CICERO Report 2009:01

Air Pollution and Congestion in Bangkok

Developing analytical tools, and implications

Gunnar S. Eskeland
Torben K. Mideksa

January 2009

CICERO
Center for International Climate
and Environmental Research
P.O. Box 1129 Blindern
N-0318 Oslo, Norway
Phone: +47 22 85 87 50
Fax: +47 22 85 87 51
E-mail: admin@cicero.uio.no
Web: www.cicero.uio.no

CICERO Senter for klimaforskning
P.B. 1129 Blindern, 0318 Oslo
Telefon: 22 85 87 50
Faks: 22 85 87 51
E-post: admin@cicero.uio.no
Nett: www.cicero.uio.no

Tittel: Air Pollution and Congestion in Bangkok: Developing analytical tools, and implications,

Forfatter(e): Gunnar S. Eskeland, Torben K. Mideksa

CICERO Report2009:01
40 sider

Finansieringskilde:
Prosjekt: DIESEL: Developing Integrated Emission Strategies for Existing Land Transport program

Prosjektleder: Gunnar S. Eskeland
Kvalitetsansvarlig:
Nøkkelord:
Sammendrag:.

Språk: Engelsk

Title: Air Pollution and Congestion in Bangkok: Developing analytical tools, and implications

Author(s): Gunnar S. Eskeland, Torben K. Mideksa

CICERO Report2009:01
40 pages

Financed by:
Project: DIESEL: Developing Integrated Emission Strategies for Existing Land Transport program

Project manager: Gunnar S. Eskeland
Quality manager:
Keywords: environmental economics, environment and technology, cost-benefit analysis

Abstract:
In a congested city with air pollution like Bangkok, there are gains to analyzing and addressing them in coordination. Higher speed, tremendously valuable in itself for firms and households, also reduce the costs of air quality improvements.

Language of report: English

Rapporten kan bestilles fra:
CICERO Senter for klimaforskning
P.B. 1129 Blindern
0318 Oslo

Eller lastes ned fra:
http://www.cicero.uio.no

The report may be ordered from:
CICERO (Center for International Climate and Environmental Research – Oslo)
PO Box 1129 Blindern
0318 Oslo, NORWAY

Or be downloaded from:
http://www.cicero.uio.no

Contents

Acknowledgements

We gratefully acknowledge financial support from the World bank and helpful inputs and contributions from Jitu Shah, Paul Procee and Sarath Guttikunda at the World Bank, Nathan Rive, Steffen Kallbekken and Tobias Persson at CICERO, and Rolf Hagman at Transport economic institute. Remaining errors or omissions are the responsibility of the authors.

Summary

The analysts start out by analyzing a decision making tool developed for capacity development and air quality improvement planning in Bangkok. While well suited and impressive, the conclusion of the review was that one should test whether it is useful to analyze air quality improvement policies jointly with mobility improvements. This is, in fact, not traditionally done. At a basic level, the results are indeed quite stark. Merely by raising speeds from 15 to 25 km/hr - no minor task - buses reduce their emissions per vehicle kilometer by 30 percent. In addition, the emission gains from having higher quality buses are higher at higher speeds. Finally, since at higher speeds a bus can do more work, fewer (high quality) buses are needed. These effects alone can allow speed improvements to cut the costs of air pollution emission reductions by 50%.

In addition to this - and for which purpose the analysts build a simple quantitative model of optimal taxation - congestion and demand management offers emission reductions proportional to demand reductions for both modes (cars and buses). Buses in Bangkok cause less negative externalities per person kilometer than cars in the three areas examined: air pollution, greenhouse gas emissions, and congestion. Thus, in managing these three externalities, substitutability between modes helps, in addition to the substitutability between travel and other goods and services. Reducing demand for road space of course has welfare costs, but since congestion in itself is extremely wasteful - typically more costly than is air pollution - chances are that congestion management can offer large and cheap emission reductions in any city with high congestion levels.

The model developed is simple, but it builds on principles and established knowledge indicating that these ideas are worth putting to work and developing further. It has long been demonstrated that fuel taxes belong in and make valuable contributions to programs for air quality improvements and greenhouse gas emission reductions, simply because demand management can provide emission reductions. The present study shows that this is even more important when to demand management there are associated gains in time for firms and households in the city. These gains are of course pursuable without objectives of emission reductions, and they are pursuable with advanced instruments such as toll rings and time-variant congestion charges (as in London and Stockholm). But they are also pursuable with simple instruments such as gasoline taxes and privileged lanes for buses. Time is money, and protecting the environment is valuable. For both reasons, it makes sense for a city to travel fast.

1 Introduction

With transport in general, and not the least in a city like Bangkok, there are numerous *externalities*, meaning consequences of the individual choice that are in the outset *not priced* or under priced and thus lead to problems and waste unless institutions and government policies are directed to address the issues.

The issues of air pollution, caused in part by emissions from vehicle tailpipes of compounds such as particulates (small dust particles), the precursors of ozone (NOx and NMHC[1]), can for instance be addressed by legislation and enforcement of emission standards (grams of NOX per mile allowed, say) in combination with gasoline taxes that discourage driving according to the damages from remaining emissions.

This report is written in response to a request to advice on strategies to reduce air pollution emissions from transport in Bangkok, and on the analytical tools employed. [2] The tools are geared towards air pollution control specifically, with solid components in all the required areas: from health effects, exposure and dispersion, inventory and emission testing, one approaches prioritization of strategies in a very methodical way. In our comment, we admit we are unlikely to improve on these tools on their own terms, but we are motivated by two observations. The first is the one we address most directly: Since the transportation system serves many purposes, not only cleaning the air but also providing mobility, we want to check how important it is to examine the provision of two services jointly: mobility and air pollution reductions. Our motivation is in part that Bangkok has long been famous for its congestion. Ordinary people and economists often find the resource costs of wasting time in traffic annoying at the same or higher level as are the resource costs of air pollution. Thus, we try to supplement the efforts in ranking ways to make vehicles and fuels less polluting with an effort to combine such a ranking with the challenge of getting more mobility and air quality out of the Bangkok transport system. Perhaps of surprise to nobody, we find that congestion management, apart from harvesting some obvious welfare improvements through time savings, provides additional gains in terms of making air quality improvements cheaper.

There are, roughly, three sources of the gains in terms of air quality from congestion management (and, more broadly, from congestion improvements). First, if congestion management means fewer vehicle kilometers but at higher speeds, then there are generally air quality improvements related to the reduction in vehicle kilometers. Second, and to many less obviously so, for emissions such as PM, NOx and CO2, there are at moderate speeds emission reductions *per vehicle kilometer* associated with higher speeds (and this occurs without assuming that lower speeds are associated with more stops and more acceleration). Thirdly, for the class of vehicles that at higher speeds can do the same work with fewer vehicles (professional vehicles, such as buses, taxis, trucks), the economics of lower-emission technologies improve when each vehicle does more vehicle kilometers, simply because the costlier machine is utilized more heavily.

It is important to notice that these gains in pollution management – true gains as they are – generally relate to congestion management and speed improvements, but that the emphasis is on management. This qualification derives from the obvious rebound effect: It will generally be the case that with improved speeds, there is increased driving (or transport). In the case of congestion management (gasoline taxes, congestion charges) however, we include in our calculations the rebound effect, so if our model quantifies a reduction in trips of 5 percent, then this is including and after a response in which people have taken the new speeds into account and adjusted their travel accordingly. For congestion management, the rebound is never more than partial, since if people expand their travel in response to speed improvement, then the rebound cannot really consume the whole speed improvement if there has not been road capacity added.

[1] Non Methane Hydro Carbons

[2] More specifically, DIESEL: Developing Integrated Emission Strategies for Existing Land Transport (March, 2007), an ambitious and advanced approach to ranking policy options.

Nevertheless, and importantly so, it is of course the case that if more roads are built and speeds improve, the total traffic increases and emissions of pollutants *may* increase. They may also fall, for the reasons cited above. Irrespective of whether emissions increase, there are or should be welfare gains associated with the mobility increases, since congestion management allows such speed improvements to be associated with an *optimal* increase in travel. Thirdly, and perhaps equally important, even if there is more travel, at higher speeds the economics of pollution control will to some extent have been improved.

The rest of the section is organized as follows. Section II describes the challenges and illustrates the problem in simple framework. Section III reviews the literature and provides a framework for quantitative simulation. In the next section, the effects of demand management instruments we investigated and the final section concludes the report.

2 Challenges and Simple illustration of the Mechanisms

One could indeed characterize 'The transportation system' in a megacity like Bangkok as chaotic, dysfunctional and unmanaged, but this would be a mistake. If one were to do so, one would emphasize that it has no single boss or single office responsible for planning and resource allocation, that those who 'manage' the 'system' have limited powers, and that even fire trucks may find themselves trapped for the most trivial of reasons. But cities everywhere are as influenced by opportunism and market forces as they are by planners and forceful public decision making bodies. And cities everywhere are congested and polluted. And cities everywhere get people to work and back everyday, even if planners and mayors have little clue what it involves except when they are charged with expanding a road or raising bus fares.

It is probably true that Bangkok does have fairly tall management challenges. Over time, the Thai economy has been expanding and economic activities around the Bangkok Metropolitan area have been booming providing better opportunity for growing proportion of the population. Growing income has been an important impetus behind increasing mobility in many cities. On the other hand, in Bangkok, like many cities in developing countries, it takes very long period to expand transport infrastructures and growing income does put additional pressure on the existing and already fully used roads.

In addition to the economic boom, population growth has been and will also be additional challenge on the transportation system. Bangkok has a population of 6.5 million, a population growth rate of approximately 6% between 2003 and 2007[3]. Projections indicate that the size of population in Bangkok Metropolitan area will grow by 9% in 2012 from 2007 attracting residents from other regions and rural areas. The booming economy in Bangkok has acted as a magnet for people from other corners of the country to the city raising the density of population.

The consequences of mechanisms can be observed by changes in fleets in Bangkok area for a decade. It had an estimated 2.9 million motor vehicles in 2003, with an average growth rate of 5.5% (Diesel, 2007), and average speeds of 15 (morning) and 22 (afternoon) rush hour. For instance, the table below indicates that the volume of cars has increased by 5.5 % annually for the decade between 1994 and 2003. The consequence of such growth is that the volume of cars in the city doubles every 12.5 years, putting great pressure on road capacity. More drastic is that of urban taxi. If it continues to grow with the past rate, its volume will triple every 7 and half years. The challenge ahead for Bangkok is how to maintain quality mobility and reduce air pollution with such fast expanding volume of cars and taxis in a fixed or very slowly growing road capacity.

[3] Asian Development Bank (2005)

Table 1: Population Projection of Bangkok Metropolitan Region

	2003	2007	2012	2017	2022
Bangkok Metropolitan Area(BMA)	6502000	6796000	7382000	8066000	8368000
Samut Prakan	1025000	1098000	1180000	1347000	1436000
Nonthaburi	906000	1011000	1132000	1346000	1488000
Pathum Thani	702000	824000	969000	1211000	1401000
Nakhon Pathom	800000	845000	895000	1007000	1059000
Samut Sakhon	446000	480000	517000	592000	633000
Total	10381000	11054000	12075000	13569000	14385000

Source: Asian Development Bank (2005)

Table 2: The Volume of Different Modes of Transport in Bangkok.

Type	1994	2003	Type of Fleet (%)	Annual Growth Rate (%)
Car	716,591	1,162,704	39.60	5.50
Microbus and Passenger Van	241,120	149,613	5.19	(5.20)
Van and Pickup	245,942	583,045	19.90	10.10
Urban Taxi	22,256	63,228	2.20	12.30
Motorcycle Taxi (Tuk Tuk)	3,645	7,394	0.25	8.20
Motorcycle	851,853	857,460	29.20	0.07
Truck	73,145	75,800	2.60	0.40
Bus	17,457	26,225	0.90	4.60
Other	13,220	11,248	0.40	3.30
Total	2,185,229	2,936,717	100.00	5.52

Source: Asian Development Bank (2005)

About half of these vehicles are cars and pickups, probably a high figure in Asia for Thailand's income level. Some parts of these management challenges, of course, are caused outside 'management's control', at least outside current management's control.

As an illustration of this, the figure below has placed Bangkok's population density with those of other cities, based on a carefully developed data set (Bertaud, 2003). The figure shows that Bangkok has a low density for its income level. Space being a normal good in the sense that people tend to want both larger dwellings and more space between dwellings when they can afford it, Bangkok defies the expected pattern that it 'should' be more densely populated than cities such as London, Mexico City and Stockholm. Stylized patterns in such data additionally are that old cities are dense and Asian cities are dense, neither of which help explain why Bangkok extends over such a large area.

Expansive, nondense cities tend to generate greater transportation demand, so that everything else equal, this would imply that a city like Bangkok would need to spend more resources (and a greater share of its land area) on transportation infrastructure than would other cities (if interpreted in line of implied causality). In addition, it is generally costlier in a nondense city to support a given share of transport work for public transport (simply because any line and any frequency must live with a tradeoff between access costs and scale economy). In consequence, for a given level of mobility in a nondense city like Bangkok, one should expect a higher rate of car ownership and use than in a city that is at the same income level but with higher density.

[Figure I Here]

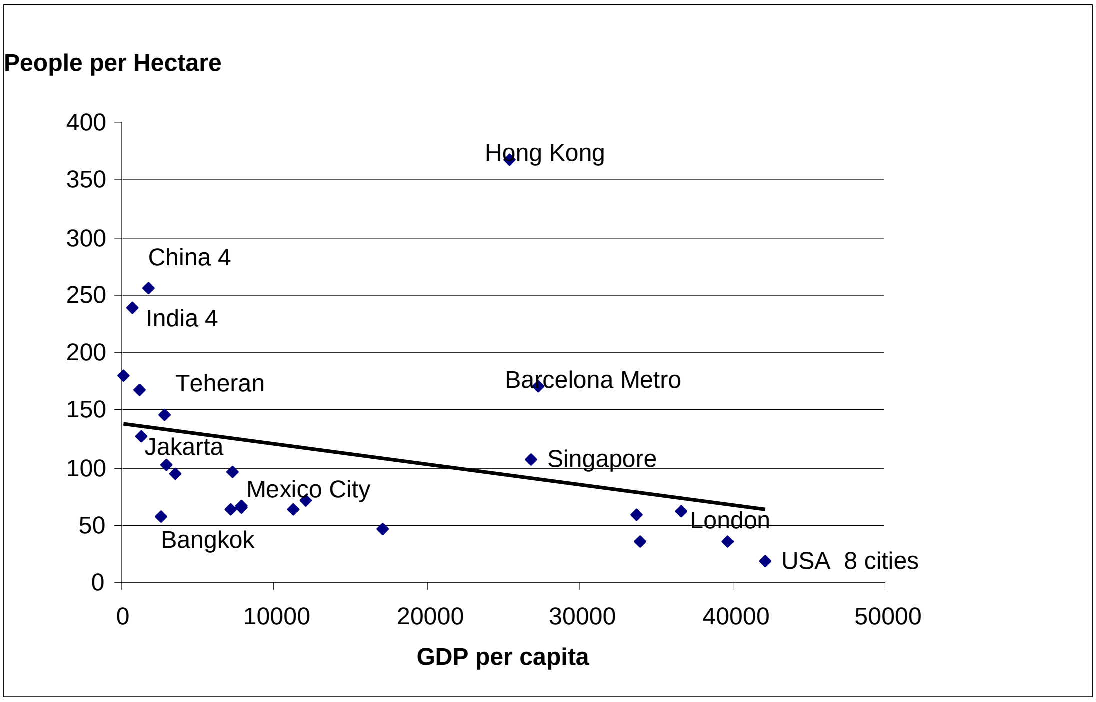

Figure 1: Urban density and Income Level

All that this means is that managing externalities in a city like Bangkok is rather challenging, and will require effort, time, and vision more than many other places. It also means that one should include the perspective of the very long run, when even ‘heavy variables’ such as density and urban development patterns are influenced. It is probably the case, however, that if wide and open roads with low gasoline taxes and road user charges can serve as a subsidy to non-density, then roads that are heavily congested serve as a tax on land use and on transportation intensive modes of production and living. In other words, it is possible that not charging sufficiently for road services in a city like Bangkok has acted as a subsidy not only to car use but also to land use. If so, the effect of the latter subsidy has its limits if the long term picture has also been ruled by heavy congestion.

