EFFECTIVENESS AND WELFARE IMPACTS OF ALTERNATIVE POLICIES TO ADDRESS ATMOSPHERIC POLLUTION IN URBAN ROAD TRANSPORT[1]

ABSTRACT

In this paper we compare the effectiveness and welfare effects of alternative fuel efficiency, environmental and transport policies for a given urban area. The urban transport activities are represented as a set of interrelated markets, one for each mode of transport and type of vehicle. For each market, four different marginal external costs are computed in the present equilibrium: air pollution, accidents, noise and congestion. The gap between marginal social costs and prices shows that congestion and unpaid parking are the dominant sources of inefficiencies. Air pollution costs are significant as well. The effects of a typical air quality policy (regulation of car emission technology) and two typical fuel based policies (minimum fuel efficiency policy and fuel taxes) are compared with the effects of three alternative transport policies (full external cost pricing, cordon pricing, parking charges). Regulation of emission technology and of fuel efficiency do not necessarily lead to welfare gains, whereas transport pricing policies yield substantial gains for the urban area under study.

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1. Introduction

Pollutant emissions from urban road transport cause environmental and health damage. Over time the attention for different pollutants has shifted from SO2, NOx and VOC to particulates and greenhouse gas emissions. The political agenda was guided by progress made on three fronts: abatement technologies for cars, estimation of dose response relationships, and valuation of the different kinds of damage. Up to know, policies in this area have had only limited success. Recently, policy makers started to call for a shift from dedicated fuel efficiency and atmospheric pollution regulation to pure transport policies (parking, road pricing, transit) that address specific transport related externalities (congestion, traffic accidents). It is hoped that these policies will have also large beneficial effects on air pollution externalities. In this paper we use an integrated approach of the urban transport market and measure the effects of different types of environmental and transport policies on externalities related to air pollution and to transport, and we trade off their total welfare effects.

Section 2 is a brief overview of the main research directions that have been pursued on air pollution by road transport. Section 3 presents the methodology used in this paper. The estimation of external costs is the subject of section 4. Section 5 presents the reference case of Brussels in 2005. Section 6 discusses the results of the policy analysis. Section 7 concludes.

2. The present approach to the air pollution problem by cars

Three main strands in the literature address air pollution by road traffic. First, there is an extensive debate on fuel efficiency of cars, which has regained attention in the present climate change policy discussion. Second, there is a literature addressing damages and emission regulation for traditional pollutants. Finally, the transport literature has focused on optimal regulation and pricing of different transport modes.

The corporate average fuel economy (CAFE) regulation of cars has been installed in the US after the first oil price shock as one of the instruments to decrease imported oil dependency. Its effects have been studied in detail. Greene & Duleep (1993) conclude that its net benefits range from slightly negative to strongly positive. The most important effects were gains in the terms of trade and the reliability of supply on the international oil market. Part of the positive effects has to do with a reduction of air pollutants. Harrington (1997) however finds only a loose link between fuel efficiency and air pollutants other than CO2. Khazzoom (1994) looks into the relation between improved fuel efficiency and automobile safety. In the EU, fuel efficient cars emerged as a result of high petrol taxes rather than as a result of standards. The primary motive for high fuel excises was revenue need, combined with a desire to discourage traffic flows in congested urban areas. Recently, there has been a proposal at EU level to require a minimum fuel efficiency of 5 litre/100 km for new cars from 2005 onwards. This CAFE type of regulation has been motivated through climate change objectives. Surprisingly, there have been almost no economic analyses of fuel tax policies in Europe.

