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OPPORTUNITIES TO REDUCE GREENHOUSE GAS EMISSIONS IN THE URBAN PASSENGER TRANSPORT SECTOR

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ABSTRACT:

This paper sets out to appraise the body of literature which has investigated the potential role of a large number of strategies designed to reduce greenhouse gas emissions, in line with the objectives set under the Rio Convention. The paper discusses the role of (i) technological vs behavioural 'fixes', (ii) the changing spatial and temporal dimension of work activity, (iii) the jobs-housing balance and land use, (iv) conventional and alternative fuels, and (v) pricing, charges and taxes. This review and assessment is part of an ongoing study funded by the Bureau of Transport and Communication Economics investigating the cost effectiveness of alternative ways of reducing greenhouse gas emissions in urban areas in Australia. We draw on a number of real experiments to illustrate the types of policies which are likely to have the greatest impact, given the cost implications.

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Introduction

Global climate change and its consequences for global warming, whether naturally evolutionary or enhanced by human habitation, is recognised by many governments as a matter of significant concern to the future of the planet. National Governments in particular have recognised an obligation to improve their understanding of the agents which contribute to climate change in both positive and negative ways and to introduce policies through various instruments (e.g. pricing, regulation, prohibition, incentive schemes) designed to reduce the accumulation of harmful agents of global warming.

At the centre of the debate on climate change is the phenomenon called the *enhanced greenhouse effect*, which warms the earth's atmosphere and its surface beyond the temperature associated with the natural greenhouse gas effect. The mean temperature of the earth's surface is about 33^{O}C warmer than it would be in the absence of natural greenhouse gases such as water vapour, carbon dioxide, methane, nitrous oxide, and ozone. In the absence of this natural greenhouse effect, the earth would be uninhabitable. Within the bounds of the long-term balance maintained between the solar energy entering the atmosphere and energy leaving it, interactions among the earth's atmosphere, snow and ice, oceans, biota and land cause variations in global and local climate change (US. Congress 1991).

Although there is a substantial amount of scientific uncertainty about the climatic system's eventual response to enhanced greenhouse warming, the balance of current opinion is that global warming will occur. There is strong disagreement however as to the timing, magnitude and regional patterns of climate change. The limited scientific "evidence" from modelling, observation and sensitivity analyses suggest that the sensitivity of global mean surface temperature to a doubling of the atmospheric concentration of carbon dioxide is in the range of 1.5 to 4.5^{O}C (Houghton et al. 1992).

Despite the uncertainty and disagreement in the scientific community, the greenhouse effect and its *potential* consequences for global warming and global climate change has captured the attention of the public, the media and governments of many nations. It is with this background of uncertainty and perceived importance that the Rio Conference and its precedents have arisen.

The Rio Climate Change Convention, signed by 154 nations in June 1992, is a framework document, containing a process of adopting future amendments and protocols (which may in the future be legally binding). The ultimate objective of the Convention (Article 2) "is to achieve ... stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system ... within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (United Nations 1992).

At the heart of the Convention is Article 4 on commitments. The most important provisions under the Commitments entered into by Australia include the preparation of national inventories of greenhouse gas sources and sinks and national programs to address climate change, and to cooperate in preparing for adaptation to the impacts of climate change. Australia has committed itself (under Subparagraph 4.2(a)) to "... adopt national policies and take corresponding measures, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs". Under subparagraph 4.2(b) Australia has committed itself to provide detailed information on its policies and measures, including the projected effect on its net emissions of such policies and measures for the period up to the end of the decade "...with the aim of returning individually or jointly to their 1990 levels of these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol".

In supporting the Rio Convention, the Australian Government (with the support of the States) has embarked on a major assessment of alternative strategies to achieve stabilisation of carbon dioxide emissions to 1990 levels by the year 2000, and to establish policies which will carry Australia well beyond the year 2000 in its commitment to improve atmospheric quality.

A major contributor to enhanced greenhouse gas emissions (GGE's) is urban passenger transport, particularly the automobile. The major source of GGE's is carbon dioxide (CO_2), exhaled by people, cars, power plants, and anything else that uses oxygen to burn up fuel. Other important sources are nitrous oxide (N_2O), carbon monoxide (CO), non-methane organic compounds (NMOC's), methane (CH_4) and nitrogen oxides (NOx) and clorfluoro-hydrocarbons (CFC's). The last 5 emissions are expressed as equivalent CO_2 GGE's through a knowledge of *global warming potentials* (GWP's) (Deluchi 1991). Although CFC's are small in quantity they are so powerful that a car with a CFC-charged air conditioner is believed to contribute more to the enhanced greenhouse effect from loss of its refrigerant than from all the carbon dioxide emitted throughout the car's lifetime. CFC's however are being phased out because of their effect on stratospheric ozone and hence on ultraviolet radiation reaching the earth. Consequently, the main greenhouse gas of concern to future transport policy is CO_2, the inevitable combustion product of carbon-based fuel such as petroleum, natural gas or coal. In most developed countries the emissions from the use of automobiles alone (including emissions from feed stock recovery, processing and distribution, and from vehicle manufacture) have constituted up to 30 percent of the total CO_2 emissions from the use of all fossil fuels (Deluchi 1991, 1993).

It is conservatively estimated that 40 percent of carbon dioxide emissions (the major greenhouse gas) from the domestic transport sector in Australia (1987-88) are attributable to the *use* of passenger vehicles (cars, buses and trains) in *urban* areas (BTCE 1993). The great bulk, 96 percent, is associated with the automobile. If we take the 23 percent figure for the contribution of the automobile to total CO_2 emissions from the use of all fossil fuels (BTCE 1993), then 9% of all CO_2 emissions are directly attributable to *urban* automobile use.

The interest in the current paper centres on changes in GGE's associated with potential policy instruments designed to reduce enhanced greenhouse gas emissions by the year 2000 in line with the Rio Convention. This paper assesses the large number of possible instruments available to government in securing a more emissions friendly future. Drawing on the expansive literature on the topic, we identify the likely influence that various instruments might have in achieving reductions in enhanced GGE. Many of the policy instruments also have implications for broader goals of urban management. In the extreme, a 'no-regrets' greenhouse gas policy requires that reducing GGEs makes sense for reasons other than just their GGE reduction effects. That is, such policies should be worth carrying out even if their CO_2 reduction benefits are valued at zero. The 'no regrets' concept is clearly minimalist in that regrets can arise from doing too little as well as from doing too much (Greene and Santini 1993).