In the tables below, we have drawn out some figures, and made some further calculations related to the line of reasoning in this report. In the first panel, we report emission factors from Guttikunda et al (Diesel team), 2007. These figures are the result of the local emission testing programs, and tell us that in terms of PM (particulate matter, or dust: probably the local air pollutant of greatest importance to health), on a per vehicle kilometer basis, there are 170 micrograms from cars (light duty vehicles, LDV), and 1494 micrograms per vehicle kilometer for heavy duty buses (HD bus). For CO_2, not a local air pollutant but the main contributor to global warming, it is also the case that a vehicle kilometer by a heavy bus emits much more than a car, but the difference is not so large as for PM. We then bring into the picture that buses on average take 30 payload persons, while cars take on average two. Dividing emission factors by these figures to arrive at emissions per passenger kilometer, we find that for both these types of emissions, the average bus is much less polluting than the average car.

In the second panel of the table, we have taken the data on congestion factors. A bus is estimated to demand 3 times as much road space in the sense of congestion as does a car, so a bus is reported as representing three personal car units (PCU). Again dividing these numbers by the average numbers of payload person on board, we find that the bus on a per passenger kilometer basis is only a fith as congesting as is a car. Thus, if considering either from an emission control perspective, local or global, or from a congestion management perspective, heavy buses should be favored by policies taking these data into account.

Table 3a: Emission Factors for PM10 and CO2

Emission factors	PM mg/ vkm	CO2: g/ vkm	PM: mg/ pkm	CO2:g/ pkm	PM: mg/ p-trip	CO2:g/ p-trip	Payload persons/vehicle
LDV	170	337	85	169	850	1 685	2
HD Bus	1494	1045	50	35	498	348	30
Truck	1238	1159					

Table 3b: The Congestion Factor of Bus and Car

Congestion	Cong/PCU	Congestion /pkm	Payload persons/vehicle
LDV	1	0,5	2
HD Bus	3	0,1	30

Note: test cycle AC2540.

Sources: Guttikunda, Rogers, 2007, ADB 2005.

Authors' calculations Note: Based on ADB 2005

The main question we ask and focus on in the rest of the report is:

How can the urban transport system in Bangkok be improved in providing greater mobility for firms and households while polluting less?

As it happens, asking this question plants seeds of change in many ways for a pollution control programming. A few illustrations of this are as follows:

- Mobility objectives are important in the sense that they can release great funds, and powerful political forces (road construction, toll rings, gasoline taxes)
- Mobility improvements can improve air quality directly, as speed and flow will often bring down emissions per vehicle mile
- Mobility improvements can improve the economics of air pollution, first and foremost because vehicles that are modern, clean and efficient become more affordable and more efficient when they can move more speedily.

In this report, we develop these points further. The obvious starting point is the observation that congestion at speeds of 15 km/hour is extremely costly in terms of wasting time. Methodologically, congestion is an externality just as is emissions, and efficiency gains are harvested if vehicle use is discouraged, for instance by gasoline taxes or by toll rings that can charge more for driving when road space is scarce.

We proceed by developing a model suited to analyze the Bangkok context, allowing for alternative assumptions. Using directly the data provided on the differences in pollution and congestion caused by a passenger kilometer by bus and by car, we ask what difference it makes to use tax instruments to manage the total demand for transportation services and its distribution between car and bus.

It is worth emphasizing that our model is stylized and simplistic, and that there are ways of improving it, including ways that would give it a more definite Bangkok content. But our model likely also has its strength in its simplicity, and it can be used alongside with models with greater Bangkok detail. We believe it is suited to put on the table whether it is not time to place demand management in transport on the agenda when developing air quality programs for urban transport. The model develops some theoretical results, and it shows beyond sensitivity analysis that if you are able to influence speeds it changes in important ways the economics of your air quality programs. By how much depends on how congested a city is, on the costs of time to citizens and firms, and on the price elasticities in demand between bus and car and between transports in general and other goods and services.

In this report we first resort to an analytical framework that is useful to understand the problem in detail and provide clues to the solutions. The report uses the metaphor from DPSIR (drivers, pressures, status, impacts, and responses) approach which analyses environmental problems from their source through their impacts and ultimate societal response towards them. Then, by going further, an economic model is presented so as to understand the determinants of optimal taxes.

2.1 Illustrative Example from DPSIR

To make the point simple, we initially draw some inspiration from the DPSIR framework, which is typically used to analyse environmental problems from their cause (drivers, in physical terms, as opposed to in policy terms, or weaknesses in institutions) via pressures and environmental impacts, to society's response.

The table below draws up the main lines from transport and mobility to a number of policy areas calling for public/government involvement. The table first draws attention to how the field of transport and mobility is special in demanding an interdisciplinary analysis both in institutional approach and in investment and operation. One reason can be taken from the simple positive observation of heavy government involvement and the use of government authority, illustrated by the use (and need for) of expropriation in the infrastructure investments, by the presence of police on the road, and by the use of tax, subsidy and regulatory tools in operation.

At a more basic level, mobility and transport is associated with impacts that are rarely 'fully priced', or externalities: Greenhouse gas emissions, energy security implications, accidents, air pollution, noise and congestion. It goes without saying, for instance, that technological change can be stimulated by high present and expected emission taxes in combination with intellectual property rights and public funds for basic research, but that technology standards can be useful in stimulating new technologies if the emission taxes are constrained at too low levels.

The transport sector thus involves certain social management challenges that are not necessarily resolved by the market alone. By and large, these may be described as public goods, and we shall here think of a list for illustration[4]. The level or intensity of these challenges can be denoted *status* in the DPSIR framework (first column). We focus here on Energy security, Climate Change (or greenhouse gas emissions), Air Quality, Accidents, Congestion, and Noise Pollution.

Our focus will be on policy instruments or *society's response* the two right hand columns. We devote attention not only to policy instruments, but also to the institutional machinery: authority, level and the balance of interests in decision making. The most important part of this, perhaps, is the possibility that society may have difficulty implementing policy strategies that are considered first best. As an example of this, an optimal societal response to a long term problem such as energy insecurity and greenhouse gas emissions may be a path of increasing taxes on energy use and emissions. To work its magic, such a path of increasing tax rates on fuels and emissions must be expected in advance to give incentives for technological investments. But to create such expectations may be beyond the powers of a present government, since it may be optimal for government in succeeding periods to renege on such promised taxes even if the promises were originally believed and successful in stimulating technological innovation (Montgomery and Smith, 2005).

Drivers:

[4] The term *public good* is here used in the Samuelson sense of being nonrivalrous and nonexcludable in consumption. This easily leads to free-riding problems: too much pollution, accidents, congestion, noise and greenhouse gas emissions can result unless society establishes mechanisms (instruments, institutions) to coordinate, as when a metropolitan or national government enforces emission taxes or emission standards in combination with fuel taxes.

The driving forces of transport and transport externalities are ultimately economic activity: in part transport is an input into production and thus a use of income: personal, national. But glancing forward to the *Pressures, States, Impacts, and Responses* we have to note that determinants of those pressures and impacts first require a further disaggregation of the transport good: passenger kilometers have different impacts by bus than by car (we may thus distinguish by transport mode: air, car, bus, rail, ship, non-motorized). Second, pressure, status and impacts will depend on local conditions: The pressures from increased driving on air pollution are greater if occurring in a polluted and heavily populated area downtown than in a rural area, for instance. Third, pressures on air quality depend on the quality characteristics of vehicle stocks (emission standards, for instance) and fuels. Fourth, there will always be underlying determinants that may be considered exogenously given in one setting, but a matter of strategic choice in other settings, as for instance residential settlement patterns and even urban shape and density[5].

From these parameters of drivers in the physical sense we pass to drivers at the deeper level, and at the level of direct or explicit policy instruments. At this point, there is a nuanced transition between drivers and society's response (see table 4), since responses of course are directed at the causes of energy consumption, of GHG emissions, of air pollutant emissions, and so on. In the example of air pollution, apart from the determinants of traffic by various modes, emissions are directly and largely influenced by policy instruments such as emission standards and fuel economy standards for cars and fuels, as well as their enforcement.

Society's response:

Society's response involves those policy instruments most directly and explicitly linked to drivers, but it will be a matter of practical judgment whether one includes broad policy instruments such as for instance fuel taxes[6]. As an example, there is little dispute that fuel taxes are instruments that will work almost in exactly the same way for transport related challenges of noise and air pollution (through reduced driving) as they will with greenhouse gas emissions. But it is for greenhouse gas (GHG) emissions that fuel taxes are most important, because GHG emissions are strongly linked to fuel consumption, while for the other policy challenges there is a greater chance to influence the problem with more narrowly directed instruments (such as standards for emissions, and for noise, for safety, and so on)[7].

[5] While cities typically grow, urban density gradients decline with time, as transport and its infrastructure develops (Anas et al, 1998). Glaeser et al., 2003 studies the effects of declining transportation costs. Bertaud and Bruckner, 2004 analyze welfare implications of policies that influence urban spatial structure. Mindali et al. 2004, question the view that urban density reduces energy consumption.

[6] It should not be too important whether a fuel tax is called a CO_2 tax, for instance, since the name of a tax barely determines its effects (except through its design, as when a fuel tax exempts renewables).

[7] David Newbery has in several articles (1988a,b) analysed fuel taxes to incorporate charges for congestion, road damage and accidents. Parry and Small, 2002, asks whether fuel taxes are at the right levels in the US or in the UK, accounting for pollution, congestion and accidents as externalities. They conclude US taxes are too low and UK taxes are too high. The cost of greenhouse gas emission reductions in the European Emission Trading system are generally much lower than those implicit in total European fuel taxes (gasoline, diesel), but those taxes of course can be argued to serve multiple purposes.

Table 4: Environmental and Other Social Management Challenges in Transport: Illustrative Example from DPSIR Framework

Status	Pressure	Driver		Society's Response	
		Direct, physical determinant	At deeper, instrument- or societal level	Direct: Explicit or implicit policy instruments	Institutional forum or mechanism
Energy security	Fossil fuel imports (typically)	Fossil fuel use less production	Subsidies, transnational insecurity	Strategic oil reserves, R&D subsidies, fuel taxes, military expenditures	National policy
Greenhouse gas emission reductions	Emissions of Greenhouse gases anywhere	Proportional to fuel use, by fuel (also, issues of land use, sequestration, carbon capture and storage	Income, fuel and car costs, city shape and density, commute patterns, public transport	Policies such as taxes and regulation, quotas, for private and public modes, and fuels	As above, plus international agreements.
Air quality	Emissions of critical air pollutants and precursors into polluted airsheds	Travel mode; Vehicle technology and fuel; total demand	Income, fuel and car costs, urban density, public transport quality and price, emission standards	Fuel and road charges, public transport policies, emission standards, urban & metropolitan planning	Hierarchical government and democratic structure; property rights
Accident prevention	Vehicle speed, likely confrontation	Vehicle kilometers and features, infrastructure features, driver behaviour	Safety policy in infrastructure and vehicles, regulations, police presence and fines, driver skill and education	Policies towards car industry, drivers, insurers, local authorities and infrastructure providers	As above, plus transport and highway authorities
Traffic management to prevent congestion, time loss	Vehicles in congested roadspace	Vehicle kilometers, spatial and time-of day variation	Income and fuel- and car costs, residential and commute patterns	Land use and infrastructure supply policies, charges, taxes, subsidies	As above
Noise	High speeds near residents	Traffic loads, Noise reduction in infrastructure and vehicle design	Income and fuel-and car costs, congestion,	Noise and related policies and regulation, infrastructure design	As above

Society's response should, however, also be studied at the institutional level, or in terms of authority, mechanisms for decisions, and political analysis[8]. This analysis first and foremost involves a clarification of how levels of government and their institutions relate to the problem in question. It is important, for instance, for a policy challenge such as climate change, to examine channels for international negotiations as well as treaties in place (as in Barrett, 2003). In contrast, for a local air quality problem it is important what authority local governments have in the context of national government institutions, and whether decisions taken at a national level are conducive both to solving the problems directly and to sensible decision making at the local level.

Table 5: Four Major Transport Related Issues

	Accidents	*Congestion*	*Air Pollution*	*CO2*
A serious problem?	Yes	Yes, though exaggerated	No longer	Yes
Scope?	National	Local	Local/regional	Global
Affected people?	Mostly car-users	Car-users	Not only car-users	Everybody
An externality?	No	No/yes	Yes	Yes
Marginal costs known?	No	No/yes	Yes	Yes
MSCP feasible?	No	Difficult	No	Yes
MSCP efficient?	No	Doubtful	No	Perhaps
Other instruments tried?	Yes	Not enough	Yes	No

Source: Rèmy Prud`homme, working document, 22/11-02,

Implications:

A likely effect of applying this broader framework is a greater emphasis on interdisciplinary analysis. Another likely effect is a greater emphasis on the institutional level and the channels for decision making. As an example, if we compare air quality control policies in the US with those in Europe, it is clear that European policies combine a pressure to make cars and fuels cleaner with policies that increase the private costs of car use (fuel taxes, public transport subsidies), while US policies focus almost solely on making cars and fuels cleaner, thus attaining air quality goals at a higher welfare cost (Eskeland and Feyzioglu, 1997, Eskeland and Devarajan, 1996; Fang, Fullerton and Gan, 2005). Certainly, the question of this difference between US and Europe asks for analysis of politics and institutions, more than the analysis of policy norms. Thus, the framework likely will result in the analysis on policy instruments and recommendations into analysis of institutions for decision making, as well as the forces and interests that are represented.

