligent Vehicle Trial (IVT) has two components, a fixed component and a variable component. The theoretical proposition underlying this structure is that the act of providing infrastructure, and the act of using the road network are essentially inter-related but can be identified separately as two distinctly different types of goods (services).

Traditional argument

Road networks are often categorised as an impure "public good". Pure public goods are characterised by a situation where a number of users can enjoy the benefits of consumption simultaneously without effecting the benefits that other users receive. Pure public goods are also characterised by an inability of the good or service provider to cost effectively exclude those who do not pay (free riders) from the benefit of enjoying consumption. Exclusion in this context does not necessarily mean prevent in a physical sense. The important issue is whether or not the supplier of the product has the capacity to enforce property rights. Being able to effectively monitor use therefore becomes a major issue.

Road networks are said to be "impure" as they do experience congestion.

Congestion can be defined as a situation where a road user(s) would be willing to pay another road user(s) an amount to not enter, or leave, the traffic stream. The concept implies that the benefits that road users receive can be affected by the use of the road network by others. This implies that there is rivalry in consumption at some point.

Proposition 1: There is always rivalry in consumption

Note that by virtue of its definition, the use of the term congestion is not linked to any particular volume/capacity ratio. To suggest that a particular part of the network is experiencing congested conditions is largely a matter of perception. Indeed, it is possible to identify an example of congestion where there are only two vehicles on a particular part of the network at a particular time. Notionally, one vehicle user being held up by another would be willing to pay the other an amount to move over and let the vehicle user pass. This does not imply that this should occur on all occasions. Some congestion is usually optimal.

Sub-optimal congestion can be defined as a situation where vehicle users, on the road, at a particular point in time, would be willing to pay a car attempting to enter the traffic stream the amount of their opportunity costs of time and additional fuel for not entering the road. Positive transaction costs further complicate this issue.

The presence of congestion concept is linked to a reduction in the level and quality of service experienced by road users. Equally, the cumulative impact of road damage caused by road users over time reduces the quality of the service that is available for others to enjoy. The recognition of the road damage issue identifies the inter-temporal form of rivalry in consumption. This perspective argues against the postulation that there is non-rivalry in consumption in off-peak periods. The latter proposition would imply that there are no incremental increases in vehicle operating costs or loss of amenity associated with deterioration in road condition. This is simply not true.

Implication

Few policy makers have actively considered the proposition that what road authorities really do is provide a service. It's a bit like saying electricity suppliers build power stations and wires rather than providing the community with electricity.

If road authorities are given the power to monitor the provision of the service they facilitate then there is no real reason why road authorities should not charge a price that reflects the cost of providing that service. Equally, if there are externalities associated with the provision of that service, government has a role to play in using its taxation powers to internalise these costs and help manage the market failure. To efficiently reflect variable costs, and tap into the range of price responses road users have available to them, it is proposed that the part of the pricing mechanism that relates to <u>use</u> of the road network should recognise that;

- Road damage costs need to be internalised to reflect the underlying scarcity of asset durability. Short-run marginal cost in this context is meant to encompass all the

pavement related costs associated with retaining durability over a lifecycle, including replacing existing durability when it wears out. This would require the price paid per kilometre to be differentiated by vehicle characteristics, mass carried and durability of roads used.

- Congestion costs caused by an individual journey needs to be internalised to reflect the scarcity of road capacity in peak periods. This requires the price paid per kilometre to be linked to the time of day in which the journey takes place and the associated traffic levels.
- The costs associated with the effects of vehicle emissions on the environment and human health need to be internalised in order to create an incentive to reduce these impacts. This requires the price paid to be linked to the quantity and nature of the emissions produced through vehicle use and fuel consumption.
- Insurance premiums need to be differentiated to reflect the "expected costs" associated with the underlying risks posed by the interaction of driver attributes, vehicle attributes, and road attributes. Collecting insurance premiums on a kilometre basis would create a real incentive to reduce the risk of an accident event occurring.
- An "access" charge would be set to cover all costs associated with maintaining the road corridor that can not be related to use. These are costs that have been identified in the literature as being non-separable and common to all road users. The use of this instrument is concerned with ensuring cost recovery.