Identifying the Potential Set of Instruments

Identifying an expansive set of policy instruments for assessment is a critical first step. It is convenient to *group* the potential instruments into a number of classes to signify the extent of impact within the transport market. The impact of some policy instruments designed to achieve change within the urban passenger transport sector will spillover to the non-urban passenger transport sector (e.g. a carbon tax), and hence achieve greater GGE reductions than might a policy instrument contained to urban activity (e.g. ride sharing). This makes for potentially more attractive instruments than those limited to urban activity, although it should not dismiss a mix of aspatial and spatial strategies. Although the primary focus is on strategies to reduce enhanced GGE's, many of the strategies contribute to the achievement of the broader goals of urban management and the performance of urban areas.

There are two primary sets of classes designed to capture the full impact of instruments imposed on urban activity: (i) spatial vs aspatial specificity and (ii) urban vs spillover impacts beyond the urban area. Potentially interesting policy instruments within each of the four combinations are presented in Table 1. For example, regulations designed to change engine technology or fuel source have an impact on all contexts of vehicle use, are aspatial and have spillover benefits to non-urban activity. Congestion pricing within an urban area is spatially specific and has no (direct) spillover effects on non-urban activity (i.e. it is a contained urban policy). Aspatial instruments are much easier to evaluate than spatial instruments because the latter require much more information on an individual's current spatial context in which a particular instrument requires evaluation. Within each class there are instruments which are market-based, regulatory, standards, planning and infrastructure initiatives, involve institutional change, and which are centred on the dissemination of better information through education and other media. Some instruments are not well-suited to an assessment via a formal set of behavioural choice models (e.g. education), although we can attempt to identify, qualitatively, strategies which might aid in community acceptance of particular policies.

The literature on travel behaviour provides disparate evidence on the impact of particular instruments in changing travel behaviour. While some broad conclusions can be stated, there are often some spatially-specific considerations which can have a strong influence on behavioural response and hence the success of particular instruments. Furthermore, any inferences are complicated by a general lack of assessment of the system-wide impacts of particular policies, especially policies which involve instruments not currently observed in real markets (e.g. congestion pricing). The system-wide impacts are closely examined in the study by Hensher et al in progress (see Hensher at al 1993). For example, any incentive scheme to encourage a compressed work week in order to reduce the levels of traffic congestion on each weekday should, from an energy and emissions perspective, identify the use made of the time while not at work. On the non-work day it is possible that extra non-work travel occurs, which may be by car, compared to public transport use for the commuting trip. It may be a shorter or longer trip length depending on the nature of the non-work activity. Anecdotal evidence suggests that if a Monday or a Friday is part of the extended non-work period, then trip length by car may increase substantially. Furthermore increased leisure time tends to increase the demand for less fuel efficient vehicles such as 4WD and light commercial vehicles. The net effect on emissions could be an increase rather than a decrease in CO_2. We have to take this ambiguity into account and attempt to accommodate the system wide response through an appropriate specification of the set of behavioural choice models.

Table 1. Targeted Instruments and Main Class Impact

Potential Instruments to Evaluate	spatial (sp) vs aspatial(as	impact beyond urban are ( )
Congestion pricing (Mix of Charges and Taxes)	sp	
Parking charges (primarily CBD, regional centr	sp	
Parking rationing/restrictions in CBD	sp	
Toll road charges	sp	
Restrictive automobile access to locations (CBD	sp	
Sales tax on new autos (skewed and elimination	asp	
Vehicle registration charges (by age, weight, fu	asp	
Company car provision and use	asp	
Maximum age of vehicles in the vehicle park	asp	
Carbon tax (linked to alternative fuels) *	asp	
Fuel excise by fuel type: change and exemptions	asp	
Tradeable permits	asp	
Fee-based compulsory emissions checks	asp	
Price rebates/discounts on alternative fuelled vel	asp	
Govt purchase and scrap high emitters	asp	
Alternative fuels - electric vehicles *	asp	
Alternative fuels - LPG *	asp	
Alternative fuels - CNG *	asp	
Alternative fuels - diesehol *	asp	
Reformulated petrol *	asp	
Automobile engine/transmission technology *	asp	
Automobile vehicle design (weight, drag) *	asp	
On-board IVHS equipment	asp	
Education on cold starts/hot soaks etc.	asp	
Urban form and density (physical planning)	sp	
Urban form and density (housing codes))	sp	
Ride sharing and employer incentives	sp	
Telecommuting	sp	
Compressed work week (time use)	asp	
Non-motorised options - bicycle, walk	sp	
New public transport - light rail	sp	
New public transport - bus priority systems	sp	
Public transport - park-n-ride/kiss-n-ride	sp	
Existing public transport - fares policies	sp	
Existing public transport - levels of service	sp	

Instruments starred (*) are associated with parameters of automobiles, fuel, vehicle operating conditions and environmental conditions.

A time-differentiated congestion charge, for example, may not assist in reducing GGE's if the substitution between time of day of travel (i.e. peak spreading) changes travel speeds *throughout the day* in an adverse way. We might be better off containing the congestion during a limited period of time if a uniform congestion charge regime is not acceptable. Now that congestion pricing is technologically feasible (Hau 1992, Martin and Michaelis 1993), the emphasis has to be placed on studies designed to understand the response of drivers to congestion pricing in the peak period, *and* at all times of the day. What fraction of users will shift their travel to off-peak times? To what extent will time-sensitive drivers be attracted to a less-congested road? What fraction of individuals will opt for ride-sharing or public transport, and how will this vary by income level and other equity-based criteria? What will be the degree of emissions reduction (if any) brought about by congestion pricing? The evidence is currently not available (Poole 1992).