In the US, the use of emission standards for conventional air pollutants originated in the late sixties. The US works with ambiant air quality goals. For ozone there are still many non-attainment areas. Krupnick and Portney (1991) found that improving the air quality in non-attainment areas by technology standards was not efficient: in general the costs outweigh the benefits by a factor 10 or more. Both benefits and costs are difficult to estimate (see Hall (1998) for a discussion of the benefits and McConnell et al. (1995) for a discussion of the costs). More recently, there has been an interest in complementary policies like zero emission vehicles (see Kazimi (1997) for an evaluation) and a better inspection and maintenance regulation (see Harrington et al. (1994)). In the EU, the first systematic assessment of air quality policy came with the Auto-Oil I programme. In this programme, all interested parties have studied the most appropriate regulation of car emissions and fuels to achieve the ambiant air quality targets at lowest cost (see Degraeve et.al. (1998)).

In the transport literature, the emphasis is on the optimal use of a fixed infrastructure. The main problem has been to correct congestion in peak hours by tolls or through second best pricing like providing cheap transit. Air quality considerations were in general absent from these pricing exercises. The assumption was that emission regulation of cars is a sufficient instrument to address air pollution so that both problems are separable.

3. An integrated approach with the TRENEN-URBAN model[2]

The objective of the model is to examine the efficiency of different policies in the transport-energy-environment domain. The basic idea is to study the transport markets simultaneously and to look for optimal prices and regulation on these markets taking into account the different types of external costs.

The demand side of the model represents the choices of transport users. Demand for passenger transport is generated by assuming that a representative individual optimally allocates his income between passenger transport and other goods. Many passenger transport services are available: the individual can choose between motorised and non-motorised transport, chooses the time period of travel (peak versus off-peak) and has the option to use his car or one of the available public transport modes (metro, tram or bus). If the car is chosen different types and sizes of vehicles are available. Moreover, the individual has the explicit options of solo driving or car pooling. This gives in total 20 alternative transport means that vary all in terms of resource costs and in terms of external costs (congestion, air pollution, accidents, noise). Demand for each type of transport service in a given geographical zone is a function of the generalised price of that type of transport service (this is the sum of money price and time cost), of the generalised prices of the other transport services and of other factors (like income and taste variables).

The supply side represents the activities and choices made by the providers of transit and by the suppliers of inputs to car use like cars, fuels, car maintenance, etc. Choices in the supply part of the model are made on the basis of profit maximising suppliers, subject to environmental constraints imposed by government. The model includes parking costs and a

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[2] For an extensive technical description, see Ochelen S., Proost S., Van Dender K. (1998)

Mohring effect for public transport. This Mohring effect stands for the possibilities to improve quality of service of public transport when the level of demand increases due to reduced waiting times and a more dense transit network (Mohring (1972)).

In the *equilibrium price* module, generalised prices are computed for the different types of transport services. The generalised price will be the sum of three elements:

- A producer price for different types of vehicle km - this price is determined by the supply module.
- A transportation time cost, function of the total volume of traffic in equilibrium. This transportation time contains the average congestion cost and in the case of public transport the value of walking and waiting times.
- A tax (or subsidy) that has two policy functions: to raise tax revenue or subsidise certain modes of transportation, and to correct for external costs like air pollution, marginal congestion costs, noise and accidents. This tax will be differentiated for the different types of transport goods. The optimal magnitude of the taxes will be determined by the cost of public funds, by the level of marginal external costs, and by demand elasticities for the different goods (Ramsey rule). The marginal cost of public funds is positive (6.6% for the Brussels case study). All changes in net tax receipts are returned to the households. The way this is done determines whether the increased tax receipts are valued at a higher or lower rate than the mere income value. We assume that all extra revenue is returned under the form of a reduction in labour taxes. Since transport taxes are paid out of all income sources, not just labour income, higher transport taxes allow shifting taxes away from labour income. This is an efficiency gain. In the case study of this paper, we will therefore assume that net increases in tax receipts receive a bonus value of 6.6%.[3]

Besides taxes, the policy maker can impose certain regulations under the form of ad hoc constraints on the supply part of the model: maximum emission limits, banning certain types of fuels, minimal fuel efficiency, etc.