Proposition 2: provision of infrastructure should be treated as a public good.

The benefits linked to the provision of new infrastructure (as distinct from the use of new infrastructure) can be classified as a public good. The benefits come in the form of a change in the opportunity set faced by the community. These benefits are clearly evidenced by the inter-relationship between land use patterns and the provision of transport infrastructure. That is to say that the efficient use of land can be enhanced by the provision of infrastructure. The external benefits are equal to the additional consumer surplus accruing from the consumption of resources made available through improved land use. The change in opportunities is available to everyone and jointly consumed by all. Arguably this is what makes the act of providing new infrastructure exhibit some characteristics of a public good.

If the benefits associated with the provision of infrastructure can be categorised as being public in nature then this has major implications for financing provision costs.

It can be shown (Samualeson 1954; Atkinson and Stiglitz 1980) that the demand for a public good is equal to the summation of individual's willingness to pay for the provision of the public good relative to their desire to consume other goods and services. In economic terms this is equal to $\sum MRS$, where MRS = Marginal Rate of Substitution between the public good and the range of private goods available.

This level of demand is then equated to the cost associated with providing the public good. This cost is equal to MRT = Marginal Rate of Transformation. This is an economic term used to describe the cost of the trade-off associated with using resources to produce one good or service instead of another.

The optimal provision of a public good therefore occurs when $\sum MRS = MRT$.

It can also been shown (Atkinson and Stiglitz 1980) that the only way to finance the provision of a public good and retain the optimally condition ($\sum MRS = MRT$) is to use a lump sum tax (a fixed fee). The alternative, using taxes on goods and services, or taxing income to raise revenue, necessarily creates a disincentive to buy certain goods and services, or not work as much as an individual might choose to in the absence of a tax. This has the effect of modifying the optimally condition.

The assumption that is required in implementing such a fee is that the government has the capacity to vary the lump sum taxes payable by various user groups. This mechanism is already afforded to the government through the use of a vehicle registration fee.

The argument is that a "capacity" charge should be used to recover costs related to road network enhancements, occurring in any one year from the type of vehicle classes that benefit the most from the investment.

Due to the nature of road construction and road damage there are legitimate reasons why certain types of vehicle classes will benefit more than others in relation to certain types of investment. For example, the depth and durability of the pavement (and associated costs) are directly linked to the need to accommodate the heaviest axle loads. Heavy vehicle operators benefit from this investment as it reduces the quantum of the price that could be charged, to reflect road damage costs, in the absence of this level of durability.

The use of the fixed fee also provides an opportunity to vary this charge from year to year and use a consultative process to establish support (or lack of support) for a specific program of construction projects. It is suggested at this point that this approach to investment decisions would improve both the level of transparency and accountability.

Summary of proposals

The model advocated here does not imply a dramatic shift away from traditional taxation instruments. The pricing model merely advocates the introduction of a direct variable road user charge, and a change in the mix of current instruments.

Australia already has a fixed fee related to State road networks and local government networks, that is, registration charges and an implicit levy on rates. Australia also has a variable road user charge that is related to vehicle emission costs: the fuel excise.

What the Australian road taxation system does not have is:

- an economic instrument then can be used to provide road users with an incentive to use the most appropriate infrastructure set;
- a mechanism that can used to allocate funding to the road owner who has suffered damage from use; and
- an integrated and transparent approach to using charging and taxing instruments.

The variability of road damage costs and congestion costs needs to be reflected in the pricing scheme. Without this information and without the incentive, road users can not be expected to make rational and sustainable decisions.

Assumptions

Financial issues

For these pricing arrangements to be sustainable over the life of the asset there will need to be a link between the use of the road network and the maintenance of that network for the benefit of road users.

It is instructive to consider this perspective as being a movement towards a system where the price paid for road use, is a payment for services rendered. The major benefit of this approach would be to provide certainty on the level of maintenance funding.