The issue of technological "solutions" versus behavioural/market-based "solutions" pervades the literature on policies to achieve noticeable reductions in GGE's contributed by the automobile (e.g. Martin and Michaelis 1992, Small 1991). There is a substantial body of literature which supports the technological "fix": although difficult to achieve any form of change concomitant with reducing greenhouse gas emissions, it appears easier to achieve progress via an initial stimulation of technology (Hensher et al. 1992). Consumers will respond if the price is right and there are enough incentives. As societies pursue greater mobility, the idea of sustainable mobility centred around clean-fuelled automobiles becomes even more attractive: *"the desire for personal mobility seems to be unstoppable"* (Lave 1992).

Market forces have had a substantial impact on the shape and density of our metropolitan areas, with a very strong trend towards suburbanisation of workplaces, self-employment and highly variable work hours and work days (Brotchie 1991, Hensher 1993b, Giuliano and Small 1993). With a trend towards a diminishing number of travel corridors of sufficient density over reasonable time periods of each day to justify rail-based public transport (be they light or heavy rail systems), the move away from monocentric to policentric urban activity reinforces the mobility benefits of the automobile (Giuliano and Small 1991). Reversal of this trend will be difficult but not impossible (Newman et al. 1993). It may also be desirable although evidence is patchy. Under this evolving scenario the future of bus-based public transport appears better than rail. Bus priority systems such as those introduced in Curitaba (Brazil) and Ottawa (Canada) can contribute much more to accommodating mobility needs in the growing number of corridors where the somewhat lower densities of movement rule out rail systems (Hensher and Waters 1993, Rutherford 1989). Together with the physical zoning of urban activity type and density codes, Curitaba and Ottawa have encouraged the linear development of medium to high density residential activity around a bus priority system, without the need to build the more expensive rail systems. The support for rail systems however is very strong, promoted by a belief that the permanence of public transport systems is an essential element of a physical planning approach to the production of better cities. 'Light rail and heavy politics' might best describe the current debate. Newman and his colleagues promote the physical planning paradigm as a major dimension of the urban reform process centred on "... the transition to a more compact, transit-oriented city which is more vital, sustainable, equitable and lively" (Newman *et al*. 1993).

In an unpublished manuscript, Sperling (1993) outlines an alternative 'suburbanisation' paradigm centred on clean-fuel automobiles in which he describes an optimistic yet achievable chronology of some of the key events along a potential pathway to sustainability up to the year 2010. In 1996 revenue-neutral rebate programs that tax polluting vehicles and provide rebates to clean vehicles should be introduced, giving substantial reductions to the cost of an electric vehicle ($US4,000). In 1998 tradeable greenhouse gas emission standards are adopted for all cars and light trucks followed closely by a more sophisticated air pollutant and greenhouse gas emission trading program for automobile manufacturers and fuel suppliers. By the end of the century, developers build a new town and purchase 20,000 very small neighbourhood electric cars, to be given free with the purchase of a home. Streets are specifically designed for neighbourhood cars. In the early years of the new century (up to 2003) the key automobile manufacturers offer 8 free days of car rentals each year for 4 years with every new purchase of an electric vehicle. A number of major local government areas ban all full size vehicles from 9am to 4pm in selected neighbourhoods. Speed limits of 35 kph are set on many streets. In the year 2003 the first fuel-cell bus enters commercial operation. The first mass-produced fuel-cell cars come on stream in 2008. In 2010 construction begins on the first solar hydrogen energy farm to supply fuel-cell vehicles.

The importance of an objective assessment of alternative paradigms of efficient, effective and ecologically sustainable transport strategies is critical to the acceptance and hence success of particular strategies. We are reminded however of the conclusion by Small (1991) who, in evaluating what might happen rather that what should happen in terms of the type of adjustment that our societies will make to diminish the potential adverse environmental impacts of transportation activities, concludes that *"People need not and will not choose solutions that reverse the trends toward increased mobility via personal vehicles"*.

Technological vs Behavioural "Fixes": The Real Challenge

In a comprehensive examination of the contribution made by transportation and land use measures to achieving the air pollution emission reduction targets of the 1991 Air Quality Management Plan in the Los Angeles Basin, Bae (1993) concludes that the measures aimed at reducing vehicle kilometres of travel have only a modest impact on reducing air pollution. The measures included alternative work schedules, mode shift strategies, and growth management. Technological solutions to the automobile emission problem were found to be much more important. Bae suggests that more transit use, ridesharing and telecommuting are *not* needed to achieve clean air objectives. They may, however, be desirable for other urban management objectives, although their success to date in altering travel behaviour has been somewhat limited (see Hensher et al. 1992, Hensher 1993b, Lave 1992, Golob 1993). Although these arguments relate to air quality, the implications translate readily to greenhouse gases, because the basis of the evidence is an assessment of how individuals respond behaviourally to these various instruments. The adjustments in vehicle kilometres travelled by the automobile, in particular, is the key to reductions in enhanced greenhouse gas emissions.

There is a very simple phenomenon at work - as a society accumulates greater wealth, the desire for personal mobility and the ability to afford it grows. The automobile is then the preferred form of transportation (Small 1991). *Sustainable automobility* is now seen by many as the most viable "solution" to the greenhouse (and air quality) debate. Some commentators, however, often cite the European wisdom of the recent past in encouraging use of public transport through massive investment in highly subsidised heavy and light rail systems as an alternative strategy. The USA attempted this strategy, but was overrun by the substantially higher growth in wealth which stimulated and enabled automobility earlier than other countries (although the incentives through physical planning to use public transport essentially disappeared as investment in roads took over). The viability of public transport is now under threat from the automobile in Western Europe. Most Western European nations, over the period 1965-87, have experienced, a 3-to-1 ratio in the growth of automobiles per capita compared to the USA. The tough anti-auto policies in Europe have been overwhelmed by a far stronger force - the growth of personal income (Lave 1992). Although the link between automobile *ownership* and wealth is some indication of the demand for the *use* of automobiles (i.e. mobility), the critical issue in the current study is the extent and pattern of automobile use, especially in urban time and space where congested traffic environments prevail and where there may be ecologically sustainable opportunities for public transport.

For the period 1965-87, vehicle kilometres travelled per person increased in Europe 154 percent compared to 69 percent in the USA. This translates into an average of 13,000 kms per annum in 1987 in Europe and 15,900 kms in the USA. for the same period. Indeed, if the number of trips on lower quality roads in Europe is higher than in the USA., then in recognising the impact on emission rates of the parameters distinguishing vehicles, fuel, operating conditions, and the operating environment, the emissions per kilometre of travel by car are likely to be higher than in the US for the same manufacturer-specified fuel consumption levels.