[8] Cropper and Oates, 1992, highlights the federalism dimension to environmental policy, and Barrett, 2003 an amazing web of international environmental treaties. Gates et al, 2005 provide a study of the association between national environmental commitment on the one hand, and characteristics such as democracy, income level and income inequality on the other hand.

Another likely effect is greater emphasis on studies that combine the various policy challenges and coordinate the approach to these, perhaps across countries. Examining table 4, for instance, it is clear that cars which are less polluting, safer, less noisy and more fuel efficient or in other ways leaner in terms of greenhouse gas emissions will serve well in many markets, many contexts. But to the extent that wide ranging strategic choices are involved, it may be too simplistic to assume that each of these desirable dimensions can be stimulated nicely and neutrally by instruments associated with each particular individual public good. Apart from coordination across 'environmental problems' it is also possible that coordination across countries will emerge. Presently, global coordination on technology (emission standards, for instance) is being proposed in its most obvious area, the area of global climate change (an example is Barrett, 2003, though he is doubtful technology cooperation reachers further than does binding emission treaties). Features reducing vehicular emissions of traditional (local and regional) air pollutants and precursors (small particles, NOx, SOx, volatile organic compounds, lead) have of course been developed for markets greater than individual countries in mind, though 'small' jurisdictions have at times taken the lead and pushed technology with success. But even for these, though the pollution problems mostly are contained within an urban area or within a country, and thus vary by status and priority, it is plausible that progress could be made more effective if standards or other types of goals were set in coordination across countries, perhaps far in advance[9]. This would obviously pose new challenges in terms of decision making at a trans-national level, but it is likely that even very slight coordination (say: indicative target dates for achievement of some vehicle characteristics) would make a difference. Thus, another likely effect of applying the broader framework is greater coordination, across environmental problems across countries.

Finally, a likely effect of applying the broader framework of is an approach that emphasizes political and administrative feasibility, perhaps with the consequence of less reliance on market based policy instruments (i.e. taxes and tradable permits).

The implication of lower reliance on market based instruments is pursued by Prud'homme in his treatment of transport related issues, claiming that the 'price the externalities' recommendation fails or is besides the point for transportation. Table 2 synthesizes his critique of the EU's stated policy to make marginal social cost pricing (MSCP) the basis for transport policy in Europe. He points at that MSCP is only one of several desirable principles, and typically not the most efficient for the transportation sector, at least not applied alone. As examples, he points out that pollution problems associated with transport are in rapid decline in developed parts of the world without any reliance on MSCP, and only for CO2 emissions is MSCP feasible and perhaps efficient: for congestion, accidents and air pollution, it is neither feasible nor efficient.

We shall apply a similar argument, but will emphasize other aspects. We shall note, for instance, that even in the case CO2 emission reductions (and other greenhouse gas emission reductions), where a tradable permit scheme or taxes are so obvious based on basic principles of welfare economics, their use fall short on several grounds. First, if it is politically infeasible (for reasons of income distribution, of national sovereignty, of the development prerogative) to let large emitting sources face the full costs of carbon taxes or fully priced permits, then alternative and supplementary policy instruments must be assessed (technology agreements including standard can be one of them). Hammar et al., 2004, for instance, demonstrate that countries with greater gasoline/car dependency have greater difficulty

[9] It is, however, plausible with tacit, non-explicit coordination. California has traditionally been a leader in setting future emission standards from new vehicles. The industry then develops technology and delivers cars that meet these standards in time. For other jurisdictions, and in particular small ones that get rich and/or polluted later, it is natural to compare emission standards already applied elsewhere when they set their standards (Eskeland, 1994). In this picture, the car industry can develop technology based on standards announced for leading states and the presumption that others will follow in a given pattern, and research is required to assess the case for more explicit coordination.

politically in raising gasoline taxes. This has the implication that a combination of fuel efficiency standards and other instruments – such as fuel taxes – can have a greater potential of reducing energy consumption over time than would fuel taxes alone.

Second, an important challenge of the climate policy regime is to change *expectations* about the future costs of emitting greenhouse gases, so as to allow investments in future emission reductions, for instance in new energy technology. If the traditionally recommended instruments of tradable permits or taxes are found too weak in terms of changing expectations, then technology standards, research and development programs and other supplementary policy instruments may be assessed in terms of whether they can increase the credibility of a societal signal about fossil fuel use.

As we shall be well aware when keeping in mind the example of sustainable mobility and transport, social management objectives are many, they interfere with each other, and feasible strategies should look far back into history and far ahead in terms of vision. This calls for pragmatic and interdisciplinary approaches.

2.2 Pollution related and other external effects from driving

An important implication of the previous perspectives is whether and how it makes sense to examine (and, with policies, address) externalities from driving one at a time, or with a more integrated approach. In terms of textbook policy analysis, it is fairly easy to justify addressing one problem at a time, and also to use exactly one instrument per problem. But two important caveats apply.

Firstly, economic theory is clear to recommend that ‘if other problems are not fixed’, then the usual policy recommendations must be adjusted accordingly. As an example, if ‘cleaner cars and fuels’ are driven by policy instruments such emission taxes (a theoretical construct, really), which also optimally discourage driving, then no ‘pollution externality’ need to be incorporated in the gasoline tax. But if ‘cleaner cars and fuels’ are driven by policy instruments such as emission standards (the typical real world case), then the marginal costs of driving are not affected, and a gasoline tax should incorporate the discouragement to driving that is justified by the damages related to the resulting emission taxes (Eskeland, 1994). Of course, if instruments such as gasoline taxes and toll roads are used to discourage driving as justified by air quality objective, they will work strongly in parallel with instruments for other externalities related to driving or gasoline use, such as energy security, greenhouse gas emission reductions, or demand management for congestion reduction.

Secondly, if for the sake of correcting externalities one does not have perfect policy instruments, then one will use combinations of instruments, and the individual instruments will then likely take on several functions. As an example of great relevance in the current case, emission control will likely involve instruments that make vehicles and fuels cleaner as well as more energy and carbon efficient. But to manage demand – in part but not limited to curtail the rebound effect – they will be complemented with demand management instruments such as gasoline taxes and toll ring charges. The toll ring charges, together with policies to promote public transport, give a welcome chance to geographically differentiate demand management, so that car driving can be discouraged more in dense urban areas where pollution is high and public transport is an alternative than in other areas. Simultaneously, instruments such as the toll ring charges give a welcome opportunity for geographical differentiation in strategies to manage congestion, and congestion management will also call for a ‘time of day’ differentiation to discourage driving more in rush-hour, when ‘road space’ is very valuable to some, less essential to others[10].

[10] Toll rings have been used with some success for many years in cities of Norway, and in Singapore, but with limited ‘time-of-day’ variation. Congestion charges have been introduced as a success both in traffic management and politically in London, and Stockholm: in Stockholm as a trial period that seems to become permanent Leape (2006).

The table below summarizes some of the studies of externalities from transport, distinguishing the externalities related to fuel use from those related to miles travelled. It appears that two important categories of externalities related to miles driven, accidents and congestion, often are far greater than the other externalities. Together with the observation that fuel efficiency standards result in a rebound in terms of travel, this is of course a strong argument against raising fuel efficiency standards, at least if not jointly raising fuel taxes (see Eskeland, 2007, on this issue).

Table 6: Comparison of Externalities Associated with Fuel consumption and with miles driven

	Externality Due to		Ratio
	Fuel Consumption***	VKM***	
Parry, Fischer, and Harrington (2004)*	11	2.5	4
ECON(2003)** Cars	0.03	0.31	10
ECON(2003)** Goods Transport	0.04	0.20	5
Schreyer et al. (2004)*	26,5	50	2
Parry and Small(2005)*	5	17	3

* Measured in Cents per mile.
**Measured in Øre per kilometer
***Congestion and accident externalities are categorized as VKM related, while energy security, greenhouse gas emissions, and air quality is categorized ad fuel consumption related Across the studies reported here, there are important differences in terms of the externalities included, but congestion and accident often are of the same order of magnitude (if both are included), and each is greater than air quality benefits (which are typically included).

The table amply illustrates that pollution and other fuel consumption related externalities need to be managed together with other externalities that are at least as important (and quite typically much more important, on a per vehicle mile basis), particularly for those policy instruments that relate to demand management.

2.3 More specifically on the relationship between congestion and emission controls

For two externalities, however, congestion, and emissions (whether regarding carbon dioxide, for greenhouse gas reductions, or PM10, for local air quality), there are reasons for integration additional to those relating to their joint proportionality to trip generation. As we shall show in the following, for both local air quality and for greenhouse gas emissions, there are sizeable reductions in emissions on a per vehicle kilometer basis, if congestion can be reduced so as to raise speeds.

To put this in simple terms, it is obvious that people benefit with time savings if congestion is reduced. Indeed, the value of time savings is important in justifying most transportation infrastructure investments, and they have been forcefully emphasized in the context of road investments in Bangkok (ADB, 2005). What is not so obvious, but is clear when one applies the economic textbook concept of externalities, is that there are welfare gains to the population if instruments such as gasoline taxes and congestion charges can be used to reduce congestion. Finally, what has yet to be emphasized in the policy literature, highlighted here, is that emissions per mile decrease when speeds increase (quite generally at low speeds up to 45 km/h, and likely more so if one assumes that lower speeds imply stop/go traffic patterns). The following section emphasizes this link, documented with the use of data from modern buses.

The negative externalities from public transportation in Bangkok can be reduced by technological shifts and/or traffic management. In this section, we compare these options using four main cases:

i. Average speed of buses meeting the Euro I standard increases from 15 km/h to 25, 35 and 45 km/h.
ii. The same speed increase as in scenario (i) but assuming Euro III buses.
iii. A shift from Euro I to Euro II buses for different average speeds.
iv. A shift from Euro I to Euro III buses for different average speeds.

For these four main cases we estimate the emissions NOx, Particulate Matter and CO2 as well as the fuel consumption. Clearly, as can be seen in the Figures, traffic management increasing the speed of buses is important for reducing the negative externalities of public transportation. An increase of the average speed from 15 to 45 km/h (which might be unrealistic) would decrease the emissions of NOx the same amount as a shift from Euro I to Euro III buses. A standard is more important for reduction of PM. On the other hand, the Euro standards do not improve the fuel consumption (and hence neither reduce the CO2 emissions as they are directly coupled). Increased average speed is reducing the fuel consumption by up to 40 percent.

It should be noted that we not have taken into account that increased speed can result in modal shifts from private to public transportation, in particular if speeds increase more for buses. This would further increase the improvements from increased average speed.

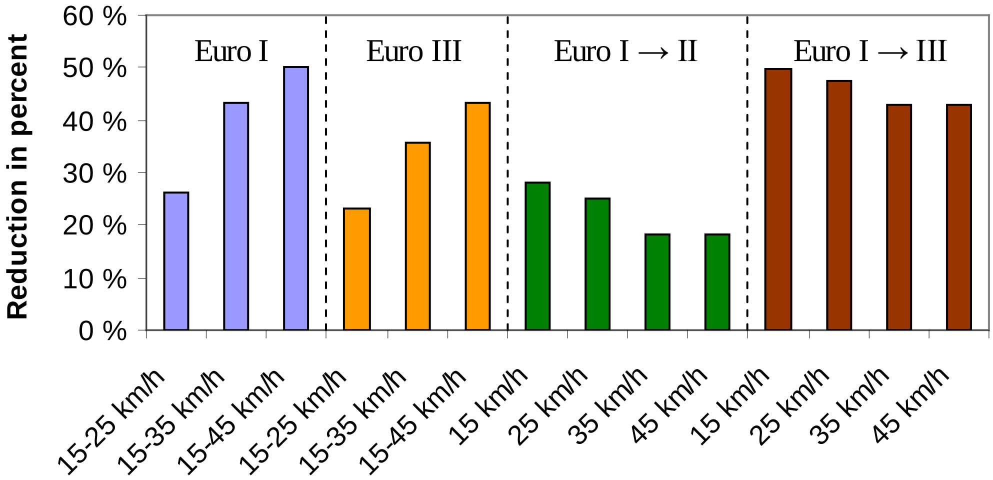

Figure 2: Improvement in NOx emissions from (i) increasing the average speed from 15 km/h in Euro I buses, (ii) increasing the average speed from 15 km/h in Euro III buses, (iii) shifting from Euro I to Euro II buses for different average speeds, and (iv) shifting from Euro I to Euro II buses for different average speeds.

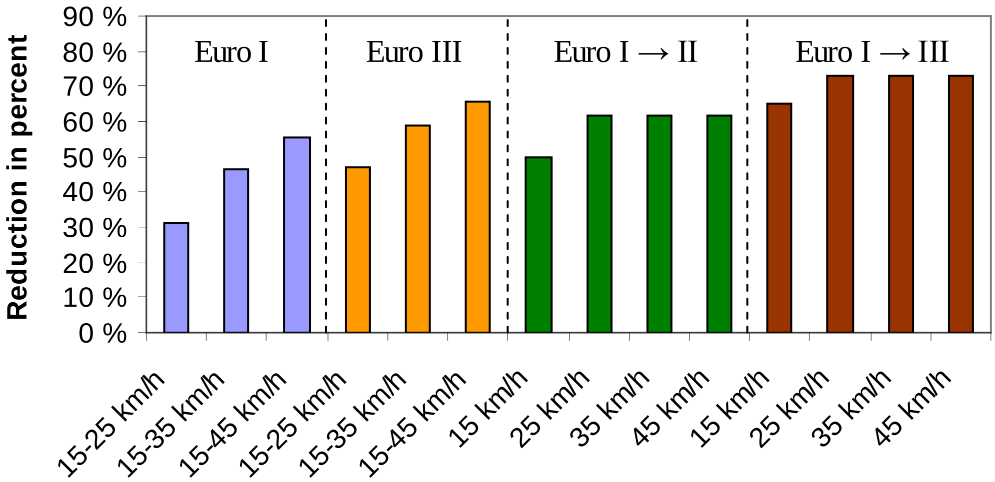

Figure 3: Improvement in PM emissions from (i) increasing the average speed from 15 km/h in Euro I buses, (ii) increasing the average speed from 15 km/h in Euro III buses, (iii) shifting from Euro I to Euro II buses for different average speeds, and (iv) shifting from Euro I to Euro II buses for different average speeds.