Stanley (1993) and others have argued in relation to roads, that the consequences of cutbacks in funding, to release money for other government priorities, usually takes time to reveal itself in poorer operating conditions (higher user costs and lower safety levels). This continues to leave road funding vulnerable. This is particularly true when there continues to be increasing demands for scarce public funds from areas such as health and education where the issues may be seen as more emotive and somewhat more political.

The real consequences of these practises is that delaying expenditure adds costs in subsequent asset maintenance requirements. Catch up programs become inevitable and wide fluctuations in resource use can occur, hardly beneficial to productivity in this resource use (Stanley 1993).

If revenue from the "road damage" component of prices where to be returned to road owners there would be two obvious benefits:

1. Funds would be available to apply the most appropriate maintenance treatment at the most appropriate time. This would avoid the significant resource waste associated with catch up programs; and

2. Funds would be allocated to road owners based on the actual level of use occurring on their respective networks. This would avoid the waste linked to State, Territory and local governments seeking to modify funding allocation mechanisms so that they can get a better deal. It would also streamline the significant level of administrative effort needed to facilitate these fiscal transactions.

In contrast, it would not be wise to give road authorities access to the revenue stream that is generated through the congestion cost component of prices. On inspection there would appear to be a significant moral hazard problem associated with this practise.

The "moral hazard" relates to the fact that if road authorities were given the revenue from congestion charges, they would have no incentive to expand capacity and reduce congestion even if it was economically justified. Indeed it is conceivable that road owners could use their monopoly power to maximise revenue.

Equally, there are possibly a number of perverse incentives associated with giving road authorities access to revenue from charges on vehicle emissions. It is certainly true that if road authorities were to act as profit seeking organisations they would clearly have an incentive to promote an aggregate increase in the level of emissions.

In both these cases it would be beneficial to direct these funds to Commonwealth and State and Territory treasuries to allow these organisations to take advantage of the double dividend associated with externalities taxation. The "Double Dividend" results from both a reduction in the externality, and the generation of revenue that can be used to either provide other government services, or reduce distortionary taxes in other sectors of the economy.

In consideration of this issues it is the recommendation of this paper that:

- Road damage cost revenue be returned to the relevant road owners;
- Access charge revenue be retained by road owners to cover non-use related costs associated with the road corridor;
- Congestion charge revenue be directed to the State and Territory consolidated revenue funds;
- Emission charge revenues should be directed to the Commonwealth consolidated revenue fund; and
- If insurance premiums are to be collected on a per kilometre basis then this revenue will need to be returned to the relevant insurance company.

Institutional issues

The application of the new charging instrument requires the collection and manipulation of a significant amount of information regarding the movement of a fleet of vehicles over the entire road network. There are a number of good reasons why the collection of this information should not be undertaken by the public sector:

1. The collection of this type of information is a serious threat to the level of privacy available to individuals. There is a general distrust of government in respect to these issues (eg possibility government might use information for enforcement) so it is suggested that the public acceptability of the concept would be improved if there was a contractual relationship between the information provider and the information manager. This would establish a legally enforceable set of rights.

2. The nature of the task does not require government involvement. The provision of the data management service is no different than the provision of accounting services, internet banking, etc, etc.

3. The private sector is far more capable of gaining the expertise and skill necessary to set up and run the processing facility, and design and build the in vehicle units.

4. It would be possible to set up a contestable market where consortia (alliances of hardware and data management service providers) compete which other on the basis of cost, reliability and value added services.

5. It is highly possible that there will be a demand for value added services from data management service providers. For example, the capacity for two-way digital communications enables heavy vehicle operators to use this information for fleet management purposes. Other road users could conceivably use the capacity to send e-mail messages based on voice recognition software. The number of different applications is quite extensive.

Due to these reasons and a number of others, it would be beneficial if both the provision of the hardware (in vehicle units) and the provision of the data management service were to be fulfilled by the private sector.