The model is calibrated for a given reference equilibrium (here, Brussels in 2005) using observed or forecasted money prices and quantities for all transport modes together with information on the ease of substitution between transport and other goods as well as between the different means of transport.[4] Other important inputs are the structure of resource costs of private and public transport, the external costs and the congestion function. The congestion function summarises the available network information on the relation between volume of road

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[3] A reduced form is used of the several mechanisms involved in this difficult subject. We relate this to the more familiar double dividend literature on environmental taxes. When a tax on transport use is increased, four effects are distinguished: (1) the environmental benefit and the external accident benefit, (2) the congestion benefit, (3) the tax interaction effect (a larger tax differential with other consumer goods leads to substitution and relatively less tax revenue), (4) the tax recycling effect (depends on the way increased tax revenue is used to reduce existing taxes). Familiar double dividend models (Bovenberg and Goulder (1996)) only consider effects (3) and (4). Our model considers effects (2) and (3) in an integrated way in the utility function. Effect (1) is added to the utility function in a separable way. Effect (4) is what we call the marginal cost of public funds parameter. It is the result of assumptions about how tax proceeds are recycled, existing labour taxes and labour market supply elasticities. See Ochelen, Proost and Van Dender (1998) for more details, and Mayeres and Proost (1997) for a general equilibrium approach.

[4] The model uses nested CES utility functions, where elasticities of substitution for each nest determine ease of substitution and price elasticities.

transport and average speed. The model is static: it represents the equilibrium for a given year and assumes that the stock of all means of transport (private and public) is perfectly adapted to the demand for transport. The road infrastructure and public transport infrastructure (e.g. the rail network) are kept fixed.

Several equilibria are possible on the transport market. We assume that the policy maker ranks them with the help of a *welfare function*, which makes a weighted sum of consumers' surplus, producers' surplus, tax revenues and external costs. The external costs include noise, air pollution and traffic accidents. The marginal external congestion costs are endogenously valued in the model because they are included in the generalised costs.

The model can be used in two ways. First, it can be used to compute the welfare effects of a given policy proposal. This enables comparison of different policy packages in terms of the resulting welfare effects (and traffic volumes, pollution, etc.). Second, the model allows the design of optimal policy packages. In this approach the welfare function is optimised by selecting the optimal transport and environmental policy variable values. The optimal values are the result of trade offs between external costs, valuation of transportation by its users, and tax revenue considerations. This optimisation can be performed under different sets of restrictions on the policy instruments. For example, different assumptions can be made about which pricing and regulation policies are technically and institutionally feasible. When there are no restrictions on the policy instruments, one has first-best policies in which transport users pay the full marginal social cost consisting of the marginal resource cost and the sum of all marginal external costs. When there are restrictions on the instruments, one obtains second best results that trade off in a complex way the deviations from full marginal cost pricing in the different transport markets. A typical example is the optimality of subsidies to public transportation in the peak when prices for car traffic cannot be differentiated between the peak and the off-peak period.

4. Estimating the external costs

The definition of external costs depends on the policy framework used. We take road infrastructure as given, so that only external costs relative to small increases or decreases of vehicle use are relevant. Moreover we use marginal external cost functions, instead of trying to represent total costs (see Delucchi (1997) for a total cost approach). The model takes marginal external air pollution costs, congestion costs, accident costs and noise costs into account. Oil market effects (security of supply and optimal import tax arguments) are not included, as these depend crucially on the imperfect competition concept used to represent the oil market. Finally we focus on passenger cars, not on trucks, such that road maintenance costs are irrelevant.

4.1 External costs of air pollution

The marginal external cost of air pollution is the money value of the damage to health and environment caused by initial vehicle emissions. The link between emissions and ultimate damages is not direct, and very complicated indeed for some types of pollutants. It is not the goal of this paper to establish the various relationships between emissions, dispersion and damage. The European Union ExternE project (1997) has studied in great detail the estimation of external costs of air pollution of vehicles for different urban and non-urban areas. We rely mainly on this source.