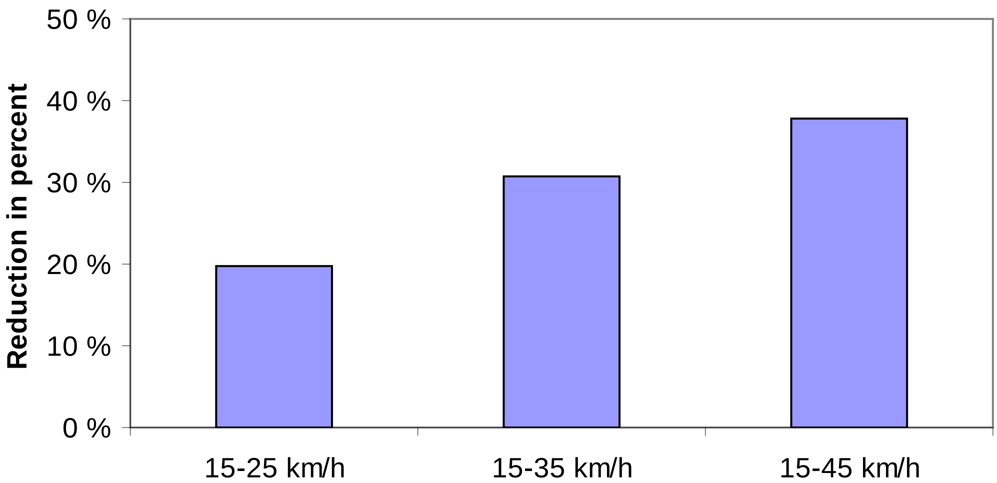

Figure 4: Improvement in fuel consumption and CO2 emissions from increasing the average speed from 15 km/h in buses. The other cases are not relevant to compare since a shift in standards do not change the CO2 and fuel consumption.

Another result that is clear from these figures is that the efficiency of raising the technical standards, as with Euro standards for buses, is higher at higher speeds on a per vehicle mile basis. Thus, on a per vehicle mile basis, better buses make less sense (it buys lower emission reductions) the lower is the average speed. This effect comes in addition to all other efficiency improvements associated with increased speeds, some of which also have a clear pollution control component. As an example, if raising bus speeds by 40 percent allows each bus to make 30 percent more trips per day, then the air quality benefits from raising standards also increase by 30 percent per bath invested. If these cost gains are combined with an assessment from above of gains of 30% on a per vehicle mile basis, then costs per unit of emission reductions have been reduced by 51% for an increase of 40% in average speeds (1-30%)*(1-30%)=49%.

Concluding this technically oriented note, we may observe that in a congested city there is a strong link between speeds and air quality, and between speeds and greenhouse gas reductions. We may answer in the affirmative that it would be strange if in an air quality assessment program one did not ask whether mobility could be improved while at the same time one could raise air quality.

3 Framework for Quantitative Analyses

The issues of vehicle congestion and pollution have attracted the attention of many, including best minded of economists and practitioners (a notable example being nobel-winners Vickrey and McFadden). The focus of our study, Bangkok, has had different transport models at least from 1985 onwards. In 1985, Halcrow Fox and Associates developed transportation model for Bangkok city for short term strategic review. Since only trip matrices were the input to the model, the need for new model resulted in a new model associated with the Seventh Plan Urban and Regional Transportation Study but had limited ability to accommodate the characteristics of public transport. The same year, the USAID financed the Bangkok Transportation Planning Unit and assisted the development of its transport model which has addressed the characteristics of public transport in more detail. After modifications are made, the Bangkok Transportation Planning Unit Model evolved into what is today known as Bangkok Extended City Model[11].

The basic model for understanding the effect of traffic congestion with fixed road capacity was reported by Beckmann, McGuire, and Winston (1956), Walters (1961), and Mohring (1976). Each traveler having downward sloping demand decides how to travel based on private marginal cost. However, the negative externality associated with congestion raises the social marginal cost above the private one and hence, the market offers too much traffic volume than what is socially desirable. This efficiency loss give rise to the proposal of congestion charging, a pricing mechanism by which users are encouraged to economize on trips by making a transfer to the government rather than by wasting time – a resource loss to society – in traffic. A good summary of the literature on economics of congestion has been reported by Arnott (2001).

The basic model is later extended to treat route choice, road capacity, user heterogeneity, modal choice, and congestion interactions by different modes to derive the optimal first best congestion charge. The models were also extended to examine how substitute modes' trips should be priced when the congestion externality of car/automobile is under-priced or ignored.[12] Sherman (1971) studied the price that ensure first best outcome during peak hours and second best outcome in off-peak periods when car trips and bus trips are imperfectly substitutable. Bertrand (1977) discusses guidelines for congestion taxes and subsidization in multi-modal transportation system taking a political constraints on taxation into account.

The analytical studies have also been accompanied by empirical studies that try to pin down the efficiency loss due to congestion. Verhoef, Rouwendal and Rietveld (1996), and Verhoef (2005) used numerical simulations and found the efficiency difference between first best and second best congestion pricing is surprisingly small. Chia, Tsui, and Whalley (2001) simulated the efficiency loss in the absence of first best congestion taxes. On the other hand,

[11] See Asian Development Bank (2005) for details

[12] Sandmo, 1976, and Wijkander, 1985, treat subsidies to substitutes to externality generating goods, justified by mispricing of the good itself.

Small and Yan (1999) argued that when user heterogeneity is accounted for, the efficiency gains from the first best congestion toll are very large.

The cumulative research in congestion pricing finally succeeded in 1975 in convincing policy makers and Singapore has been the first country to implement congestion price. Hau (1990) describes the state of congestion pricing in Hong Kong between 1983 and 1989. In 2003, London has also implemented a congestion fee whose impacts are better studied than any other country. Leape (2006) reported that the congestion tax has had a significant substitution effect. One year after the congestion charge has been introduced, the proportion of private automobiles, vans, and trucks entering London city had dropped by 27%. About 50% of the consumers shifted to public transport, 10% shifted their trips to charge-free hours, and the rest shifted to taxis, bicycle, and other forms of private transport. Its effect is also reflected in average speed and time. Average speed in the charge area has increased by 17% while travel time has decreased by 30%. Flamm and Rosston (2005) reported that Norway, Netherlands, Italy, and France also have used some form of congestion pricing.

There is also a sizable research concerning the economics of vehicle emissions and optimal policy response. Vehicles are often a chief source of urban air pollution through their tailpipe emissions, which involve the release of emissions of hydro carbons, Nitrogen oxides, carbon monoxide, and carbon dioxide, and particulates (or dust particles in various size categories). Vehicles are also the source of evaporative emissions, that involve release of gas tank venting, running losses, and refueling. Such pollutants are sources of urban smog, acid rain, green house gasses, and some of them have serious health consequences[13]. Systematized economic analysis of pollution was first forwarded by Pigou.

Pigou (1932) has provided a master piece that clearly identified the need for internalizing fees in the presence of externalities, especially for pollution. Agnar Sandmo (1975) studied the revenue generation motive and corrective motive of taxation and argued that the Pigouvian element in the optimal tax remains even when distortionary effects of taxation is taken into account. Eskeland and Jimenez (1992) and Devarajan and Eskeland (1996) described policy instruments for pollution control and their effectiveness in different situation. Eskeland (1994), with relevance for the current study, developed a formula on how optimally to seek emission reductions from cars with and optimal combination of standards that make them cleaner with taxes that discourage their use. He calculated that thee welfare cost of emission reductions in Mexico City in the absence of presumptive Pigouvian tax, amounts 24% more than when a gasoline tax is included in the policy instruments.

Apart from emissions (of air pollutants and greenhouse gases) and congestion there are typically other important negative externalities associated with transport. These would include such environmental impacts as noise, but also accidents and road damage. Studies combining the different effects have often found that the emission externalities are important but in no way predominant. Indeed, externalities related to congestion and accidents are typically found to be greater, resulting in the interesting conclusion that externalities of vehicle use are more important than those related to fuel consumption (Fischer et al, 2007).

According to the Asian Development Bank (2005), the existing framework for Bangkok, namely Bangkok Extended City Model, is a large transportation model that simulates traffic behaviour first by generating trips and distributing them among different traffic zones, and then in each zones the trips are mapped to different modes of transport. It is depends on survey data as an input and is not based on the behaviour of individual agents who pursue their own objectives. As such it is not an economic model that is based on individual's decision and it is not an easy framework to understand the consequences of various transport demand management instruments.

[13] http://en.wikipedia.org/wiki/Vehicle_Emissions

In this study, we are interested in the joint occurrence of emissions and congestion. For this reason, we must look at the consequence of modal choice and travel demand on congestion and emissions, as this is relevant to Bangkok's situation.

This model attempts to show the following insights. First, the framework we offer analyzes traffic behaviour as a consequence of individual agents pursuing their objectives given constraints of time and income. To these individuals, different modes are imperfectly substitutable, and for each of them the individual's time cost is an important part of the trip's unit cost. The fact that time is valuable means that a change in taxes on fuels (and bus fares) raises the relevant trip cost for the consumer in a modest way, partly explaining a modest price sensitivity in travel behaviour. Our framework offers a simple way to to simulate the impacts of different economic instruments on traffic and air quality parameters. The unified treatment of the cost of time and the rebound effect in a model of modal choice and trip generation makes the welfare costs of congestion (and of demand management) tractable. To the best of our knowledge our treatment of the cost of time in a multimodal trip decision model is novel. Finally, we provide numerical simulations based on empiricaly chosen parameters to show the strength of the mechanisms we emphasize in the analytical model.

3.1 A Simple Model with Congestion and Air Pollution

Urban transportation is of course essential to facilitate production, consumption, exchange, raising the time spent on work, and generating intrinsic utility[14]. Indeed, if a city is a structure minimizing the costs communication and exchange, then it is hurt in its 'core competence' if marred with more than moderate congestion.

In the absence of market failures such as externalities, a standard result that markets allocate goods and services in a socially desirable way. But, in the presence of negative externalities such as accidents, congestion, air pollution and emissions of greenhouse gases, markets tend to over-supply and overuse goods and services such as motorized transportation. The policies that fix such problems often make agents taking in to account the social benefit from reduced travel directly by being confronted with taxes (hence the terms corrective, or Pigouvian taxes). To understand strategies under such mixed consequences of transport, we develop a framework that helps to pin down the optimal policy response. We compare the decision by a representative agent with that of a benevolent social planner, and allow the latter to choose policies to influence the former.

In order to drive the travel demand functions and their determinants, we follow a static representative agent framework. This is essential, since we are not simply interested in whether the person *can* be 'pushed' to change her travel behaviour (from car to bus, for instance), but we need to know the welfare costs of doing so. This means we need to know how costly it is to the consumer to be bade to make a choice she otherwise would not do. In the model we draw below, the representative agent drives utility from consumption of products, leisure, and travel. Moreover, the agent chooses from two modes of transport, namely automobile and bus, which are imperfect substitutes[15]. The choice of one of the arguments affects the choice of the rest through competition for expenditure and provision of utility. We assume that only the consumption of travel results in externalities, namely congestion and pollution.

The framework, which is used in the rest of the report individuals are at the center of decision making and choice. Individuals make two-stage decision in which they choose the optimal

[14] According to Mokhtarian and Salomon (2001) about 33% of travel is due to 'intrinsic value, the rest is derived demand.

[15] Imperfect substitution ensures interior solution for both modes of transport as in Sherman (1971) or Bertrand (1977).

amount of travel and other consumptions given the cost of travel, other consumptions and the total income. Once the optimal travel is chosen, in the second stage individuals choose the optimal bus trips and car trips given the unit cost of trips by alternative modes and the total travel as well as optimal leisure and other goods and services given the respective prices. The unit costs of each trip include the producer prices and the cost of time in the presence of congestion. The structure of the model is presented in the figure below.

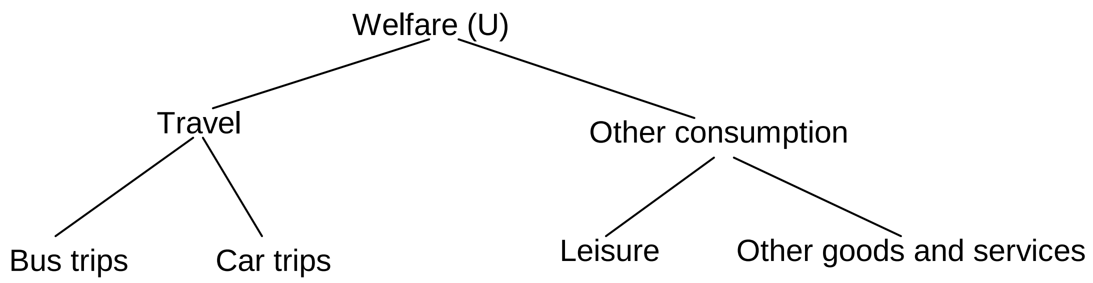

Figure 5: Structure of the Utility Tree

The decision with representative agent is compared with that of a benevolent social planner such that the planner takes in to account all the externalities that travel generates to the rest of agents. An optimal tax which includes both congestion and pollution externality is determined after taking into account the variations in the choice between the representative agent and the social planner. By imposing taxes on the producer prices of car trips and bus trips, we try to investigate the consequences of inter modal substitution and resulting effects on air pollution and congestion. The details of the model and necessary computations are presented in the appendix section.

By releasing PM, CO, NOx etc to the environment, consumption of trips raises the level of pollution in the ecosystem. We focus on the particulate matter as a contributor to urban air pollution, and in addition include the treatment of CO2, as a contributor to global warming. For most practical situations, a measure of the contribution from buses will be higher than that for cars when compared per vehicle kilometer. But on a passenger kilometer basis (in Bangkok, heavy buses carry on average 15 times as many persons as do cars), buses will be less polluting than cars (DIESEL, 2007; ADB, 2005). Similarly, a bus is generally taking more road space (is more congesting) than a car, but per passenger kilometer, buses cause less congestion. Thus, from the perspectives both of air quality and greenhouse gas reduction, a person's substitution from bus to car will make a positive contribution.[16].

In addition to pollution, a choice to travel has an external effect through congestion. According to the estimate made by Texas Transport Institute, the 75 largest metropolitan areas of US lost 3.6 billion vehicle hours due to congestion which resulted in additional loss of 21.6 billion litres of fuel and $67.5 billion in productivity in 2000 alone. It also reported that the yearly cost of congestion for each traveller in large (small) cities has been $1000($200)[17]. In addition to the private cost, congestion also has external cost. The entry of one more vehicle into the road raises the cost of the rest drivers. For example, like the case of

[16] See for instance Mohring(1972) and cited references

[17] http://en.wikipedia.org/wiki/Traffic_congestion

pollution, most buses involve lower congestion factor per passenger than most automobiles for the same reason.

The optimal demand for goods other than travel, leisure, bus travel, and car travel, is determined by a representative agent that maximizes her welfare without taking into account her own effect on the rest of the agents. The agent does take into account the status of pollution and congestion variables, and most importantly takes into account the time cost of travel when travelling. On the other hand, the social planner considers the welfare of all agents taking into account the impact of the consumption of each agent on the rest. To the planner, imposing costs on consumers has a cost, whether the consumer is burdened with costlier vehicle technology (through standards), through burdensome living with fewer trips, or through tax payments. Importantly, our model does not entail a financing need by the government, so taxation neither has value nor cost beyond the fact that it causes consumers to change their consumption bundle. It is the observation that a tax-induced change in the consumption bundle can enhance overall welfare which motivates and regulates the level of taxation. Our treatment of taxes is consistent with an assumption that the revenue proceeds are returned to consumers as lump sum transfers.