It is the proposition of this paper that government's role in the implementation of the new pricing instrument should be restricted to:

- specifying the information to be collected for the purposes of pricing;
- setting the prices to be charged;
- accrediting consortia as being able to provide this service;
- provider of concurrent administrative functions;
- auditor of official consortia records; and
- ensuring that technologies are compatible (regulatory of standardisation issues)

These are the assumed characteristics of the administrative system associated with the pricing reform.

Evaluating the prospect of reform

Having considered a model for reform, economic feasibility is concerned with whether or not it is worthwhile implementing the reform in practice. That is to say, it may be accepted that the proposed pricing model is superior to the current system of taxation in theory, but do the benefits of reform out weigh the costs.

This is the critical issue. It requires both an examination of the change in direct and implicit transaction costs, and an evaluation of how demand patterns have changed in response to cost reflective prices.

The nature and level of transaction costs associated with implementing a road pricing mechanism vary with the type of system being used.

Under the fuel excise system, petroleum taxes are collected by the Commonwealth Government at a reasonably high level up the distribution chain. The higher up the distribution chain an item can be taxed, the lower will be the compliance costs, administrative costs, and opportunities for evasion (NCHRP 1997).

Fuel taxes are also relatively easy for the final consumer to comply with; the price is higher because of the tax, but there is no compliance burden of extra time or paperwork. This is significantly different from registration fees, mass distance charges, congestion charges or emission fees. In regard to these systems, arrangements need to be made for each vehicle so that use related charges can be processed.

Transaction costs must be financed from somewhere and seeking to minimise them is essential. The burden of transaction costs may be borne either by the provider of the infrastructure or by the road user themselves. If this burden were to be borne by the infrastructure provider there would be a decline in revenue available for reinvestment in the network or, in the case of a public road authority, this may mean other public expenditures have to be foregone. If these charges were to be borne by the road user themselves it would impact on the outcomes associated with road pricing. Having to pay these transaction costs (in the presence of cost reflective prices) would reduce the number of trips below the socially optimal amount and would therefore result in a welfare loss to road users.

Problem definition

The feasibility of implementing network wide road pricing (based on GPS information) will depend on whether the efficiency gains from introducing a refined pricing mechanism, out-weigh the additional transaction costs associated with implementing the model. If the efficiency gains are low, and the transaction costs are high, then there would be no benefit accruing to the community from implementing reform. Both of these considerations deserve greater attention.

The Quantum of transaction costs

Fixed costs associated with the GPS/GSM system trialed in Tasmania include the individual In-Vehicle-Units, enforcement set-up system costs and processing facility set-up costs. The marginal costs are those associated with auditing, enforcement, processing and transmission. If a network wide system of road pricing were to be implemented then the later two of these marginal costs are the most important.

Why?

The additional costs of data transmission and processing are the main difference between the status quo (existing taxation and regulatory system) and the reform proposal. These costs are also the most relevant to the road user who will bear the burden of payment and respond to these cost incentives. New fixed costs are additional, and therefore important in evaluating reform, but are likely to be amortised over many uses and users and may be paid for through subscription fees.

Transmission costs are clearly a positive function of the <u>amount</u> of information that is to be transmitted, and the <u>timing</u> of these transfers. While peak price communication periods can be avoided through relatively simple algorithms, there is a trade-off between the degree of differentiation in the pricing scheme, and the amount of information that is required to be collected and transmitted. The scale of the trade-off will depend upon the minimum amount of information that is needed to accurately infer the characteristics of individual journeys using processing algorithms. This scale will clearly change as the software develops and becomes more sophisticated over time.

Both processing and transmission costs are clearly influenced by the quantity of information required to implement the pricing scheme. For example, using zone pricing may approximate a reflective price mechanism for urban conditions. In this case the

level of information shown in Figure 1 would not be required. All that would be required would be zone, time of day, and distance travelled. A charge could be calculated at the processing facility using just these data points. At the other extreme, the complexities of the urban system may be such that lane pricing is needed. In such a situation the number of GPS fixes recorded and transmitted may have to increase beyond that shown in Figure 1 in order to achieve a given level of reliability in calculating the charge. This would imply increased cost.