Traffic emissions depend on a number of factors. On the level of the vehicle, they are determined by emission technology, speed, degradation of technology, fuel characteristics, vehicle age and vehicle size (fuel consumption). The TRENEN model captures most of these factors. The major limitation is that we have no direct method for evaluating the impact of age fleet and inspection schemes on emission levels. Indeed our model is a static model that only contains one representative car (averaged over ages and states of maintenance) per type of vehicle (large or small) and type of fuel (diesel, gasoline). The number of cars is assumed to adapt to the demand for transport per type of vehicle. It is possible, however, to assess the impact of regulation of technology on representative cars (e.g. fuel efficiency standards, imposing new types of emission reduction technology, fuel quality requirements). This feature of the model will be used for the analysis in sections 6.1 and 6.2.

Atmospheric pollution is linked to traffic volume and composition through the assignment of constant per vehicle kilometre emission factors to different types of vehicles (size of car, fuel used, type of emission technology or type of fuel efficiency) in the different transport markets (time of day, occupancy rate). An overview of emission factors for *passenger cars* is given in table 1. Emissions are given for standard and for improved emission technology, and for normal and increased fuel efficiency. In the reference situation all vehicles use standard technology and are normally fuel efficient. Improved technology or increased fuel efficiency can be imposed by regulation.

The basis for the computation of emission factors are ExternE (1997) emission factors. Adaptation to values for standard and improved emission technology for 2005 is based on Auto-Oil I data (EC 1995). The improved emission technology contains, amongst others, heated catalysts, double wall exhaust pipes, De-NOx catalysts, further improvement of electronic engine control and of fuel preparation and injection. These techniques are able to reduce emissions by some 40% at a cost between 225 and 824 ECU per car. This is an engineering type of cost estimate.

The normal fuel efficiency (called NF) in 2005 is the result of technological progress. The average fuel consumption for cars is expected to be of the order of 7.5 l of gasoline (6.5 l of diesel). There have been proposals by the European Commission to impose minimum fuel efficiency for 2005 of 5 litre/100km for gasoline cars and 4.5 litre/100km for diesel cars. We call this case the improved fuel efficiency case (IF). This improvement is implemented proportionally for all types of cars. The increased investment cost of this fuel efficiency improvement has been estimated at 19.5% for petrol cars and at 17% for diesel cars (Proost, 1997). The estimate is of an indirect nature as it is based on the assumption of efficiency on the car market.

Values for increased fuel efficiency are derived from the values for standard technology and normal fuel efficiency, assuming proportionality between fuel consumption and emissions. This has been a point of discussion in the literature (see Khazzoom (1995) and Harrington (1997)). In a static model where we compare two cars of average age and with proper maintenance, proportionality is a reasonable assumption. Disaggregation to car types and other conditions (time of day, occupancy rate) builds on results from VIA (1995). Detail on the computation of emission factors and the complete set of emission factors as used in the model are in appendix 1.

Table 1 Average emission factors (gram/km; kg/km for CO2) for petrol and diesel cars, with standard emission technology (ST) and normal fuel efficiency (NF), improved emission technology (IM) and increased fuel efficiency (IF)

	NOx	CO2	VOC	CO	PM	SOx
Petrol, NF, ST	0.128	0.217	0.192	2.041	0.008	0.027
Petrol, IF, ST	0.082	0.140	0.123	1.314	0.005	0.017
Petrol, NF, IM	0.074	0.217	0.112	1.604	0.008	0.027
Diesel, NF, ST	0.356	0.179	0.140	0.598	0.087	0.140
Diesel, IF, ST	0.309	0.155	0.121	0.518	0.076	0.121
Diesel, NF, IM	0.274	0.179	0.122	0.498	0.067	0.140

Damage is measured in money terms by attaching damage estimates to emissions (table 2). These figures are taken from ExternE (1997). The values take into account the impacts of air pollution on human health, materials, crops, ecosystems and global warming. For global warming the highest ExternE estimate has been used.