3.2 The Effects of Demand Management Instruments, Numerical Examples

Since managing congestion and urban pollution involves an important policy problem, one would like to see the comparative static results for different policy parameters. Our analytical tool is one that does not simply count budgetary costs to the government, or out of pocket costs for the consumer/driver/operator/owner, but takes into account the time cost and inconvenience of the consumer in changing his/her travel behavior. That being said, in the sample calculations made here, we perform sensitivity analysis with respect to the difficulty consumers have in reducing travel, and in substituting one mode for another. It is these results that are presented here.

Importantly, in addition to reducing emissions by using taxes to manage travel and modal substitution, emissions can and should be managed by technical improvements, according to the costs of making cars and fuels cleaner. Figure 6, below, displays such a curve for particulate matter, (IIASA, 200x). According to our optimality rule (equations 33 and 34, in the annex), for a point selected on such a curve, there is an optimal level of taxation to discourage both trips in general and the choice of car trips rather than bus trips. For such a combination of optimal emission standards, and taxes on car trips and bus trips to manage pollution and congestion, it is the case that the options consumers have to reduce emissions and congestion are optimally exploited: they could not be happier.

The simplifications involved are of course important. A model with a representative consumer ignores differences between consumers, between cars, etc. A a model with two modes, it conveys some important insights even on ‘what about motor cycles’, but strictly speaking it says little about a city’s transportation system except in general terms that congestion and pollution should be managed in coordination, rather than separately. As a static model, it conveys results about the value of road space and how to use it, but is says little about road construction or about east and west, except that both charging and construction is more important where traffic stands than where it flows. As an a-temporal model, and in particular as it uses simple instruments like gasoline taxes in its discussion, the model speaks only abstractly about the time-of-day phenomenon of congestion.

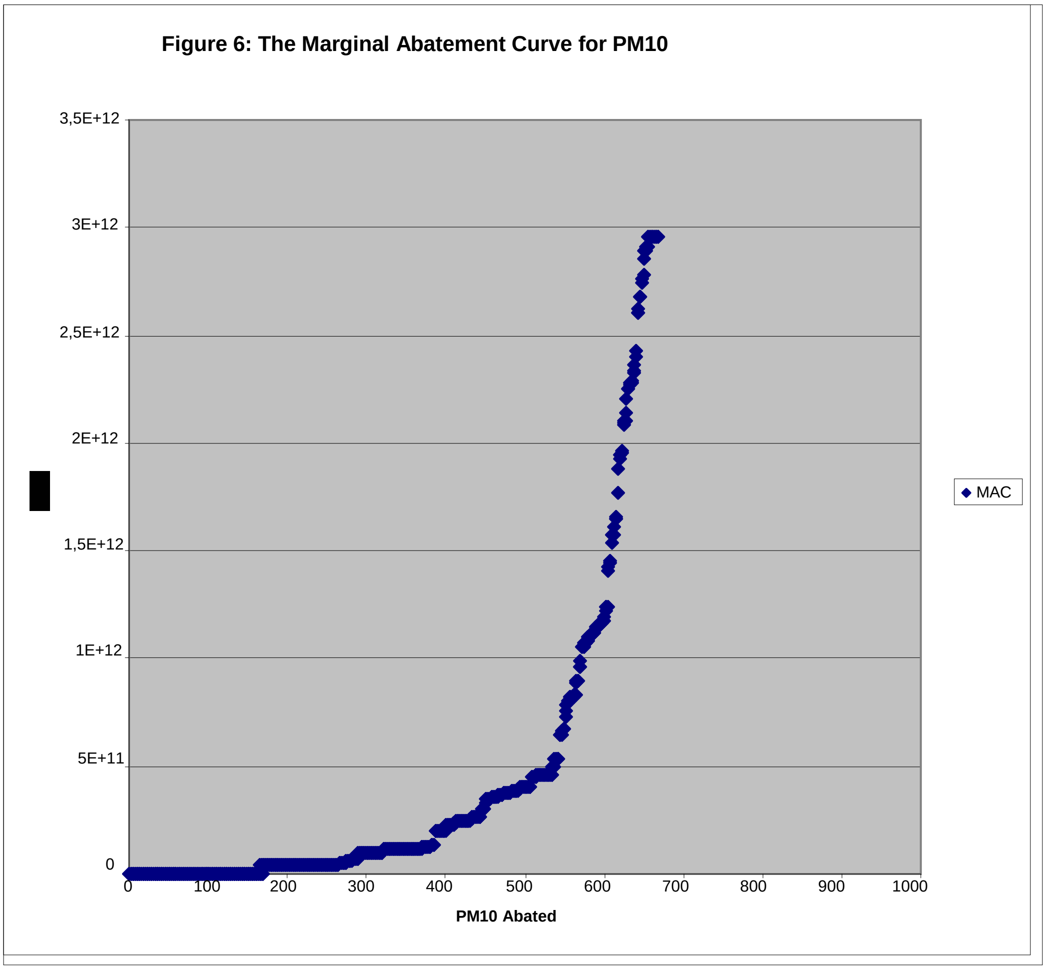

Figure 6: The Marginal Abatement Curve for PM10

Source: IIASA[18]

A relatively simple policy measure is to use a corrective tax (i.e. motivated by externality correction) imposed on gasoline. The merit of this policy is straight forward. It has little administrative difficulty in implementation, as the same rate is imposed on all vehicles using the same type of gasoline. However, its disadvantage is its advantage. In other words, a good policy instrument is the tax that internalizes the externality imposed by each agents and the uniform tax imposes the same charge regardless of the contributions for the externality. While in reality a congested city could choose time-of-day variation (as in London), as long as gasoline taxes are used, they should be based on a weighted average of consumers[19]. For example if gasoline taxes are used and gasoline is used both during rush hour and outside rush hours, then taxation should apart from the relative quantities take into account differences in price sensitivity. If the most congestive use is least price sensitive, then this would reduce the way the gasoline tax takes account of congestion.

Suppose a gasoline tax is imposed on vehicles using an often congested road and one would like to see the effect on congestion, say measured in terms of time delay, and pollution, say measured in terms of PM and CO_2 released to the atmosphere. Let us first see the effect on congestion, and then the effect on pollution.

[18] IIASA's Rains MODEL

[19] In addition to Sandmo (1976) and Wijkander (1985), Diamond (1973) and Greenwald and Stieglitz (1986) examine how corrective taxes deal with heterogeneity in externality generation.

An immediate consequence of a gasoline tax is to raise the unit cost of trips since taxes are additive to producers' price of trip, as reflected in the bus fare or in the car's gasoline cost. An increase in the unit cost of trips reduces bus and car trips consumed, thereby also reducing time delay. Thus, while the gasoline cost is a modest share of the trip's unit cost compared with the time cost, a secondary effect of the gasoline tax increase is the reduction in the time cost spent traveling. However, the effect does not stop here. It has frequently been observed that whenever a policy is enacted to reduce traffic volume and delay in traffic, then traffic decreases initially but then rises again. Additional individuals who initially opted not to join the traffic responds to less delay with new trips and reduce the impact of the policy on traffic. This effect, which is known as *the rebound effect*, quite generally reduces (or curtails) the intended effects of policies that reduce transportation costs. A fuel efficiency standard, for instance, also results in a rebound effect as people made to buy more efficient cars respond by traveling more. In some cases, the rebound effect might be large enough to almost nullify the expected impact, while in other cases it may turnout to be weak. The ultimate success of the policy rests on the size of various elasticity parameters. Importantly, however, if one believes time spent is important, then congestion in itself limits traffic, and congestion reduction alone (as with road expansion) causes more traffic. As importantly, however, the additional mobility, even if in the limit speeds are unimproved, is of value to consumers, producers and the city. Also, if congestion management tools are used, then not only is congestion managed but so is the rebound effect.

Referring to the model development in the annex, travel time is a function of total traffic volume, $t = \Psi(V)$ where $V = mX_B + \theta X_C$ and taking the total differential of time delay with respect to uniform tax, ε gives the effect of taxes on congestion.

(4.1) $$\frac{dt}{d\varepsilon} = \frac{\Omega_{t,X_B}\Omega_{X_B,P_B}}{1-\left[\Omega_{t,V}\Omega_{V,P_B}\frac{t^*}{P_B}\right]} + \frac{\Omega_{t,X_C}\Omega_{X_C,P_C}}{1-\left[\Omega_{t,V}\Omega_{V,P_C}\frac{t^*}{P_C}\right]}$$

Equation (4.1) states that the over all effect of a tax on congestion is the sum of the separate effects of car trips and bus trips (see annex) on congestion. The above formula takes into account the famous rebound effect. When the respective denominators of equation (4.1) are one, there is no rebound effect and the total effect of the tax is the direct effect of the tax. But, time delay responds positively for traffic volume and the volume of traffic responds negatively to the unit cost of trip and the denominator is greater than one and the direct effect is dampened by the rebound effect.

The overall effect is a function of various elasticities, final traffic time, and the final unit costs. The unit cost elasticity for bus trip and car trip are given by (4.2).

(4.2a) $$\Omega_{X_{B,PB}} = -\frac{1+\sigma_T\left(\frac{1-\phi}{\phi}\right)^{\sigma_T}\left(\frac{P_B}{P_C}\right)^{\sigma_T-1}}{1+\left(\frac{1-\phi}{\phi}\right)^{\sigma_T}\left(\frac{P_B}{P_C}\right)^{\sigma_T-1}}$$

(4.2b)
$$\Omega_{X_{C,PC}} = -\frac{1+\sigma_T \left(\frac{\phi}{1-\phi}\right)^{\sigma_T} \left(\frac{P_C}{P_B}\right)^{\sigma_T - 1}}{1+\left(\frac{\phi}{1-\phi}\right)^{\sigma_T} \left(\frac{P_C}{P_B}\right)^{\sigma_T - 1}}$$

Equations (4.2a) and (4.2b) suggest that the overall effect of a uniform tax on congestion is negative. In other words, the sign of $\frac{dt}{d\varepsilon}$ is negative which implies that a uniform tax on gasoline reduces congestion. The magnitude of reduction depends upon the magnitude of various elasticity parameters. In general, however, taxation and demand management yields a higher effect a) the higher is the substitutability between goods, b) the higher are the differences between goods in their externality generation. For our consumer, the elasticity parameter σ_T describes the substitutability between car trips and bus trips. Since cars are both more polluting and congesting, this parameter describes ability of consumers to reduce externalities, in this case in response to taxation that is heavier on car trips than on bus trips.

What about the impact on emissions? Taking emission factors as exogenous, which is likely in the short run, taking the total differential of emissions with respect to a uniform tax provides the overall effect of taxes.

(4.3)
$$\frac{dE}{d\varepsilon} = \frac{e(a_B)\frac{\partial X_B}{\partial P_B}}{1-\left[\Omega_{E,V}\Omega_{V,P_B}\frac{E^*}{P_B}\right]} + \frac{e(a_C)\frac{\partial X_C}{\partial P_C}}{1-\left[\Omega_{E,V}\Omega_{V,P_C}\frac{E^*}{P_C}\right]}$$

Again the respective denominators of (4.3) reflect the rebound effect on emissions due to the induced demand for travel. Since emission is increasing in total traffic volume and total traffic volume is decreasing in unit costs, the net effect of uniform taxation on emissions is negative. Once again, the magnitude of the effect depends up on the size of the different elasticity values, final emission, and unit costs.

It is of interest now to examine the quantitative implication of the model. Especially, we want to understand how demand management instruments affect congestion and air pollution together. Given the large number of agents in the transportation sector, applying Pigouvian fee could be very costly due to cost of monitoring. However, presumptive taxes applied for instance to fuels could be easier solution. For example, tax on gasoline reduces the demand for car use. Taxes on bus use, similarly, could be implemented either through diesel taxes or in other ways, depending on whether also other parts of the transportation system (like trucks) are targeted. Hence, we experiment with the quantitative implications for trip demand by imposing different taxes on ‘car use’ and ‘bus use’ without going in detail about how this is being implemented. In reality, when congestion and demand management are important objectives, a city administrator would ask for opportunities to differentiate policy instruments both geographically and by time. Still, due to their simplicity, fuel taxes (and bus taxes or subsidies) would play an important role and perhaps a dominant role in many city circumstances.

To proceed with quantitative analysis, we need to have the values for three different set of parameters. The first set of parameters we need is the set of elasticity of substitution at different nests of the utility function. To the best of our knowledge, the literature in transport economics is silent about the elasticity of substitution between car and bus trips in general and specifically for Bangkok. For instance Gibbons and O'Mahony (2000) use two elasticities of substitution between public and private travel (1 and 2) while Berg (2007) uses the elasticity of substitution between leisure and other consumption 0.6, 1.1, and 1.6 for sensitivity analysis. None of the above models is based on estimated values. Hence, we use the elasticity of substitution between leisure and consumption value of 1. This value suggests that the utility function has a property of Cobb Douglas function. Practically speaking, an elasticity of substitution equal to one implies a price elasticity of one, meaning that demand for the good that increases in price contracts in such a way that 'its budget' remains constant, so that other consumption can remain unchanged. We also as our central value use an elasticity of substitution in the upper nest of the utility function of 1. Thus, if transport becomes more expensive, transport consumption contracts enough that other consumption can be retained unchanged. On the other hand, the elasticity of substitution between bus trip and car trip is two. This is intended to reflect that bus trips and car trips are more substitutable than are other pairs of goods in our model. Importantly, since 'out of pocket' costs (gasoline, bus tickets) are only a fraction of the unit costs for each mode (which includes the time costs, too), bus taxes and car taxes of 100 percent, say, makes more modest unit cost changes, and this reduces the demand responsiveness to taxes.

We want to understand the impact of changes in taxes on the overall traffic volume, congestion, and emission of PM10 and CO2[20]. Our ultimate interest is related to reduction of congestion and air pollution. One way to measure congestion is to take the amount of time it takes to cover a given distance. Another, equally valuable way is to take the average speed. We use time spent on a distance of the average trip to measure congestion. Cars emit more pollution on a per passenger basis, and entail more congestion on a per passenger basis.

In the following we experiment with the consequences of taxing gasoline and diesel on carbon dioxide and PM10 emissions, and congestion. Since the cost of trip is composed of producer's price, taxes, and cost of time, taxing gasoline or diesel alone does not change the cost of trip equally much. This is the case, since in congested cities like Bangkok, whose average speed is 15km/hr, the major portion of the cost of trip is accounted by the cost of time. In the present calculations, we measured time costs in terms of forgone wage[21].

The figure below simulates the change in congestion under alternative combinations of gasoline and diesel taxes. As can be seen from the figure, large reduction in congestion can be attained by taxing car trips than bus trips. This is basically due to the fact that is car is less congestive than bus per vehicle km bases while it is more congestive per passenger km basis compared to bus. Even, more reduction can be attained by taxing both trips since such a tax results in additional reductions of aggregate trips.