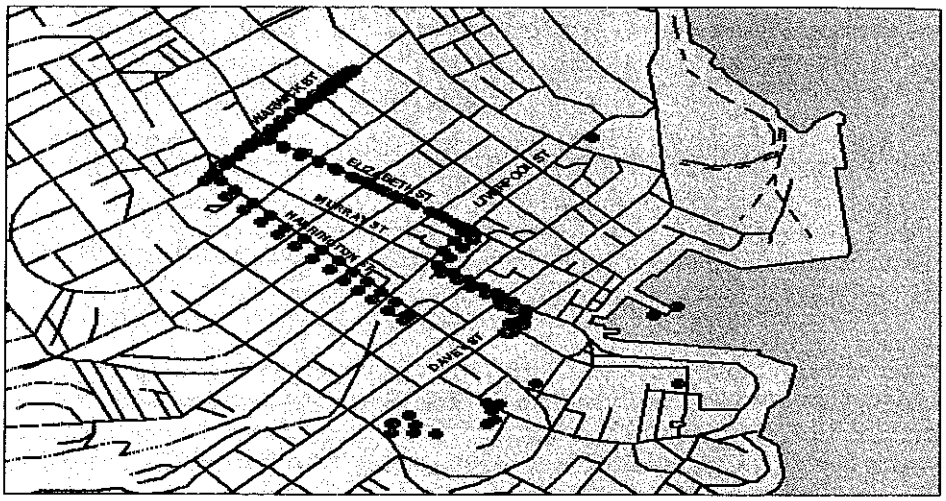


Figure 1. Urban trip in Hobart. Purple (darker) dots represent differential GPS fixes. Green (lighter) dots represent non-differential fixes.

Transmission and processing costs are also clearly substitutes in seeking to find the least cost technical solution to this particular information problem. As processing algorithms develop only a small number of GPS fixes may be needed to accurately infer the characteristics of a journey. For example, it may be possible to reduce the number of GPS fixes in Figure 1 by a factor of three, yet still observe and determine where the vehicle has been. This would reduce transmission costs but would probably involve some up-front costs associated with software development.

Potential efficiency gains

Truly cost reflective prices would require road user charges to vary by factors such as, vehicle characteristics, distance travelled, roads used, time of day travelled, axle loading of the vehicle, tyre pressure of the vehicle, and engine emissions from the vehicle. Fuel taxes, registration fees and other government imposts are instruments that do not have the capacity to vary in value by virtue of all these characteristics. In this context, there is currently a fair degree of cross subsidisation between groups of road users and between vehicle users and the general community, who suffer from the effects of poor road quality, congestion, vehicle accidents, noise and emissions. Direct (network-wide) monitoring of vehicle operations would permit these costs being internalised.

In a refined pricing scheme, a high degree of differentiation would seek to make consumers consider these costs when making the decision to travel at a particular time, through a particular space and using a specific mode. This would not eliminate these road damage, congestion, noise, accidents and emission costs but would reduce them to an "optimal" level where individual road users are willing to pay the full marginal social costs associated with their travel (and not just the private costs they must pay at the moment).

The aggregate reduction in social costs minus the aggregate reduction in private benefits describes the gross efficiency gains (related to road use) of implementing a refined pricing system - changing demand patterns and resource use.

The level of efficiency gains will ultimately depend upon the elasticity of consumer demand to a change in the pricing mix. That is, how do travel patterns change as a result of the increase in price for certain types of journeys and the reduction in price for other types of journeys?

High cross-price elasticity would indicate that road users have responded to the change in price signals and are changing their behaviour. Low cross-price elasticity would indicate that road users are not changing their behaviour, or if they have, the change has not been significant.