Table 2 Damage Estimates (ECU/gram, CO2: ECU/kg)

NOx	CO2	VOC	PM	CO	SOx
0.0073	0.0252	0.00078	0.347	0.0000027	0.0113

Less information was available to compute emission factors and damage for public transport. A direct estimate of the per passengerkilometre cost of air pollution for buses was derived from ExternE. This results in our model to a per passengerkilometre air pollution cost of 0.025 ECU for buses and trams (aggregated into one mode in the Brussels application), and 0.005 ECU for underground.

The results of table 2 can be compared with recent estimates by Delucchi (1998). Overall they seem to be in the same range, except for CO2. For CO2 we represent world damage estimates while Delucchi concentrates on damages in the US. The Small and Kazimi (1995) estimates do not include CO2-damage, and obtain estimates that are somewhat higher.

4.2 Other external costs[5]

4.2.1 Marginal external congestion costs

Marginal external congestion costs are endogenous to the model. A speed-flow function relates average speed on the network to aggregate traffic flow. The functional form is based on simulations with a network model. Kirwan et al. (1995) concludes that the following form is most suited for an aggregated model like TRENEN.

$$t_{i,j} = 60/s_{i,j} = \delta_j (\alpha + \beta \exp(\chi q_i))$$

Minutes t needed to drive one kilometre by mode j (car, bus, tram) in period i (peak, offpeak) depend on the number of equivalent passenger car unit vehicle kilometre per hour in that period (q_i). The conversion from vehicle kilometre per hour to equivalent passenger car unit vehicle kilometre per hour is done assuming that busses and trucks count for two passenger car units, i.e. they contribute twice as much to congestion as passenger cars. Parameters α, β and χ are determined by calibration: observations on speeds and flows for the given case study are combined with the general functional form.

The speed of bus and tram modes is proportional to that of cars. The proportion is expressed by parameter δ. To arrive at the total time cost of buses, trams and metro, walking and waiting time is added to travel time. Waiting time depends on traffic demand, reflecting the fact that public transport frequencies are higher when demand is higher (see Mohring (1972)).

The speed flow function allows computing the time loss caused to other road users by an additional passenger car unit. Conversion to money costs is done using estimates of monetary valuations of travel time savings or losses. Using the method and information from HCG (1990), Bradley (1990), Bradley and Gunn (1991), Stratec (1992), MVA Consultancy (1987), the value of a marginal time saving in passenger transport in Brussels in 2005 is estimated to be 7.7 ECU/hour for peak period private transport, 7.3 ECU/hour for peak period public transport, 5.4 ECU/hour for offpeak private transport, and 5.7 ECU/hour for offpeak public transport.

4.2.2 Marginal external accident costs

The marginal external accident cost is the difference between marginal social and average private accident cost. These two cost types and their relation to total traffic volume need to be determined. There is an ongoing debate in the literature on these issues. For the model, estimates from Mayeres, Ochelen and Proost (1996) are updated and brought in line with more recent information from ExternE (1997) and Peirson (1998).

The marginal social accident cost is the derivative of total accident cost with respect to traffic volume. This equals the own accident risk of the vehicle plus the costs of increased accident risks for other traffic participants. With respect to the relation between accident risks and traffic volume, it is assumed that the risk does not depend on traffic flows (see recent evidence

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[5] This section is mainly based on Mayeres (1997).

by Peirson (1998)). This implies that marginal external accident costs in the model are not differentiated between peak and offpeak.

The average private accident cost includes the insurance premium, road users' own utility loss due to the accident risk, and road users' relatives and friends utility loss. The extent to which net output losses, ambulance costs and medical costs are parts of the average private accident costs depends on the type of insurance. In Belgium, these costs are covered by the premium for car passengers, but not for car drivers.