Efforts internationally to "lure" auto users back to urban public transport, especially during the peak periods, have not met with any significant success. The predominant instruments have been subsidised fares, more modern and air conditioned vehicles, increased reliability and schedule frequency, free and secure parking at interchanges, and advertising campaigns. At best we can say that the long-term decline in patronage may be showing some signs of being slowed down and possibly halted, but there is no evidence of any noticeable reversal. What has been absent in the strategy to revive public transport has been any effort to make the automobile less attractive. Making a currently inferior product more attractive in the absence of making a superior good less attractive is never going to secure significant changes in behaviour (Hensher 1993b). Throwing money at a relatively inferior form of mobility is no remedy.

One challenge is to identify public transport options which can assist the reversal of the current widespread trends, if such trends are deemed to be socially undesirable. Analysts have called for congestion pricing of urban automobile travel. Efficient pricing alone however is unlikely to produce a socially optimal investment outcome. What is required is a study framework which can evaluate the social benefits and costs of a large number of urban strategies including those directed by physical planning instruments, which have the capability of influencing the density and structure of urban areas. If we are able to assume that the preference functions of the current generation are sufficiently rich in their capability of evaluating alternative futures which include non-marginal changes in urban activity profiles (e.g. moving to a medium density living environment and a greater use of public transport compared to a low density living environment and a car-orientation), then we can identify socially optimal investments which are not heavily conditioned on incremental-creep determined by the current status quo.

At the same time that some planners are searching for viable public transport solutions, the automobile is becoming more energy efficient. There is enormous scope to do much more, up to a doubling of fuel efficiency (Greene and Santini 1993, IEA 1993). Given the high correlation between fuel consumption and emissions of greenhouse (and noxious) gases (0.85 or better), the relative emissions benefits of a public transport “solution” are dissipating rapidly. The arguments in terms of traffic congestion and stress then become predominant in the debate on the future of public transport. Using the evidence on efforts to reduce local air pollution (which gives us good clues on behavioural responses to accommodate reductions in GGE’s), if we take a city such as Los Angeles with a reputation as being one of the most polluted in the Western world (predominantly smog), automobile emission controls introduced in the last 10 years have resulted in significant *reductions* in reactive organic gases (18.2% from 1987 to 1991), 20.6% for nitrogen oxides and 45.7% for carbon monoxide. There has been much progress through major improvements in vehicle technology through tougher regulations. The downward trend is *not observed* for pollutants little caused by automobiles. Ozone (O_3) is the critical pollution problem in Los Angeles, being 2.7 times the federal standard. The real challenge may be to achieve *sustainable transport* through the *civilisation of automobility*. This civilisation includes continuing improvement in the fuel efficiency and de-polluting impacts of automobiles as well as the application of pricing and planning instruments to ensure that the full social costs of automobile use as well as opportunities for land use and public transport options are revealed. There is a great deal that can be achieved with fossil-fuelled automobiles through technological improvements to the engine, the transmission system, and the overall design of the vehicle (NELA 1991).

Changing the Spatial and Temporal Dimension of Work Activity

If we revisit the sixties and the seventies we will observe the rigidity of working hours, the predominance of full-time employment, the one worker household and the requirement to have employees physically located at their place of employment. This was pre-fax, pre-mobile phones, pre-desktop computers, and pre-electronic mail. There are over 1 million mobile phones in Australia and 1 in 5 households have a fax machine. We will also observe the very dominating role of central business districts in the supply of jobs. In combination with relatively low personal incomes, location and labour market practices worked well to assist the case for substantial public transport service (especially rail-based in the larger urban areas). Throughout the eighties and beyond, information technology combined with a *new order* in the employment market produced a new set of opportunities and constraints. At the same time personal incomes were increasing substantially.

Attitudes and opportunities to work changed, commencing with the increased participation of women in the work force. Initially we observed a significant growth in female employment on a part time basis and subsequently on a full time basis as child care facilities improved, as economic necessity became even more real, in part attributed to higher rates of divorce and loss of employment of the main bread winner, and as employers changed their attitudes about the commitment and contribution of women in the workforce. The opportunities for more leisure worked alongside a substantial increase in the wealth of households (aided significantly by the growth in multiple-worker households), with each reinforcing the need for the other, especially as leisure activities diversified substantially, notably in the overseas holiday market.

No longer was it necessary in all work activities to be physically located at the main employment location. With the support of labour unions, alternative work schedules were introduced giving greater scope for both extending the actual hours that a business was "open" as well as offering more scope for worker preferences in defining the hours per day, the days per week and the location of work activity. Although it is very early days in the full cycle of work time and space opportunities, the increased flexibility may work against the future of public transport, especially public transport which requires a relatively dense corridor of movement activity in order to be economically and environmentally sustainable. At the same time that work practices are loosening up, and more and more jobs are being suburbanised in part due to firms (i.e. jobs) following people, the radially biased high density public transport corridors are losing their growth opportunities (even though preserving in many instances their patronage).

Telecommuting, compressed work weeks, and flexible working hours are all evolving employment options (Pratt 1994, Yen et al. 1994). Telecommuting involves working from a remote office site which is typically the employee's home, although in the future satellite 'telework' centres near or in residential areas, fully equipped with appropriate telecommunications equipment and services, can serve employees of single or multiple firms, co-located on the basis of geography rather than business function (US DOT 1993). It is a specialised although growing activity in some countries, notably the USA (Urban Transportation Monitor, July 9, 1993). 7.6 million people in the USA are estimated to telecommute, typically spending 1 or 2 days per week working from home. They rely increasingly on computers and advanced telephone services to communicate with their regular office. One-third of the telecommuters are contract employees. The opportunity to telecommute will be determined by both the desire of the potential telecommuter, the policy of their employer and especially the attitude of immediate bosses. Telecommuting is currently an experiential issue - it is not known well enough for enough individuals to make a well-informed judgement about its prospects (Mannering 1993). It raises important questions about *jobs-family balance* and the social and personal benefits of degrees of spatial separation.