Elasticity is greatest when substitute routes, times and/or modes are available. At an aggregate level, using a blunt pricing instrument such as fuel taxes, the elasticity for travel has always been viewed as fairly low. This can be explained by recognising that the tax is highly pervasive and cannot be avoided by travelling at different times, using different routes or even using different modes (with the exception of walking and cycling alternatives). Having costs that are linked explicitly to the generation of the externality improves the effectiveness of the instrument. This statement can be explained simply by observing that there is now more likely to be an incentive and capacity to avoid these costs. This implies that the greatest gross efficiency gains are to be associated with the pricing system with the highest level of differentiation. However, in order to implement this system there would need to be a larger data set transmitted via the communications system, implying that transaction costs are higher.

The question remains when will the greatest net efficiency gains occur? Obviously this implies finding a balance between price differentiation and the transaction costs associated with implementing the pricing instrument. Finding this balance requires knowledge of the cross-price elasticity.

In practise the absolute level of cross-price elasticity is unknown and is likely to differ at different points on the network, for different types of road users. While very few empirical studies exist there are a number of practical considerations that will help identify when and where there are likely to be significant responses to changes in prices.

Responses to prices

For prices to have a real effect on behaviour, individual road users will need alternatives and substitutes.

Heavy freight will continue to travel down roads that cannot handle their mass if another more appropriate route is not available or if a rail alternative is not commercially attractive.

Light vehicle users will continue to be dependent on their vehicles and build homes further from there place of work if public transport services are insufficient, walk and cycling infrastructure is not available, and if land use planning remains decentralised.

The ability of commuters to change the timing of their journeys will also be constrained by labour market arrangements and the availability and pricing of other complementary goods such as parking.

The effect a price will have on an individual's consumption will also depend on other costs that are associated with the transaction. In the case of the road user, the direct costs associated with travel include the capital cost of the vehicle, time, depreciation, interest on loan (if any), compulsory third party insurance, insurance, fuel, tyres, services and repairs. Indirect costs include money spent on complementary goods such as parking

The price the consumer would observe could include all of these components, not just the price charged. The response to a change in the variable price will depend on how other costs change as the price changes. In practise, changes in other costs observed by the individual can contradict the price signals. For example, a heavy vehicle operator may still have a clear cost incentive to use one route (relative to another available route) because it means travelling a shorter distance. This may be the case even when the road links on that part of the road network are less durable, and attract a higher price per kilometre (for a particular vehicle with a particular load). The implementation of road pricing therefore may have no effect in this context or it may create an incentive to shift freight onto rail (in a dynamic sense, it also provides vital information regarding willingness to pay. This should feedback into investment decisions).

Another issue relates to the perception of costs. The private costs that road users perceive they pay (fuel, etc.) and the real price they pay may be two substantially differing amounts. Drivers may take a range of cost perceptions into consideration when making travel decisions. These perceptions range from only considering time costs, through to also considering fuel and other vehicle operating costs plus parking costs too (Bray and Tisato 1998).

The implication is that an over (under) estimation of the level of user perception leads to an under (over) estimation of the welfare loss of the underpriced (and overused) road, which in turn leads to an under (over) estimation of optimal charges for road use.

The issue of user perception also has implications for *how* the system of road pricing is in fact implemented. Different levels of perception among users can be partly attributed to the nature of bill payment. Because most of the costs of travel are fixed and periodic to some degree there is no temporal link between the use of the road network and the payment of charges. Fuel expenses would seem the closest example of a user cost, however even this may be viewed as a periodic payment (be it weekly) rather than a fully variable charge. The question then becomes how would road prices be viewed by the consumer?

Consider a case where privacy concerns associated with direct road user charging necessitate innovative solutions that allow payment of charges without vehicle identification. Pre-payment by "smart" card credit, or post payment by account debit are solutions that do not provide any temporal links between the decision to travel and payment. Indeed, these technologies facilitate a "buy now, pay later" attitude. This signal contradicts attempts to introduce a demand management ethos through road pricing (ARRB 1992). Indeed such a conjecture has been shown to hold empirically for use of Norwegian toll roads (EC 1995a) where it was found that users with a "card-ticket" have half the elasticity of demand of those users who pay cash.