The resulting estimates of marginal external accident costs are (ECU/vkm, for Brussels in 2005):

Car	0.033
Bus	0.023
Tram	0.026
Metro	0.003

4.2.3 Marginal external noise costs

Institut Bruxellois pour la Gestion de l'Environnement (1995) presents functions relating the noise level in a street to traffic levels. The noise propagation mechanism implies that marginal noise damage is a decreasing function of traffic volume. This information is converted to an average city wide noise function (see Mayeres, Ochelen, Proost (1996)).

The money value of marginal contributions of vehicles to noise is determined with a hedonic housing market method. This boils down to an econometric estimate of the impact of noise on the value of a house. The result is a value of 0.6 ECU of noise cost per decibel per kilometre stretch of road.

5. The reference case: Brussels 2005

The geographical area covered by the case study is the zone within the outer ringroad of Brussels. This area nearly coincides with the administrative boundaries of the Brussels Capital Region. Moreover, available data (Région de Bruxelles-Capitale (1993)) show that magnitudes of transport flows and average speeds clearly differ between the areas within and outside the ring. One public transport operator services the area.

Trips per average workday within the area by inhabitants (0.94 million, average trip length 4km) and commuters (0.65 million, average trip length 5.5km) are taken into account. The majority of trips (52% for inhabitants, 72% for commuters) takes place during peak hours (morning peak from 7 am to 9 am and evening peak from 16 pm to 19 pm). Average driving speed for passenger cars is 23km/h in peak hours and 49km/h in offpeak hours.

The most straightforward way to draw attention to the main inefficiencies of the current urban transport equilibrium is to examine the external costs of the different types of vehicles and to compare them with the current tax levels. Currently the main tax instrument used is fuel taxes.

As can be seen in table 4, the sum of the external costs far exceeds the tax level and this is a source of inefficiency. Marginal external congestion costs in peak hours are by far the most important type of external costs.

Table 4 Level and Structure of Marginal External Costs and of taxes of car use, reference

situation Brussels 2005 (ECU/vkm)

	Petrol		Diesel	
	Peak	Offpeak	Peak	Offpeak
Air poll.	0.004	0.004	0.042	0.026
Accidents	0.033	0.033	0.033	0.033
Noise	0.002	0.008	0.002	0.008
Congestion	1.856	0.003	1.856	0.003
Total	*1.895*	*0.047*	*1.932*	*0.068*
Tax	0.12	0.11	0.08	0.07

Inspection of table 4 also tells that the marginal external air pollution cost of diesel cars is 10 times as high as that of gasoline cars. This is due to the higher emissions of highly damaging particulate matter by diesel vehicles. Busses and trams have on average a lower external air pollution cost per passenger (0.025 ECU/pkm) than diesel cars.
The relative magnitudes of the external costs in table 4 will strongly influence the efficiency of different policy instruments. All instruments that improve the congestion externalities will have a larger effectiveness in welfare terms. The total welfare effect of air pollution and fuel efficiency policies will depend strongly on their side effects on congestion.

A second source of inefficiency is that the majority of passenger car drivers in the reference situation do not pay for parking space at the trip destination in the city centre. The share of ‘nonpayers’ for parking is estimated at 70%. Given that the share of parking resource costs in the total per kilometre resource cost equals approximately 47% for inhabitants and 27% for commuters, the impact of free parking on transport demand and its modal distribution is important (Calthrop et al. (1998)).

6. The effects of alternative policies

This section assesses the impact of policy instruments on the urban transport situation in general and on the level of atmospheric pollution in particular. We discuss first the effect of regulations on emission technology (section 6.1) and the effect of imposing improved fuel efficiency for cars (section 6.2). In this same section we also discuss the effect of higher fuel taxes. Section 6.3 briefly presents three transport approaches to the reduction of urban transport inefficiencies: full external cost pricing, cordon pricing, and parking charges. These policies address the main inefficiencies, mentioned in section 5, directly, while they also influence atmospheric pollution. In section 6.4 the different policies are compared.