These results (and inputs) are is not in general accordance with the belief among many that transport is very inelastic and little progress can be made with demand management tools. This is an important discussion, but we believe it is important also to keep in mind that urban management decisions relate to the long term (in the extreme, see figure 1, for a reminder), and demand elasticities are greater if informed by long term demand studies than by (the more frequent) short term demand studies[22]. However, even if aggregate transport is inelastic, there

[20] The central simulation is made assuming the elasticity of substitution between bus and car is one. A table presenting the same simulation but changing the elasticity of substitution is presented in the next section.

[21] ADB 2003 suggests an alternative approach based on revealed preference of travelers. Though we could differentiate the time price between bus passengers and car drivers and passengers, other aspects of their approach are not implementable in our representative agent model.

[22] See Eskeland and Feyzioglu, 1997, for estimates and review distinguishing long term demand elasticities. Most demand models of intermodal substitution are of a short term nature, for instance in taking as given a trip's origin, destination, available infrastructure, and so on.

is a substantial substitution opportunity between different modes. Certainly, people can substitute between car trips and bus trips, even if there is little substitution possibility between consumption of other goods and transport. This inter modal substitution possibility suggests that it is effectively possible to significantly reduce congestion in Bangkok by discouraging modes of transport that result in more congestion and more pollution.

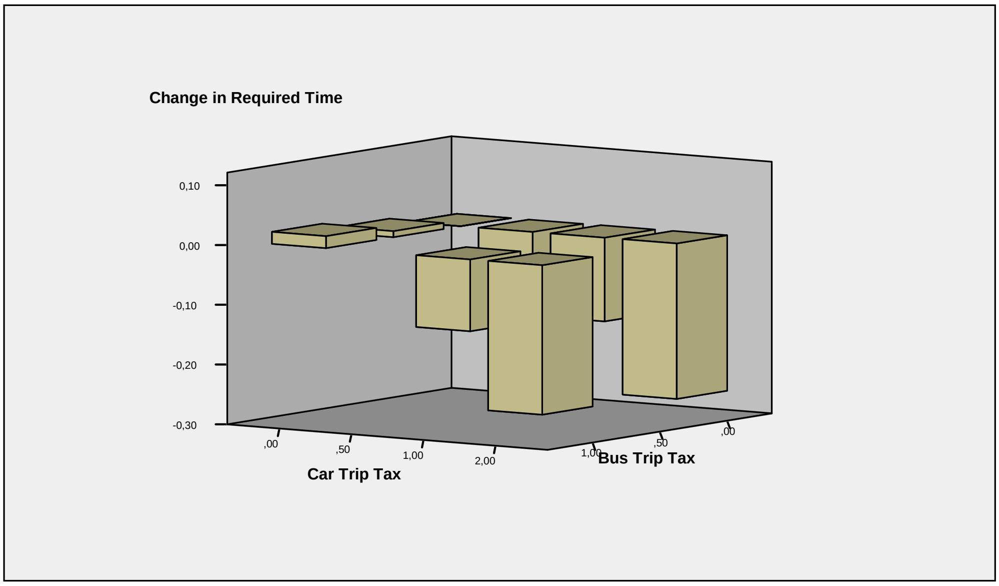

Figure7: Simulating the Impact of Alternative Tax Combinations on Congestion

Another important externality from transport is air pollution and contribution to global warming. Diesel and gasoline combustion contributes with emissions of fine particulates that have important health consequences. On the one hand combustion of diesel contributes more than gasoline per liter to the emission of PM10. Thus alternative combinations of taxes on gasoline and diesel have wider consequences on PM10 emissions. The simulation in the figure below indicates that taxing both car and bus trips reduces PM10 emissions the most.

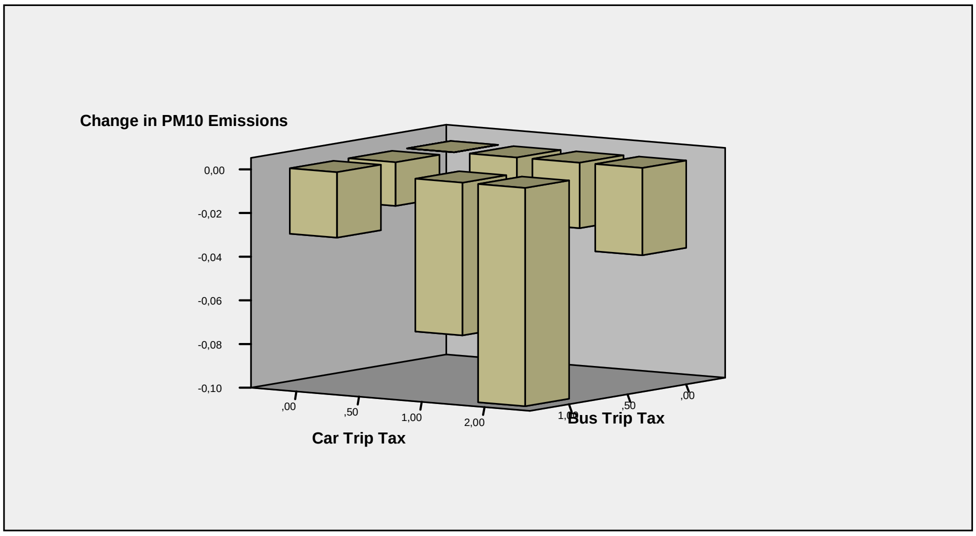

Figure 8: Simulating the Impact on PM10 Emissions of Alternative Tax Combinations

The other emission in focus is Carbon dioxide. Although carbon dioxide does not result in air pollution in itself it is an important externality of transport through global warming. Unlike the impact on congestion and emission of particulate matters, sharper reductions in carbon dioxide emission is obtained when no tax is imposed on bus trips while the largest possible tax is imposed on car trips.

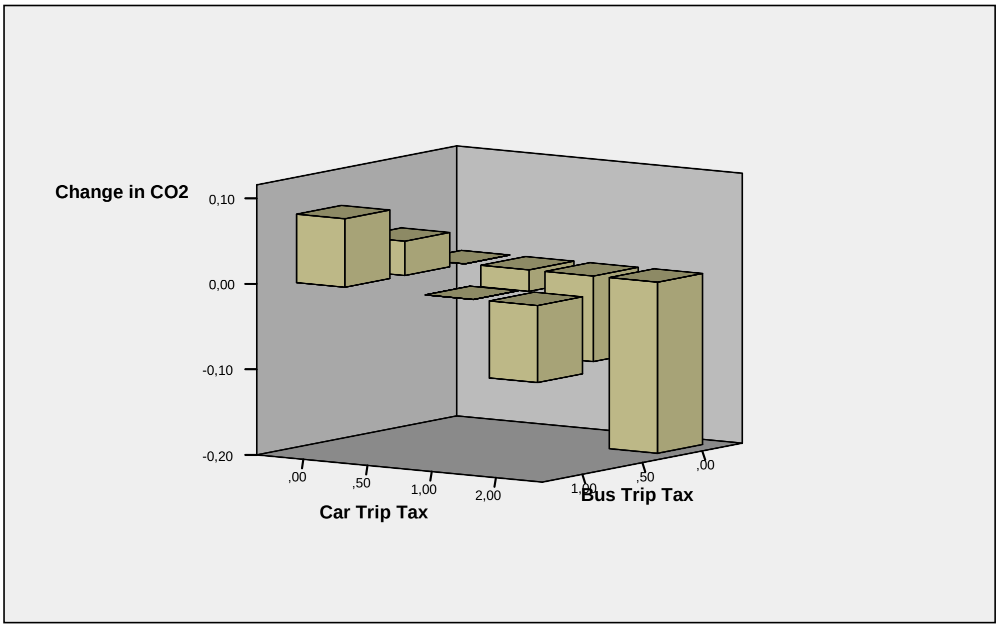

Figure 9: The Impact on CO2 Emissions of Alternative Instruments

This outcome is basically a consequence of variations in the per passenger emission factors of bus trip and car trip for a given distance. Emission tests (Diesel, 2007) indicate that a passenger car trips per km results in emission of 169 grams while bus rests in emission of 35 grams of carbon dioxide. So for a given trip demand, more reduction can be attained by shifting from car to bus trips and instruments that facilitate or enforce that shift have better capacity to reduce the emission of carbon dioxide.

Comparing the results for the three externalities displayed, they all reflect that travel causes negative externalities, and the car more so of the two. For congestion, Pm10 and CO2, the bus is less externality generating than the car on a per passenger mile basis. For CO2, the bus is dramatically ‘better’ than the car, so the additional taxation of buses reduces the gains in terms of CO2. For the two others, the externality is either unaffected by the additional taxation of buses (congestion) or the externality reduction is enhanced by including bus taxation (PM10).

For sensitivity analysis, the results described above hold more or less the same, although there are some changes in size of reductions, when the elasticity of substitution between bus and car increased to two. The table below reports the result of the sensitivity analysis.

Table 7: Simulation of the Impact of Gasoline Tax on Modal Choice of Trips, Time Delay, and Emissions

Parameters	Tax Rate as % of		Car Trip	Bus Trip	Car's Share of Trips	Time Delay	PM10(μg)	CO2(g)
	p_C	p_B						
$\sigma_{BC} = 2$	0,00	0,00	0,00	0,00	0,64	0,00	0,00	0,00
	0,50	0,00	-0,04	-0,04	0,64	-0,06	-0,04	0,00
	0,50	0,00	-0,06	0,12	0,62	-0,07	-0,01	-0,05
	0,00	0,50	0,02	-0,14	0,66	0,01	-0,02	0,04
	1,00	0,00	-0,12	0,27	0,60	-0,14	-0,03	-0,10
	1,00	1,00	-0,07	-0,07	0,64	-0,12	-0,07	0,00
	0,00	1,00	0,04	-0,25	0,68	0,02	-0,03	0,08
	2,00	0,00	-0,25	0,60	0,55	-0,26	-0,04	-0,20
	2,00	1,00	-0,18	0,14	0,60	-0,25	-0,10	-0,09

4 Conclusion

The described model of urban transport was developed to shed new insights on the problem of urban transport management and pollution in Bangkok. The comment given to a decision making tool for emission reductions (Diesel) was that it was impressive and well developed, but that one additionally should ask whether the transportation system could provide emission reductions while also increasing mobility.

The model developed allows congestion to be an externality from transport, greater when trips go by car than by bus. Also, it allows consumers to reduce transport or to substitute car trips for bus trips at a cost. The result is, as one might expect, that emission reductions from transport demand management come easily if there is elasticity in demand. But we were surprised to find that demand management – apart from the obvious welfare gains to reduced time wasted in congestion – is important for pollution reductions in several other ways.

First, buses pollute less per vehicle mile when travelling faster, for instance by 30% if raising speeds by 40% from 15km/hr to 25. Secondly, the emission reductions from raising bus quality (say, from Euro 1 to Euro 2) are greater at higher average speeds. Thirdly, since any bus – and a high quality bus – can do more work at high speeds than at low speeds, the same emission reductions can at higher speeds be provided by fewer buses (and by fewer high-quality buses), reducing the costs of emission reductions.

These effects come in addition to those emission reduction benefits of congestion and demand management that are proportional to the shifting of demand from cars to buses, and to reductions in total travel.

According to the available data, buses in Bangkok *are* on average contributing less per passenger kilometer than cars to externalities such as local air pollution, congestion and greenhouse gas emissions. Thus, one should not be surprised that travel demand management can be a useful well to draw from when managing these externalities. Demand management and congestion management has its costs, and should not be dealt with carelessly. But it seems warranted to look carefully into such aspects of the transportation system as mobility, air quality, and out of pocket costs for consumers. Not doing so, one risks spending much resources on vehicles moving slowly. That is costly, even measured narrowly in terms of air quality gains.

References

Arnott. Richard (2001)"*The Economic Theory of Urban Traffic Congestion: A Microscopic Research Agenda*." Boston College Working Papers in Economics 502. Boston College Department of Economics.

Beckmann. M.. C. B. McGuire and C. B. Winsten (1956) "*Studies in the Economics of Transportation*." Yale University Press. New Haven

Berg Charlotte (2007) "Household Transport Demand in a CGE-framework" *Environmental and Resource Economics* Volume 37. Number 3. 573-597

Bertrand.T.(1977) "*Second Best Congestion Taxes in Transportation Systems*" **Econometrica**. Volume 45. Number 7

Chia.N.-C.. A.Tsui. and J.Whalley (2001). "*Ownership and Use Taxes as Congestion Correcting Instruments*" **NBER working paper 8278**. Cambridge. MA

Diamond, Peter A. 1973. "Consumption Externalities and Imperfect Corrective Pricing" *The Bell Journal of Economics and Management Science* 61(1): 8-27 and 61 (3):261-278

Eskeland, Gunnar .1997. "Is demand for polluting goods manageable? An econometric study of car ownership and use in Mexico". *Journal of Development Economics* Vol. 53 (1997) 423-445

Eskeland. Gunnar S. (1994). "*A Presumptive Pigovian Tax on Gasoline: Complementing Regulation to Mimic and Emissions Fee*." **The World Bank Economic Review**. Volume8. Number 3

Eskeland. Gunnar S. and Emmanuel Jimenez. (1992) "*Policy Instruments for Pollution Control in Developing Countries*" **The World Bank Research Observer** Volume 7. Number 2.

Eskeland. Gunnar S. and S. Devarajan.(1996) **Taxing Bads by Taxing Goods: Pollution Control with Presumptive Charges**. Washington D.C.: World Bank.

Eskeland. Gunnar S. and Tarhan Feyzioglu (1997) "*Rationing Can Backfire: The " Day without a Car" in Mexico City.*" **The World Bank Economic Review .** Volume 11. Number 3

Eskeland. Gunnar S.. Emmanuel Jimenez. and Lili Liu. (1998). "*Prices that clear the air: Energy Use and Air Pollution in Chile and Indonesia*." **Energy Journal** Volume 19. Number 3

Flamm. Bradley and Gregory Rosston (2005) "*Traffic Congestion. Congestion Pricing. and the Price of Using California's Freeways*" **Policy Brief: Stanford Institute for Policy Research**. Apr*il*

Gibbons E. and M. O'Mahony (2000) "Transport policy prioritisation for Dublin" *Transportation* Volume 27. Number 2. 165-178

Hau. Timothy D. (1990). "*Electronic Road Pricing: Developments in Hong Kong 1983-89*". **Journal of Transport Economics and Policy**. Volume 24. Number 2

Leape. Jonathan (2006). "The London Congestion Charge" Journal of Economic Perspectives. Volume: 20. Issue: 4

Likens. James D. (1975) "*Some Theoretical Issues in the Pricing of Transportation Systems*" **The Annals of Regional Science.** Volume 9. Number 3

Mohring.H. (1972). "*Optimization and Scale Economies in Urban Bus Transportation*". **American Economic Review** Volume 62. Number

Patricia Mokhtarian and Ilan Salomon (2001) "*How Derived is the Demand for Travel? Some Conceptual and Measurement Consideration" **Transportation Research** A.* Vol. 35. No. 8

Sandmo, Agnar.1976. "Direct versus Indirect Pigouvian Taxation" *European Economic Review* 7:337-49

Sherman.R. (1971). "*Congestion Interdependence and Urban Transit Fares*" **Econometrica** Volume 39. Number 3

Small**.** Kenneth A. and Jia Yan (2001) "T*he Value of "Value Pricing" of Roads: Second-Best Pricing and Product Differentiation*" **Journal of Urban Economics**. Volume 49. Issue 2

Verhoef. E. J (2005). **"***Second-Best Congestion Pricing Schemes In The Monocentric City"* **Journal of Urban Economics***.* Volume 58. Issue 3

Verhoef. E. J. Rouwendal and Rietveld. P. (1996). "S*econd-Best Congestion Pricing: The Case of an Unpriced Alternative*" **Journal of Urban Economics** Volume40 Number 3

Verhoef.E and K.A. Small (2001)."*Product Differentiation On Roads: Second-Best Congestion Pricing With Heterogeneity under Public and Private Ownership*" **Discussion Paper TI99-066/3** Tinbergen Institute. Amsterdam-Rotterdam

Walters.A. (1961) "*The theory and measurement of private and social cost of highway Congestion*" Econometrica. Volume 19. Number

Wijkander, Hans.1985. "Correcting Externalities thorough Taxes on/Subsides to Related Goods" *Journal of Public Economics* 28:111-125.