The implications for greenhouse gas emissions are ambiguous and need careful assessment (Pendyala et al. 1991, Nilles 1991), although unpublished work by Tom Golob suggests that telecommuting monitored in California may reduce vehicle kilometres by as much as 10%. The ambiguity is in part due to the relationship between commuting and non-commuting travel activity, the interrelationships between activities of household members, especially but not exclusively workers, and the suburbanisation of workplaces (which may open up opportunities for deeper suburbanisation of residential location given the phenomenon of time budgeting). To take a very real and rich example, a two-worker household with children at different schools:

> Currently one worker has a multi-purpose city commute of 20 kilometres one-way, dropping off a child at school en route to the regular work place. The other worker has a part-time job within 4 kilometres from home, uses a bus and starts at 10 am., finishing at 1 pm. The other child is driven to a local bus stop to catch a school bus (the trip is 12 kilometres one way). Suppose the full-time employee opts for a 4-day working week, taking every Friday off and working 10 hours each day. They no longer take the child to school because they leave too early and get home too late. The first child now catches a local bus 5 days per week. The commute to the city now has a lower auto occupancy for much of the trip. On the day off the amount of driving is less but the number of trips (hence cold and hot starts) is double that of the commute, even though total kilometres have reduced a little. The part-time worker takes the car for the 3 hours on the other worker's day off, instead of using the bus. The opportunity to telecommute for two days for the full time worker subsequently is used to justify a residential location change further from the city, which increases vehicle kilometres

per trip but reduces the number of commuting kilometres for this person. The part-time worker however has a longer commute and now requires a second car. The children have to be driven to school.

There is a lot of activity substitution occurring, with some of the change being emission-friendly, while other changes are emission-unfriendly. This example illustrates the response possibilities which need to be accounted for in determining the net impact of changing the spatial and temporal opportunities for work activities.

Jobs-Housing Balance and Land Use

A particularly important feature of the debate on the role of the daily commute is the jobs-housing balance (Wachs et al. 1993). It has often been claimed that if we can balance jobs and housing spatially that commuting times can be reduced, automobile kilometres reduced and emission levels improved. Jobs-housing balance vehicle kilometre targets have been suggested as a way of reducing emission levels of transport modes. The success of directed action (on growth management) seems unlikely; rather spontaneous location adjustments due to firms decentralising to gain access to growing suburban labour pools (i.e. *jobs follow people*) is consistent with observed trends (Brotchie 1991, Gordon et al. 1989).

Other considerations affecting location choice and ipso facto commuting times such as high job turnover, high residential relocation costs, and employment heterogeneity in multi-worker households have been suggested as reasons why households seek accessibility to an array of possible future jobs rather than just to their current employment. If this is true, when combined with the growing importance of non-work trips, residential amenity and the location of the better schools, the current debate on “excess” commuting (e.g. Small and Song 1992) requires cautious interpretation. Excess commuting is the commuting cost above the lowest possible average commuting cost consistent with the geographical distributions of work and residential sites. Given the (inadequate) current pricing regimes, even if jobs and housing appeared to be in balance, there would be substantial inter-area travel as people take advantage of low priced mobility.

Wachs et al. (1993) track the differences over 6 years between home and work location among employees of 30,000 employees of a larhe health care provider in Southern California. They found that work trip length had in general not grown over the six years, but the growth of the workforce had contributed more to the growth in local traffic congestion than had a lengthening of the work trip over time. This implies that the strategies for reducing vkm should reconsider the predominant interest in commuting activity and give more emphasis to non-commuting travel as vehicle kilometres increase. Indeed, the Natioanl Person Travel

Survey (NPTS) shows that nearly 50% of AM peak person trips are for non-commuting activity, while 67% of the PM peak person trips are non-commuting.

Land Use and Transport: How Strong is the Density Argument

Urban form and density are argued to have an important role to play in shaping transport needs. While this is true as an urban area matures, this is not so for established urban areas, typical of most Australian cities. Cardew (1993) provides compelling evidence to support the view that for the next 30 years, Australia’s urban areas will display essentially the current land use structure with minor variations anticipated. Under this scenario we assume that as the population grows through net immigration and as household size and composition changes through time, we will see some infilling within established areas, with continued growth of residential activity at the urban fringes both in terms of detached housing and multi-unit dwellings, with some slight increase in residential densities. Downs (1992, 80-81), in support, suggests that although some demolition of existing structures and subsequent redevelopment on their sites will occur in every metropolitan area in the USA, the vast majority of homes and workplaces that will exist ten years from today - perhaps even 20 years (to 2013) - are already there and will not be removed or drastically altered.

Downs and Cardew both indicate that most additional housing units and workplaces will be built around the periphery of these existing settlements. It will be difficult for any locational tactics to have much effect on the movement patterns within such existing settlements. Under this scenario the stock of residential dwellings (by type) is assumed to be in elastic supply (i.e. the demand for dwelling types by location will not be hampered by a supply constraint - reflecting the situation in the main at present), enabling existing and future households to live in alternative types of dwellings subject to the ability to afford such housing.

Cardew (1991) argues that the relatively higher cost and risks to property developers of financing multi-unit dwellings (including town houses, villas, and flats) under current planning codes places a major disincentive on the provision of higher density housing. Furthermore, in recent years as infill opportunities diminish, development costs favour peripheral growth (Travers Morgan Pty Ltd and Applied Economics Pty Ltd, cited in Cardew 1993), with an increased proportion of medium density housing demand being satisfied at the fringe, and consequently the more efficient subdivision design leaving fewer opportunities for later redevelopment or densification.

The interest in residential location and density arises because of the possibility of reducing the amount of travel by automobile, especially at times of day when there is traffic congestion.

Downs (1992) and many other authors have shown that low density settlement patterns tend to generate widely dispersed job locations which reduce commuting distances, in spite of considerable cross-commuting. Thus the objective of reducing average commuting distances significantly by changing residential densities in areas of new growth requires extremely large increases in density there. In simulation work he shows how a 21 percent reduction in average commuting distance resulted from a 924 percent increase in residential density. The futility of this strategy may be revealed when we see that only a 50 percent increase in overall average density within 10 years would, for new growth areas, require a marginal density 50 percent higher than the current average density of New York. The challenge for existing established areas is not promising either - in-filling will not affect densities significantly. Unless there is significant removal of low density housing and replacement with medium to high density housing, the role of residential density in affecting vehicle kilometres of travel looks limited. This is unlikely to occur.