Yet another issue relates to the availability of information on prices and the timeliness of the provision of this information. Because societal costs vary according to the location of travel and the timing of use (peak or off-peak), efficient prices will need to be variable. However, to achieve any useful effect, they should be predictable and obvious, to ensure that travel decisions are made before travel commences, not once caught in congestion. Indeed, the schedule of charges for varying quality roads, different vehicles, and different times of day will need to remain as simple and uncomplicated as possible. Failure to adhere to this "simplicity principle" may result in road users making ill-informed travel decisions due to a misconception of the charges that have been incurred.

For prices to be effective, drivers would need to be given indications of travel costs before they travel (perhaps as part of route guidance), and during their trip. Concepts similar to the taxi-meter on the dash board are not entirely irrelevant in this context (ARRB 1992).

Conclusion

As it becomes technically feasible to implement a refined network wide road pricing system, the quantum of benefits and costs associated with the proposition are largely unknown.

This paper has highlighted that:

- The quantum of transmission costs is highly dependent on the type of information road owners require to implement a particular road pricing scheme, and how post processing methods (at a cost) can be used to minimise the data required to infer this information.
- Gross efficiency gains are likely to be greatest when the pricing system is highly differentiated. Price elasticity is highest when avoidable cost disincentives, substitute modes, routes, times and/ or activities are available and/or enforced. This implies that pricing will only be effective when it is one component of an integrated policy platform including infrastructure provision, public transport and land use planning considerations.
- When the pricing system is highly differentiated the data set to be transmitted is large and so transaction costs are high. Maximising the net efficiency gains therefore involves finding a balance between the degree of differentiation and the cost associated with implementing such a refined price mechanism.

Future research

There is a need to evaluate whether the efficiency gains associated with introducing network wide road pricing outweigh the additional transaction costs incurred in implementation.

An assessment of this kind requires:

- The application of a legitimate Cost-Benefit framework where the demand patterns and resource uses linked to the Status Quo (the existing system of government imposts) is compared with the resource uses resulting from responses to improved price signals;
- Quantification of the pricing model;
- Quantification of Transaction costs;
- Estimation of relevant cross-price elasticity;
- Simulation of the effects of cost reflective prices on resource use for a number of case studies;
- Evaluation of the outcomes linked to changes in resource use; and
- An appreciation of the potential to improve investment decisions over time.

It is only in this context that the most efficient outcome can be identified.

References

Bureau of Transport and Communication Economics (1998) Public road related expenditure and revenue in Australia, Information sheet II, Commonwealth of Australia

Coase, R (1960) The problem of social cost, Journal of Law and Economics, Chicago.

Campbell, D.E. (1997) Incentives, Motivation and the economics of information, Cambridge University Press, Melbourne.

European Commission (1995) Towards Fair and efficient pricing in Transport, Policy options for internalising the external costs of transport in the European union, Directorate – general for transport – DG VII.

National Cooperative Highway Research Program (1997) Alternatives to Motor Fuel Taxes for financing surface Transportation Improvements,

Bray, D. & Tisato, P. (1997) Broadening the debate on Road pricing, 21st Australasian Transport Research Forum, Adelaide.

ARRB (1992) Congestion management, proceedings part 5, Perth

EC (1995) cites study of Tretwick, T. "Inferring variations in the value of time from toll route diversion behaviour," TRR 1395, 1993.

Cox, J. & Meyrick, S. (1998) Road Charging and funding study, Australian Automobile Association, Melbourne.

Cotgrove (1998) Civilising Motor vehicle Use, CITIA National Symposium, Launceston

Marschall C R (1998) Natural Gas Vehicles – Fuelling a better future, CITIA National Symposium, Launceston

Cox, J. & Meyrick, S. (1998) Road Charging and funding study, Australian Automobile Association, Melbourne.

Atkinson and Stiglitz (1980) Lectures in Public Economics, CP, Cambridge.

Stanley, John (1993) Funding the roads infrastructure, 16th ARRB conference, Perth.