Annex

APPENDIX- A: Optimal Taxes Derived from the Model in Appendix D

Mode	Relative Congestion Factor	Congestion Tax/ Factor	Relative Pollution Factor	Pollution Tax/ Factor	Total
Bus	$mX_B(P_B, P_C)$	$n\rho h'(\bullet)P_l$	1	$-\frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}}$	$\xi_B = n\rho m h'(\bullet)P_l X_B(P_B, P_C) - \frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}}$
Car	$\theta X_C(P_B, P_C)$	$n\rho h'(\bullet)P_l$	$\frac{e(a_C)}{e(a_B)}$	$-\frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}}$	$\xi_C = n\rho\theta h'(\bullet)P_l X_C(P_B, P_C) - \frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}} \frac{e(a_C)}{e(a_B)}$

APPENDIX -2: Composition of Bangkok Bus Fleet. 1999

Category	Bus Colour	Number of Buses	Fare (Baht)
BMTA Own Fleet			
Euro II A/C	Orange	808	8 to 18
Euro I Non A/C	Blue/White	80	5
CNG A/C	White/Green	82	6 to 16
Articulated A/C	White/Green	16	6 to 16
Non-emission controlled A/C	Blue/Cream	996	6 to 16
Non-emission controlled "hot bus"	Red/Cream	2.215	3.5
Sub-total BMTA		4.197	
Private Subcontractors to BMTA			
Non-emission controlled A/C	Blue/Cream	446	6 to 16
Non-emission controlled non A/C	Red/Cream	1.550	3.5
Minibus non A/C	Green	1.432	3.5
Sub-total BMTA Subcontractor		3.428	
Separately Licensed by LTD			
Bangkok Microbus Euro II A/C	Purple	863	20
Songtaew (2 row truck)	Varies	1.550	3.5
Sub-total Separate License		2.413	
Total		10.038	

APPENDIX -3 : Simulation of the Impact of Gasoline Tax on Modal Choice of Trips, Time Delay, and Emissions

Parameters	Tax Rate as % of		Car Trip	Bus Trip	Car's Share of Trips	Time Delay	PM10(µg)	CO2(g)
	p_C	p_B						
$\sigma_{BC}=1$	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.00
	0.50	0.00	-0.04	-0.04	0.64	-0.06	-0.04	0.00
	0.50	0.00	-0.04	0.05	0.62	-0.06	-0.02	-0.02
	0.00	0.50	0.01	-0.08	0.66	-0.01	-0.02	0.02
	1.00	0.00	-0.08	0.10	0.60	-0.11	-0.04	-0.05
	1.00	1.00	-0.07	-0.07	0.64	-0.12	-0.07	0.00
	0.00	1.00	0.01	-0.15	0.68	-0.01	-0.03	0.04
	2.00	0.00	-0.16	0.20	0.55	-0.20	-0.07	-0.10
	2.00	1.00	-0.15	0.01	0.60	-0.22	-0.11	-0.04

APPENDIX-4: The details of the quantitative model

Representative Agent

In this section, we consider the problem that the representative agent faces and the demand functions that its optimization results in. First we drive results using general preference structure and then specify it using CES utility function so as to obtain closed form demand functions. Neither the results nor the optimal policy values are dependent on the closed form specification. In the next section, we consider the problem that the social planner faces and concomitant differences in demand. Finally, we will investigate the optimal policy variables that minimize the welfare loss from pollution and congestion.

Suppose the representative agent has a utility function that satisfies the usual regularity conditions of concavity, continuity, and twice differentiability. Let, the utility function is given by a continuous mapping $U:\Re_+^4 \mapsto \Re$. By denoting a set of consumption of products other than travel, leisure, and bus (car) trip for a given vehicle distance by Y, l and X_B (X_C) respectively, and the utility function that describes the preference set of the agent is expressed by (1)[23]. We assume that utility is increasing in products ($U_1(Y,l,X_B,X_C)>0$), leisure ($U_2(Y,l,X_B,X_C)>0$), the quantity of trip of a given vehicle distance consumed by bus ($U_3(Y,l,X_B,X_C)>0$), and the quantity of trip of a given vehicle distance consumed by car, ($U_4(Y,l,X_B,X_C)>0$) where the subscripts indicate that the derivative is taken with respect to the first, the second, the third, and the fourth argument respectively.

(1) $$U=U(Y,l,X_B,X_C)$$

[23] The vehicle distance could be vehicle kilometers

The per-unit final prices of the quantity of bus (car) trip have different components in addition to producer prices. These components are fare price, taxes per unit of each trip, mandated abatement cost per unit of each trip, and the opportunity cost of time delay caused by congestion.

Let p_B represent the fare per unit of time for a unit of distance travelled by bus while p_C represents the fare per unit of distance travelled for single unit of trip by car. We also assume that the producers fare prices, p_B and p_C , are constant throughout. Fare prices represent the “normal” prices for delivery of travel services in the ideal situation.

Moreover, let the amount per unit of trip taxes on bus and car trip of a unit distance, denoted by ξ_B and ξ_C respectively. The presence of congestion and emission externality associated with trip consumption may justify some sort of external intervention in terms of maintaining technical standard or managing traffic through taxes or subsidies. In the absence of intervention, the representative agent faces zero demand management taxes and no technological restrictions. The taxes would be zero in the absence of any intervention and it could be positive/negative in the presence of intervention. We designate the cost of mandated abatement per unit of each bus (car) trip by $p_{a_B} a_B (p_{a_C} a_C)$ where p_{a_i} is the price of a unit of mandated abatement a_i.

In addition to producer prices and taxes, final prices include the cost of time used for a trip. Naturally, congestion increases the total time to cover a given distance or decreases the speed to cover a given unit of distance. The time used is a function, $h(\bullet)$, of the total traffic volume, $t = h(\sum_j mX_B^j + \theta X_C^j)$. This specification is natural to model travel time and has been frequently used in the literature once it was discovered by Danish mathematician Agner K. Erlang[24]. The parameters $m > 0$, and $\theta > 0$ are constants. We consider (2) with the natural property of $h'(\bullet) > 0$; and since travel time is a function of traffic, we can write $P_i = P_i(X_B, X_C)$.

(2) $$P_i(X_B, X_C) = p_i + \xi_i + p_{a_i} a_i + P_l t \text{ Where } i = \{B, C\}, \text{ and } \xi \in \Re$$

The budget constraint of the consumer with regard to travel is given by the sum of expenditures on consumption of leisure, products, and the quantity of trip of a given vehicle distance consumed by bus, the quantity of trip of a given vehicle distance consumed by car, and the amount of income the agent scarifies due to time delay caused by congestion less or equal to the amount of endowment income[25]. Without loss of generality, we assume that $\forall q \in \{i\}_1^n, X_j^i = X_j^{i+q}$ where $j \in \{B, C\}$. Tax is assumed to be non-distortionary and composite good other than travel (Y) is the numéraire.

(3) $$Y + P_l l + P_B(X_B, X_C)X_B + P_C(X_B, X_C)X_C \le I$$

[24] See for instance, Linkens (1975) for references.

[25] Mohring (1972)

The assumption $U_1(Y,l,X_B,X_C)>0$, $U_2(Y,l,X_B,X_C)>0$, $U_3(Y,l,X_B,X_C)>0$ and $U_4(Y,l,X_B,X_C)>0$ implies that the Khun-Tucker complimentarity and slackness conditions can be ignored. Since the $U(Y,l,X_B,X_C)$ function is concave and the budget set is convex set, the value function which depends on P_B,P_C,P_l and I exists. Formally, $\exists V(P_B,P_C,P_l,I):\Re_+^4 \mapsto \Re$, which is given by $V(P_B,P_C,P_l,I)$
$= \max_{Y,l,X_B,X_C} U(Y,l,X_B,X_C)$ s.t. $Y+P_l l+\sum_{i=B,C} P_i(X_B,X_C)X_i = I$

The first order conditions that satisfy the value function above, with the shadow price of income λ, are given by the following equations.

(4) $$U_Y(.,.,.,.)=\lambda$$

The demand for goods other than travel satisfies (4). According to (4), the marginal utility of goods other than travel is equal to the shadow price of income since goods other than travel are the numéraire in this model.

(5) $$U_l(.,.,.,.)=\lambda P_l$$

The optimal leisure satisfies (5), according to which the marginal utility of leisure is equal to λP_l units of goods other than travel. The representative agent maximizes utility subject to a given mode of trip taking the traffic density as it is. Thus, we have (6) and (7) since $\frac{\partial}{\partial X_B}P_C(X_B,X_C)=\frac{\partial}{\partial X_B}P_B(X_B,X_C)=\frac{\partial}{\partial X_C}P_C(X_B,X_C)=\frac{\partial}{\partial X_C}P_B(X_B,X_C)=0$. At optimum, the utility of 1$ spent on bus (car) trip is exactly equal to the shadow price of income as the standard demand.

(6) $$U_{X_B}(.,.,.,.)=\lambda P_B$$

(7) $$U_{X_C}(.,.,.,.)=\lambda P_C$$

The marginal rate of substitution between trip and products is obtained using the FOCs and are given by the equations below. The marginal rate of substitution between bus trip and the other products is proportional to the sum of price of fare, tax per unit of trip, opportunity cost of time, and the cost of technical standard imposed per unit of each trip.

(8) $$\frac{U_{X_B}}{U_Y}=P_B$$

Taking (7) and (4), the marginal rate of substitution between car trip and set of other products is the sum of far price, tax, technical standard, and the opportunity cost of time due to travel.

(9) $$\frac{U_{X_C}}{U_Y} = P_C$$

Both (8) and (9) show that when traffic tax and/or technical standard per unit of trip for a given mode increase, the representative agent substitutes trip by other products.

We analyze the closed form problem of the representative agent by dividing it into two distinct stages for analytical simplicity. In the first stage, we analyze how the agent divides its total endowment income among products, leisure, and travel. Once, the optimal division is investigated, in the next stage we look into the demand for products and leisure given the income determined in the first stage and then we investigate the optimal choice of modes of travel and the resulting social welfare in the absence of any external intervention. This approach has sizeable analytic utility by allowing us to have different elasticity of substitution between modal trip choice, leisure – products choices, and travel and composite good. Since it is only the demand for travel that generates externality, the decision of the agent concerning leisure and other goods is the same with the planner.

Optimal allocation of income between products and leisure on the one hand and travel on the other hand requires the representative agent to maximize its composite utility for a given income. We assume there is one unit of time that is available for leisure, work, and travel.

(10) $$U((Y,l),T) = U\left(\psi(Y,l), T(X_B, X_C)\right)$$

Where ψ is utility from consumption of products and leisure while T is a composite good called travel. We specify the composite utility as CES in the optimal ψ and T for a given scaling constant A_U as follows.

(11) $$U = A_U\left(\alpha\psi^{\frac{\sigma_U - 1}{\sigma_U}} + (1-\alpha)T^{\frac{\sigma_U - 1}{\sigma_U}}\right)^{\frac{\sigma_U}{\sigma_U - 1}}, \ \alpha \in (0,1) \text{ and } \sigma_U > 0$$

As is in the standard text book model, σ_U refers to the elasticity of substitution of the arguments of the composite utility function. Maximizing the composite utility function subject to the budget constraint provides an elegant way of allocating a given income between travel on one hand, and products and leisure on the other hand. Denoting the price of utility from travel by P_T and the utility from goods and leisure by P_ψ and the total endowment income of the representative consumer by I , the budget constraint reduces to $P_T T + P_\psi \psi = I = I_T + I_\psi$. The optimal income allocated to travel and goods and leisure is given by equation below.

(12)
$$I_{\psi} = \frac{I}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\sigma_U} \left(\frac{P_T}{P_{\psi}}\right)^{1-\sigma_U}}$$

A rational agent allocates its income between the two components of the composite utility function. Since the relative prices are positive, the denominator of the above equation is greater than one. Intuitively, the agent spends a constant fraction of her income for products and leisure given relative prices are constant. For given prices of utility for trip, and goods and leisure, and the elasticity of substitution between travel and products & leisure, the amount of income allocated to travel and products are constant. The corresponding income for travel consumption is given below. As is expected the sum of the two incomes provides the total income of the agent which is in turn given.

(13)
$$I_T = \frac{\left(\frac{1-\alpha}{\alpha}\right)^{\sigma_U} \left(\frac{P_T}{P_{\psi}}\right)^{1-\sigma_U}}{1 + \left(\frac{1-\alpha}{\alpha}\right)^{\sigma_U} \left(\frac{P_T}{P_{\psi}}\right)^{1-\sigma_U}} I$$

Thus, (12) and (13) provide the optimal allocation of income endowment between travel, and products and leisure. Once the relative income is determined, the agent maximizes its utility for products and travel given the income determined above. Given the allocation of income between the two entries of the composite utility function, we can determine the demand functions for consumption of products, for leisure and travel endogenously.

The agent's demand function for goods and leisure is again determined following the behaviour of rational agent. Among other things, it has a preference relation for consumption of goods and leisure which can be represented by continuous, twice differentiable, strictly concave utility function ψ. We assume that ψ to be $\psi : \Re_+ \times [0,1] \mapsto \Re$ with $\psi_1(Y,l) > 0 \wedge \psi_2(Y,l) > 0$. The function ψ is assumed to be CES in consumption of good Y and leisure l with elasticity of substitution σ_{ψ} and a scaling constant A_{ψ}.