Surprisingly, it is suburban zoning that tends to prevent the creation of higher density, and therefore relatively lower cost housing. Local governments impose local zoning ordinances designed to prevent lower-cost housing within their communities. The deregulation of the market (i.e. less interference by planners and planning) might support more opportunities and incentives to raise residential densities by expanding the permissible set of dwelling types and plot sizes. This is unlikely to be achieved without State governments imposing more influence, using the interests of the entire urban area as the catalyst for change at the local government level. The role of property taxes (especially a greater differential by plot size) should be reconsidered. Even however with an essentially tax-incentive structure in place (land rates being a function of plot size), the inability to get permission from local government to build higher-density housing is the major constraint. Giuliano and Small (1993) state that in the absence of market forces, extensive regulation would be necessary to promote compact city development. A coordinated land use program would require the preemption of land use regulatory authority from local government and an historically unprecedented level of control over private property decisions. They go on to say:

> *Moreover, it is unlikely that the desired congestion reduction would occur even if such a policy were implemented, because transit would not attract sufficient numbers of trips from private autos and because auto trips would not be significantly shortened. Simulation studies support this (Giuliano and Small, July 1993, 11-12).*

McLoughlin (1993) suggests in an assessment of Perth, that under reasonable but demanding assumptions about urban consolidation through increasing net residential densities, about 2 per cent of land would be saved in 15 years and the city might be 200 metres less (in 26 or 27 km) in its diameter. This discussion of residential density as a pivotal influence on urban form is important in highlighting the likely impact of land use strategies on overall automobile use and traffic congestion. The evidence and argument point to a situation where land use strategies within established urban areas are unlikely to be effective: even very dramatic controls on new development only have an incremental effect on overall land use distribution, and consequently traffic flow patterns, within a metropolitan area. This suggests priorities in terms of strategies which can have significant impacts on travel activity and hence greenhouse gas emissions. The literature provides compelling evidence that improvements in local air pollution, traffic congestion and global climate are most likely to be attainable through congestion pricing and improvements in automobile fuel-related technology. Other strategies will have a marginal impact. The study in progress (Hensher et al 1993) has the challenge to test the positions taken within the extant literature.

Conventional and Alternative Fuels

There is a great deal that can still be done with conventional automobile fuels to make them significantly cleaner, while recognising some of the inherent environmental benefits of non-fossil fuels. Such a strategy must be accompanied by a policy designed to ensure that owners of automobiles maintain them to the highest standard required to ensure that the full environmental benefits of improved oil-based fuels are achieved. Owners of automobiles, especially older vehicles, could assist in emission reductions by improving their maintenance program. Directed incentives to this effect may be required. Small (1991) views the alternative fuels strategy as more technological than behavioural; this has important implications for the way we investigate consumer demand for alternative-fuelled vehicles.

In addition to the enormous potential to *clean-up* conventional automotive fuels, alternative fuels worthy of consideration are compressed natural gas (CNG), liquefied petroleum gas (LPG), electricity for electric vehicles, and diesel. Although identifying the GGE implications of policies which impact on behaviour *within* the transport sector is important, it is necessary to take into account the *full fuel cycle* of GGE impacts. Electric vehicles, for example in Australia, are most likely to derive their electricity from predominantly coal-based electricity generation. Such fuels used in electricity generation give rise to some 40 percent of carbon dioxide emissions in providing some 19% of final energy (ESD 1991). Since coal releases higher carbon dioxide emissions per unit energy than petroleum fuels, this is compounded by substantial energy conversion and distribution losses in the electricity power system. Thus assuming a continuing domination of coal-fired systems in Australia, electrically-powered transport will need to achieve very high energy efficiency and high passenger loadings to have a noticeable impact on GGE's.

Hence, we might reject electric vehicles in the context of GGE's because of the full fuel cycle implications. If we accept the international evidence that electric cars are likely to raise costs by more than $US0.013 per vehicle kilometre, the amount up to which an individual will support policies for internalising the costs of air pollution (Small 1991), then they are of doubtful attractiveness as a widespread strategy for even reducing air pollution. Furthermore, if we accept Nordhaus's analysis of greenhouse gases (Nordhaus 1991) which suggests that the efficient package of policies to achieve the GGE reduction targets would have a marginal cost of $US0.13 per kilogram of carbon removed, then if the 10 kilometres of travel by electric vehicles does not give value to users in excess of their current costs by $US0.13 for every kilogram of carbon they produce, it is unlikely to be an efficient instrument for change. Indeed, higher costs above this amount have in the past produced technological changes in the form of downsizing and more fuel efficient automobiles, but little if any impact on the total use of passenger vehicles.

Are prospects internationally for electric vehicles real? Are government mandates such as California's requirement that roughly 25,000 electric vehicles be on its streets by 1998 distortionary in development of electric vehicle technology as much as it may encourage it? The only technical obstacle to electric cars is the development of a compact battery that will produce the equivalent power of a petrol engine. General Motor's experimental car can travel 135 km before a recharge, limited to 112 km in city driving. Ford's Ecostar electric van can go 160 kms. The traditional automobile manufacturers claim that such vehicles would cost a minimum of $US100,000 to produce, but that they would have to price them at $US25,000 and add $US50 or more to the price of their other vehicles to make up the difference. Smaller niche manufacturers such as AC Propulasion Co in San Dimas (USA)has developed a car with a 192km range and a 90 minute recharge period at a normal household outlet. The vehicle sale price is currently $US70,000. AC Propulsion suggest favour hybrid technology - arguing that batteries, including advanced battery technology, will not improve significantly in the future, a view strongly point by the Chairman of AerVironment at the 73rd Annual Meeting of the Transportation Research Board. Hybrids are discouraged in California because of the ambiguity in defining a zero emission vehicle (ZEV). Other reserachers, including Ford argue that the fuel cell, which combines the quality of a battery and an engine, will allow much greater power and will be commercial as a hydrogen cell, according the Deluchi (reported in Los Angeles Times December 12, 1993, page D6)in 10-15 years. This is well past the 1998 Californian mandate.