6.1 Air quality policy

The impact of improved emission technology on emission levels can be read from table 1 and table A.1.2. Emission reductions are obtained for NOx, VOC and CO. Emissions of CO2 and of SOx do not change; those of PM are unaffected for petrol cars while they decrease for diesel cars. The changes in emission levels per kilometre are the result of a number of specific improvements to engine and exhaust technology, which will not be discussed here (see EC (1995), 8-9). These improvements come at a cost, ranging from 225 ECU to 824 ECU per car, the precise figure depending on car size and fuel type (EC (1995)). Conversion to a per kilometre cost increase for the purposes of the TRENEN model gives per kilometre capital cost increases of 0.0027 ECU for a large petrol car, 0.0024 ECU for a small petrol car, 0.0029 ECU for a large diesel car and 0.0027 ECU for a small diesel car.

In the analysis of the welfare impact of imposing the use of improved emission technology through regulation, two assumptions were made on the way the extra vehicle cost is financed. First we assume that consumers bear the capital cost increase (scenario 1). The per kilometre vehicle consumer price is increased with the resource cost of the improved technology.

In a second scenario we require the government to pay for the improved technology by lowering existing taxes on vehicles such that consumer prices remain the same (scenario 2). This could happen when the government puts a large weight on the reduction of transport related air pollution but has insufficient political power to make the users pay directly.

Table 5 summarises the main effects of these scenarios and compares them with the reference situation. Imposing the improved technology through regulation on all the vehicles does not yield net welfare gains. Note that in scenario 2 the welfare loss is somewhat larger due to the reduction in transport tax revenue. The transport tax revenue is valued more than the consumer surplus because of the assumption that it is used to reduce existing labour taxes (a tax shifting operation).

The results should be interpreted with care. First, improved technology was imposed on all types of vehicles. Probably only imposing enhanced technology for diesel cars would bring a small net benefit. Secondly, as the costs of improved technology are probably increasing with the degree of abatement, it could be that smaller improvements are worthwhile. Finally, the air pollution damage estimates are only relevant for a medium sized city like Brussels. In more densely populated areas, improved emission technologies could still be useful.

6.2 Fuel efficiency policy

6.2.1 Construction of the scenario

The objective is to analyse two scenarios: one in which passenger cars are made more fuel efficient via regulation and one policy where the same level of fuel efficiency is reached through increased fuel taxes. The fuel efficiency in 2005 in the reference case is the result of normal technological progress. In the two fuel efficiency scenarios, the fuel consumption decreases from 7.5 litre/100km to 5 litre/100 km for gasoline cars and from 6.5 litre to 4.5 litre for diesel cars.

In the second fuel tax scenario we use a fuel tax increase of 1.02 ECU/litre for gasoline and of 1.26 ECU/litre for diesel. These increases are necessary to make the supply of more fuel efficient cars (5 litre per 100 km and 4.5 litre per 100 km respectively for petrol and diesel) interesting for producers and consumers of cars.

Table 5 Main Components of Welfare (changes with respect to reference)

	1 Improved Emission Technology	**2** Improved Emission Technology
	Consumer paid	Government paid
Levels *		
Welfare (mio ECU/day)	-0.003	-0.013
Cons. Surplus (total, mio ECU/day)	-0.008	-0.015
Total tax revenue	-0.001	-0.023
External costs excluding congestion (mio ECU/day)	-0.005	-0.004
Tax revenue private transport (mio ECU/day)	-0.001	-0.022
Air pollution costs (mio ECU/day)	-0.006	-0.006
% Change w.r.t. reference		
Welfare	-0.005	-0.023
Cons. Surplus	-0.015	-0.028
Total tax revenue	-0.047	-0.822
External costs excluding congestion	-1.126	-0.970
Tax revenue private transport	-0.259	-4.322
Air pollution costs	-4.763	-4.771

* The change in welfare equals the change in consumer surplus minus the change in external costs (other than congestion) plus 0.06 times the change in total tax revenue.