(14)
$$\psi = A_{\psi} \left(\tau Y^{\frac{\sigma_{\psi}-1}{\sigma_{\psi}}} + (1-\tau) l^{\frac{\sigma_{\psi}-1}{\sigma_{\psi}}} \right)^{\frac{\sigma_{\psi}}{\sigma_{\psi}-1}}$$ where $(1-\tau) \in (0,1)$ and

$\sigma_{\psi} > 0$

The agent chooses a consumption plan that provides it the maximum of ψ subject to the budget constraint. Its budget set specifies the feasible expenditure it can spend on goods and leisure given fixed income. The price of leisure is the amount of wage the agent scarifies so as to enjoy one unit of leisure.

(15) $$Y + P_l l \leq I_\psi$$

Given the assumption of strictly increasing utility function with respect to consumption and leisure, the inequality in (15) becomes binding at the optimal solution. The quantities of consumption and leisure that maximize utility subject to the budget constraint are given by the following equation.

(16) $$l(I_\psi, P_l, P_Y, \sigma_\psi) = \frac{I_\psi}{P_l + \left(\frac{1-\tau}{\tau}\right)^{\sigma_\psi} P_l^{\sigma_\psi}} = \left(\frac{1-\tau}{P_l}\right)^{\sigma_\psi} \left(\frac{I_\psi}{\tau^{\sigma_\psi} + (1-\tau)^{\sigma_\psi} P_l^{1-\sigma_\psi}}\right)$$

Like the standard demand function, the demand for leisure is decreasing in its price. Depending on the value of the elasticity of substitution, consumption of products could be substitute or compliment to leisure. Moreover, the demand for leisure is increasing in income as leisure is normal good in this model. The income elasticity of leisure decreases in the price of leisure and the elasticity of substitution between leisure and consumption of other products. The demand for goods other than travel that maximize ψ is given by the equation below.

(17) $$Y(I_\psi, P_l, P_Y, \sigma_\psi) = \frac{I_\psi}{1 + \left(\frac{\tau}{1-\tau}\right)^{\sigma_\psi} P_l^{1-\sigma_\psi}} = \tau^{\sigma_\psi} \left(\frac{I_\psi}{\tau^{\sigma_\psi} + (1-\tau)^{\sigma_\psi} P_l^{1-\sigma_\psi}}\right)$$

The Marshallian demand for goods is the standard one in the literature. As it is stated earlier, depending on the elasticity of substitution between leisure and consumption of other products, consumption of goods can be substitute or complimentary to leisure. The demand for Y is increasing in income. The relationship between the demand for Y and the price of leisure depends on the elasticity of substitution of ψ leisure and other products.

Thus, concave objective function with a convex constraint is sufficient for the existence of the value function. Formally $\exists V_\psi(P_l, I_\psi) : \Re_+^2 \mapsto \Re$, for $\psi^* = \max_{l,Y} \psi(Y, l)$ such that $Y + P_l l \leq I_\psi$.

(18) $$\psi^* = A_\psi I_\psi (\tau^{\sigma_\psi} + (1-\tau)^{\sigma_\psi} P_l^{1-\sigma_\psi})^{\frac{1}{\sigma_\psi - 1}}$$

The value function is increasing in income and the sign of its response price of leisure depends up on the elasticity of substitution.

The next point to investigate is the demand for trip. Since the demand for bus trip and car trip involves pollution and congestion, we consider externality problem as viewed by the representative agent. Although both congestion and pollution are negative externalities, there is sufficient difference between the two. In the case of congestion, the representative agent considers the effect of others on congestion but makes its travel decision while ignoring its own effect on congestion. On the other hand, in case of pollution the representative agent considers neither its effect nor the effect of others while making travel decision. We, thus, first we analyze congestion and incorporate pollution into the picture by the planner. The composite product, we call travel, is assumed to depend on the amount of trip consumed by bus and the amount of trip consumed by car. We assume that bus trip and car trip are substitute to each other. Hence, the travel technology T is specified, where X_B represents the quantity of trip of a given vehicle distance consumed by bus and X_C represents the quantity of trip of a given vehicle distance consumed by car, in (19). We assume that $T:\Re_+^2 \mapsto \Re$ and $T_1(X_B, X_C) > 0 \wedge T_2(X_B, X_C) > 0$.

(19) $$T = A_T\left(\phi X_B^{\frac{\sigma_T - 1}{\sigma_T}} + (1-\phi)X_C^{\frac{\sigma_T - 1}{\sigma_T}}\right)^{\frac{\sigma_T}{\sigma_T - 1}} \text{ where } \phi \in (0,1)$$

The optimal travel is attained when the agent maximizes the value of travel given its budget constraint of $P_B X_B + P_C X_C \le I_T$. The Lagrangian with the shadow price (λ) of income reserved for travel, after assuming very large number of consumers, is given by $L = T(X_B, X_C) - \lambda(P_B X_B + P_C X_C - I)$

The first order conditions that maximize the concave Lagrangian function are sufficient. The unique optimal demand for bus trip and car trip are obtained from the set of first order conditions.

Using (19), the budget constraint and the relative prices, the optimal demand for bus trip and car trip as a function of prices, income reserved for travel, and the elasticity of substitution in travel are given by (20) and (21).

(20) $$X_B(P_B, P_C, I_T) = \frac{I_T}{P_B + \left(\frac{1-\phi}{\phi}\right)^{\sigma_T} P_B^{\sigma_T} P_C^{1-\sigma_T}}$$

The demand function clearly reflects the effect of time delay due to congestion, taxes per unit of bus trip, the elasticity of substitution between car and bus trip, and the trip fares along income. Thus, demand for bus trip is decreasing in bus fare, the time it takes to reach a given destination, opportunity cost of travel, and the elasticity of substitution between car and bus trips. Since car trip and bus trip are substitutes, demand for bus is increasing in car fare per given distance, tax per unit of car trip and time it takes for car to reach a given destination.

(21) $$X_C(P_B, P_C, I_T) = \frac{I_T}{P_C + \left(\frac{\phi}{1-\phi}\right)^{\sigma_T} P_C^{\sigma_T} P_B^{1-\sigma_T}}$$

The demand for car trip is also a function of effective price of bus, effective price of car, elasticity of trip substitution between car and bus and income available for travel. Demand for car trip is increasing in effective price of bus trip and income and decreasing in effective price of car and the elasticity of trip substitution between car and bus trip. More congestion reduces the demand for trip.

The value of travel utility the representative agent obtains given the income allocated to travel, effective prices, and elasticity of substitution of travel is given by equation below.

(22) $$T^{*} = A_T I_T (\phi P_B^{\sigma_T} + (1-\phi)^{\sigma_T} P_C^{1-\sigma_T})^{\frac{1}{\sigma_T - 1}}$$

As can be seen easily, the value function is increasing in income allocated for travel which is in turn determined by the relative price of trip and other products and their elasticity of substitution. The value function defines the welfare of the representative agent once it has taken her decision rationally given fixed endowment of income, elasticity of substitution and prices. The total welfare of the agent when it faces no regulation is given by CES combinations of ψ^{*} and T^{*}.

(23) $$U = A_U I (\alpha^{\sigma_U} P_{\psi}^{1-\sigma_U} + (1-\alpha)^{\sigma_U} P_T^{1-\sigma_U})^{\frac{1}{\sigma_U - 1}}$$

The welfare of the representative agent is a nested CES function. It depends on elasticity of substitution, effective prices, and coefficients of absolute substitutions. It is increasing in income and the effects of prices depend on the elasticity of substitution of the composite utility function.

The Social Planner

The problem in this section tries to take in to account the problem of externality namely congestion and pollution, which is associated with consumption of trip but ignored by the representative agent due to lack market mechanism for externality. The planer takes the preference relation of representative agent given and considers the effect of externalities in to account. The degree of traffic congestion depends up on the number of trips as before. But, the planner takes in to account the effect that the representative agent fails to consider, namely its own effect on the rest of the other travellers. Since by assumption leisure and consumption of other goods and services do not involve externality, the analysis for demand of products and leisure is the same with that of the representative agent. However, the consumption of travel involves externality of congestion and pollution.

The quantity of pollution depends up on the level of technical standard or abatement effort, a exerted. Let the emission released by single consumer for a given trip and abatement effort is $e^{i}(X_j^{i}, a^{i})$ where $j \in \{B, C\}$ depending on the mode of transport used. The total pollution is the weighted sum of total pollution emitted by car trip consumers and bus trip consumers for a given distance and abatement standard. Following Eskeland, Jimenez, and Liu (1998), we specify the pollution equation as follows.

(24) $$E(X_B, X_C, a_B, a_C) = \sum_{i=1}^{n} e(a^{B}) X_B^{i} + e(a^{C}) X_C^{i}$$

The parameters $e(a_B)$ and $e(a_C)$ represent emission factor as a function of abatement effort, a_j for bus trip and car trip respectively. We assume that $e(a_j)$ continuous and differentiable every where and $e'(a_j) < 0$ .The planer maximizes utility subject to the constraint that aggregate emission is lesser than or equal to some constant $n\bar{\varepsilon}$. Hence the total emission constraint is given by (22).

(25) $$e(a_B)X_B + e(a_c)X_C \leq \bar{\varepsilon}$$

The social planner maximizes utility subject to emission constraint and the budget constraint through which takes in to account the effect of all congestion inducing agents. Since we have $\forall q \in \{i\}_1^n, X_j^i = X_j^{i+q}$ where $j \in \{B, C\}$, and the planner refunds taxes in lump sum amount, the budget constraint is given as

$$Y + P_l l + (P_B(X_B, X_C) - \xi_B)X_B + (P_C(X_B, X_C) - \xi_C)X_C = I \,.$$

Since the planner's utility function is increasing in the first two arguments, the inequality can be replaced with equality. The first order conditions are given below.

(26) $$U_Y(.,.,.,.) = \lambda_P$$

As for the representative agent, the planner's marginal utility of composite goods is equal to the shadow price of the budget constraint. The marginal utility of $1 unit of leisure is again equal to the shadow price.

(27) $$U_l(.,.,.,.) = \lambda_P P_l$$

When choosing the amount of trip by bus (car), the planner takes into account, unlike the representative agent, the effect of each entrants into the road to the rest of the drivers as well as the emission of each driver to the ecosystem and hence, we have (28), and (29).

(28) $$U_{X_B}(.,.,.,.,.) = \lambda_P(P_B + X_B \frac{\partial}{\partial X_B} P_B(X_B, X_C) - \xi_B + X_C \frac{\partial}{\partial X_B} P_C(X_B, X_C)) + \vartheta e(a_B)$$

(29) $$U_{X_C}(.,.,.,.,.) = \lambda_P(P_C + X_C \frac{\partial}{\partial X_C} P_C(X_B, X_C) - \xi_C + X_B \frac{\partial}{\partial X_C}(P_B(X_B, X_C)) + \vartheta e(a_C)$$

(30) $$\frac{\partial E}{\partial X_B} = e(a_B) \text{ and } \frac{\partial E}{\partial X_C} = e(a_C)$$

The social marginal rate of substitution between bus trip and products is proportional to the sum of fare price, opportunity cost of travel time, the abatement cost per unit of trip, and net value of marginal disutility of pollution.

(31) $$\frac{U_{X_B}}{U_Y} = P_B + n\rho m h'(\bullet) P_l X_B - \xi_B - \frac{p_{a_B}}{e'(a_B)} e(a_B)$$

The social marginal rate of substitution between bus trip and other goods is greater than the private marginal rate of substitution, at zero tax, indicating that the planner prefers lower amount of bus trip at equilibrium. In (31), this can be seen from the fact that emission is decreasing in abatement and utility is decreasing in pollution.

Like the bus trip, the social marginal rate of substitution between car trip and products is proportional to the sum of fare price, opportunity cost of time, the abatement cost per unit of trip, and net value of marginal disutility of pollution. Equation (32) also shows that the planner chooses lower car trip at optimum than the representative agent.

(32) $$\frac{U_{X_C}}{U_Y} = P_C + n\rho\theta h'(\bullet) P_l X_C - \xi_C - \frac{p_{a_B}}{e'(a_B)}) e(a_C)$$

Comparing (8) with (31) and (9) with (32), it can be noted that there is difference between the social marginal rate of substitution and private marginal rate of substitution. Specifically, the market tends to over supply travel in the absence of any intervention.

Optimal Policy

The fact that the social marginal rate of substitution is different from the market marginal rate of substitution implies the need for an optimal policy to internalize externalities due to congestion and pollution.

In the case of congestion externality, each bus (car) trip induces an opportunity cost of $n\rho m h'(\bullet) P_l X_B$ ($n\rho\theta h'(\bullet) P_l X_C$) on the rest of the agents. Hence, there is a need for traffic management tax per unit of trip that amounts to $n\rho m h'(\bullet) P_l X_B$ for each bus trip and $n\rho\theta h'(\bullet) P_l X_C$ for each car trip.

Moreover, each unit of trip consumed also induces pollution that creates disutility to the rest of agents. On the other hand, the amount of enforced abatement measure reduces the effect of pollution. Hence, there is also an equally important need for emission tax that amounts to the ratio of abatement cost per unit of trip to elasticity of emission to abetment for a unit of bus trip, $-\frac{p_{a_B}}{e'(a_B)} e(a_B) = -\frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}}$ or a unit of car trip $-\frac{p_{a_B}}{e'(a_B)} e(a_C) = -\frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}} \frac{e(a_C)}{e(a_B)}$ consumed[26].

[26] where $\Omega_{e(a_B),a_B} = e'(a_B) \frac{a_B}{e(a_B)}$

The amount of traffic management tax rate for a given level of technical standard is given by (33) and (34).

(33) $$\xi_B = n\rho mh'(\bullet)P_l X_B(P_B, P_C) - \frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}}$$

(34) $$\xi_C = n\rho\theta h'(\bullet)P_l X_C(P_B, P_C) - \frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}} \frac{e(a_C)}{e(a_B)}$$

Equation (33) and (34) is the main message of this model. For a given level of abatement, individuals should internalize the amount of additional congestion their travel decision imposes on the rest of the agent, $n\rho mh'(\bullet)P_l X_B(P_B, P_C)$ and $n\rho\theta h'(\bullet)P_l X_C(P_B, P_C)$, the amount $-\frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}}$ or $-\frac{p_{a_B} a_B}{\Omega_{e(a_B),a_B}} \frac{e(a_C)}{e(a_B)}$ for pollution.

In sum, the representative agent chooses trip levels that are higher compared to what is socially desirable. Such variation emanates from the fact that the consumption of some goods entails externality that the market can't handle. In this model, the externalities are congestion and pollution. In order to let the market reflect socially desirable outcomes, there is a need for individuals to internalize the externalities they generate. In case of congestion, demand management tax is good instrument in the short run. In the long run, policies directed at raising average speed for each trip which could be due to construction of new roads or adoptions of better technology seem promising. For the pollution externality, both abetment in the form of technical standard and demand management taxes can complimentarily be used. The efficient emission tax plays a significant role as it forces polluters internalize the externality they induce and does this with the lowest cost by fixing the marginal reduction of emission using abatement and tax equal.