A Government-decreed market for electric vehicles is not the soundest reason for going into business. Schipper (Lawrence Livermore Laboratories, Berkeley) argues that one cannot legislate behaviour - individuals will not be forced to buy or drive a slow-moving or limited vehicle. Range is the excuse, but the lack of support goes much deeper. The development of electric vehicles is a global issue for automobile manufacturers. It is unlikely that the interest would be as high if California had not manadated a percentage of ZEV stock. A great new market is dawning in non-polluting transportation. The uncertainty is in the choice of fuel and the timing of its penetration onto the market worldwide. The motivation for the USA automobile manufacturers to sign a declaration of cooperation in the presence of the US President which has lead to the promotion of the 'clean car' is certainly a strategy to stifle the Californian mandate; it does however reflect an incremental creep towards a commitment to do something to clean up the air. The tragedy of the process is that nobody really knows what will be the real global warming and local air pollution gains of the technological 'solution'. The behavioural responses to preserve much sought for mobility from past endeavours are unlikely to be handed back ligthly.

Santini of Argonne National Laboratories, in unpublished research, has evaluated strategies to hold CO_2 emission levels in the USA constant in the next 30 years based on trends in technology using conventional fuels, population growth and vkm growth. He concludes that Seattle needs a 100% increase in fuel economy to hold CO_2 constant up to 2020; nationwide he suggests 30%. These estimates assume that laboratory fuel efficiency estimates are accurate. the US Department of Energy (Phil Paterson, private communication) suggesst that laboratory calculations are low by an average of 20% for cars and 27% for trucks.

What is hybrid propulsion? There are many types of two or more energy conversion systems, although the predominant emphasis has been on a heat engine and electric drive. The attraction is due to the greater energy storage per unit volume of liquid fuels compared to electric or electrochemical storage. As an approximation, 1 kilowatt-hour equals 0.03 US gallons of petrol (Siegel and Sutula 1993). Modern electric vehicle developers are struggling to find the space to store 30 to 40 kWhrs (ie., 1 US gallon of petrol) to guarantee a range of 240 to 320 kms at an acceptable cost. In ICE systems, only 15% of the energy contained in the fuel is converted to mechanical propulsion in urban driving. Large portions are lost from engine idling, engine conversion inefficiencies and kinetic losses (braking). Using electric propulaion to decouple the mechanical link to the drive wheels permits much more precise control over these high loss areas. For an electric vehicle, half of the energy goes into heating brakes. Best estimates based on optimised operation suggest that a 44% gain in fuel consumption is achievable under the urban cycle for a hybrid vehicle.

Pricing, Charges and Taxes

It is generally recognised that a lot more can be achieved through pricing to improve the efficiency of transport systems. The historical under-pricing of both urban public transport and automobile use has made it very difficult, politically, for governments to redress the distortions of the past in recognition of the opportunity that pricing instruments have in externalising the environmental costs of transport mobility. A large number of pricing instruments are worthy of consideration (Table 1). Although some of them may not be introduced for political or administrative reasons, it is nevertheless important to identify their potential contribution or lack of significant contribution in reducing GGE's.

Incrementally, society is adjusting to a new regime of pricing incentives, such as tolls on private urban roads, which in the longer run should make it "relatively easier" to introduce widespread congestion pricing. An important feature of a strategy to achieve 'pricing acceptability' is to use the revenue to compensate travellers. Support for any pricing concept will be much higher when it is presented as a complete financial package with explicit proposals for using revenues (Jones 1991). Any package should explicitly recognise that in return for a user charge and the inconvenience to those who change behaviour to avoid such a charge, individuals and society receive benefits in the form of less traffic congestion (savings in time and operating costs), *and* the benefits from the use of the revenues. Where the new revenue replaces inefficient taxes (e.g. a vehicle sales tax) and/or facilitates attractive expenditures that are currently foregone through lack of funds (e.g. improved public transport and/or improved roads), the appeal to self-interested individuals and through them, the government, should be clear. We ignore the implications this might have on who collects the revenue (i.e. Federal vs State governments) and the ensuing debate on apportionment.

Small (1992) investigated a large number of revenue-using strategies with the objective of compensation and salient appeal to important political groups. It is important to recognise that the individuals who benefit from congestion relief and revenue uses do not necessarily coincide with those who pay the fees or who suffer inconvenience in order to avoid them. A financial package which accommodates specific objectives about the equity effects of the overall package is essential in gaining acceptability. Alternative pricing packages need to be considered on efficiency grounds together with consideration of the distributional implications within the sampled population. This is a very important point:

> *a pricing strategy, to be acceptable, should be packaged to compensate for financial and distributional consequences. The stated choice experiments designed to elicit the impact of pricing regimes should evaluate alternative financial packages, and not isolated pricing options.*

The revenues from a congestion pricing strategy are likely to be so large (Goodwin et al. 1991) that for the first time there will be sufficient *annual* funds to offset negative impacts, promote social goals and obtain political support from interest groups (Small 1992). For automobiles only (i.e. excluding trucks and buses), approximately $4bn per annum for all of Australia's capital cities would be available (based on a congestion charge of 10 cents per kilometre). (Note that users of the M4 motorway in Sydney pay a toll of $1.50, which given an average distance travelled on the M4 of 15 km, equates to 10 cents/km). This approximates the current annual receipts from fuel and sales taxes on automobiles. Current taxes are not strictly charges (indeed the debate on the incidence of a charge and a tax is still open). Consequently the case for earmarking back to the transportation sector must allow for some amount of revenue from congestion pricing going into consolidated revenue where there is substitution with current sales and fuel taxes. A congestion pricing scheme is unlikely to be revenue neutral from a government point of view, in respect of lost revenue from reduced sales and fuel taxes. Some of the revenue can substitute for general taxes now used to pay for transport services, but a significant visible amount should be allocated as monetary reimbursement to travellers as a whole and to the provision of new transport services. The Federal and State governments will be no worse off; they almost certainly will be better off. Small (1992) proposes that two-thirds be earmarked to transportation users and facilities.

There are many possible compensating strategies within a pricing/finacial package. They should be evaluated individually and in combinations:

(i) *employee general commuting allowances*: a fixed amount per month for each employee (independent of mode or time of commute), designed to give money back directly to commuters while giving them the flexibility to avoid some or all of the higher use costs by shifting modes, routes or times of day. Those who do not shift are compensated, those who do shift are also compensated, and those in the past who did not contribute to traffic congestion by commuting at other times of the day and/or used public transport are rewarded for their prior travel behaviour. This general commuting allowance (not tax deductible *or* taxable) is incentive compatible with the objectives of congestion pricing (including offsetting any regressive aspects of congestion charges). It should be administered by the employer. The measure could be widened to include priced parking currently supplied for free by an employer (or as part of a salary package).

(ii) *Replace part or all of the fuel tax component returned to the transport sector*: as a more economically efficient method of raising revenue, we might see an amount of the revenue raised by congestion pricing being explicitly earmarked for *urban* transport programs. As a regressive tax, a fuel tax is partially replaced by a somewhat more progressive explicit user charge. The Federal government component of fuel tax which is retained can remain revenue neutral. We must recognise that a sizeable quantity of the fuel tax derives from non-urban travel which is not under congested traffic conditions, and so this component of fuel tax returned to the States should be separated out. The allocation of these funds to particular transport projects has to be carefully thought through. Some should go to new road infrastructure with the recognition however that the existing capacity can now handle road traffic better than before, thus lessening the pressures for new road investment. The case for high-occupancy vehicle (HOV) lanes may also be lessened, further increasing the effective road capacity already in place.

Some funds might be expected to go into improving public transport. If the case is greatest for bus priority systems, then the opportunity to "add one lane" rather than "take one lane" from the existing road system becomes financially feasible and politically much more attractive (Hensher and Waters 1993). Johnston (1993) has recently thrown doubt on the emissions benefits of HOV lanes. An investigation of HOV lanes in Sacramento for vehicle occupancies of 2 or more persons suggests that the introduction of such lanes leads to an increase in vehicle kilometres. The revenue from any pricing strategy should be tied to projects with acceptable benefit-cost ratios to avoid the risk of a "cash-cow" or "pet-projects" mentality. This will destroy the value of congestion pricing.

(iii) *Transport-related improvements to the urban commercial centres*: congestion pricing increases the cost of access to commercial areas. There are a number of transport-related improvements to facilities and services which can "compensate" the local business community in ways which secures their support for congestion pricing. These include pedestrian walkways and plazas, landscaping, improved public transport interchanges, especially for bus systems, and loading bay offsets for urban goods deliveries and collections. Local Chambers of Commerce are influential and important interest groups to be accommodated.

There are other pricing strategies which can complement congestion pricing. Some of them are likely to be easier to introduce, given their aspatial nature. The major contenders include: new vehicle sales tax reductions and/or elimination, designed to increase the scrappage rate of high emitter vehicles; a higher sales tax on new relatively high GGE emitting automobiles (which are not necessarily the luxury class vehicles currently subject to higher sales tax than other vehicles); changes in registration fees either by a skewed registration charge designed to favour low polluting vehicles or a smaller fee to compensate for increased use-related charges; differential duties on imported vehicles designed to encourage overseas manufacturers to import low emitting vehicles.

Like congestion pricing, a financial package is an attractive way of securing individual and political support. Part of the package might be *marketable emission permits* (MEP) and an *emissions equity fund.* Two issues are of great importance: (i) the recognition that high polluting vehicles may be owned and operated by low income households, and (ii) that an ongoing incentive scheme is necessary to attract consumers into the low-polluting vehicle market segment. MEP's provide a mechanism for securing low-emitting loyalty through credits to low emission vehicles. These credits should accrue to both consumers and manufacturers. There are many ways in which the consumer's credits can be used - discounts on repairs and maintenance, and a vehicle buy-back plan with attractive financial guarantees.

Some revenue raised from fuel taxes can be allocated to an emission's equity fund to assist individuals whose vehicles have non-complying emission levels. The options could include a major overhaul of the vehicles emission system or the scrapping of the vehicle. Indeed a manufacturer could offer marketable credits to an owner of a high emitting vehicle in return for having the vehicle scrapped. The credits could be at least equivalent to the trade-in price for the vehicle as part of a purchase deal on a low emitting vehicle. In both instances some financial assistance may be required on equity grounds. This is analogous to child allowance for households with a taxable income less than $50,000 per annum.

In the USA, marketable credits are created by setting standards and allowing vehicle and/or fuel suppliers to average around the standard: if they do better than the standard, then they are allowed to bank and trade those excess credits, thus creating a market - with marketable credits as the currency - for whatever attribute is being regulated. The trading of greenhouse gases is quite feasible, although not as yet implemented anywhere in the world. Although averaging and banking of attributes are not essential components of marketable credits, they do provide flexibility and lead to much greater efficiency in attaining standards. Averaging gives manufacturers the flexibility to average emissions across their fleet of vehicles; with emissions being lowered the most in those vehicles where the cost of reducing emissions is least and to not reduce emissions as much in other vehicles where the cost is greater, provided the average for all vehicles was below the standard.

Emission banking allows manufacturers to bank emissions from years they outperform the average for use in years when they fall short. Banking is especially critical to trading schemes; since banking rules allow trades to occur when and where they are needed and desired. Emission banking also provides an incentive to introduce new technologies and products sooner in anticipation of continuing tightening of emission standards. McElroy et al. (1984) showed that the cost savings associated with emission averaging and trading but no banking was 25% compared to a regime of uniform emission standards for the equivalent reduction in total emissions. A major study is under way at ITS-Davis to explore this issue more thoroughly. The Director of ITS Davis (Dan Sperling) believes that the cost savings are much greater than 25%.

Conclusions

This paper lays the foundations for a formal inquiry into the identification of strategies to reduce greenhouse gas emissions in the most cost effective manner possible. The empirical evidence reviewed suggests that the most cost effective strategies in the medium term are likely to be a mix of fuel efficiency based technological change of automobiles and congestion pricing embedded within a financial package (which can include changes in fuel prices). Promising policies in the longer term include changes in work practices and alternative fuelled automobiles.

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