6.2.2 Results

We compare 2 alternative scenarios with the reference equilibrium:

- A : regulated increase of fuel efficiency (increased fuel efficiency, reference fuel prices)
- B : tax induced increase of fuel efficiency (leading to the same increased fuel efficiency)

Note that in all these scenarios cars are equipped with standard emission technology. Also, all other market conditions are unchanged with respect to the reference scenario.

Table 6 summarises the impact of these scenarios on the main welfare aggregates. It is clear that increased fuel efficiency has a positive impact on non-congestion externalities (pollution, accidents, noise). They decrease by 5% in scenario A. External costs of air pollution diminish by nearly 13%. The overall welfare impact of a fuel efficiency regulation is negative however. The fuel tax scenario, on the contrary, has a positive effect on pollution levels and on overall welfare. To explain this result, we need to look at welfare components. It will become clear that the welfare improvement due to reduced pollution is more than compensated by reductions of other welfare components.

A minimum fuel efficiency regulation comes down to obliging the economy to invest in more expensive cars that save fuel. This fuel is already heavily taxed in Europe so that a fuel efficiency regulation has important losses of tax revenue as side effect. This loss has two components: there is the direct effect of consuming less taxed fuel per kilometre and there is the indirect effect of reduced car use. The latter effect is relatively less important. The losses of tax revenue have to be seen as a welfare loss to society. The savings in fuel of more fuel efficient cars should thus be measured at the price before tax.

Summarising we have:

- On the cost side an investment in fuel efficient cars. The marginal cost of this fuel efficiency improvement will be high because high taxes on fuel have already depleted the cheapest fuel saving options.
- On the benefit side a decrease of fuel resource costs (measured before tax, i.e. approximately 1/3 of consumer prices) plus a decrease of air pollution costs plus a decrease of other externalities. The decrease in other externalities, in particular of congestion, will be limited because there is only a small net rise of the user cost of car use and because the user cost increases in peak as well as in off peak periods.

In the fuel tax scenario, we also give the consumers a wrong incentive in the sense that they start investing in saving highly taxed fuel so that they overestimate the benefits of fuel savings. At the same time however we make car use much more expensive. This has important positive side effects on congestion certainly in peak periods. This can be seen in the consumer surplus term that does almost not decrease: the direct reduction in purchasing power due to the higher fuel taxes are almost completely compensated by decreased time losses due to congestion.

Regulation of fuel efficiency leads to an important decrease in the level of air pollution costs. Overall welfare decreases however. Foregone tax revenue from fuel taxes is the main cause of this loss.

6.3 Transport policies

In the *full external cost pricing* scenario, taxes are set such that all initial inefficiencies are alleviated. The main inefficiencies are that drivers do not pay for marginal costs of congestion, pollution, accidents and noise, and that a majority of drivers do not pay for the resource cost of parking. The optimal consumer prices will reflect marginal external costs and marginal resource costs perfectly. In addition, tax levels are partly determined by the marginal cost of public funds. This will lead to taxes above marginal external costs.

Full external cost pricing is not a feasible policy option at present. The results of this scenario should be seen as a benchmark, defining the maximal welfare gains that could be achieved through a perfectly efficient urban transport market.

Table 6 Main Components of Welfare (absolute values and changes with respect to reference)

	A Increased fuel efficiency	**B** Increased fuel efficiency
	Reference fuel price	Increased fuel price
Levels *		
Welfare (mio ECU/day)	-0.120	0.038
Cons. Surplus (total, mio ECU/day)	-0.136	-0.006
Total tax revenue	-0.073	0.210
External costs excluding congestion (mio ECU/day)	-0.021	-0.030
Tax revenue private transport (mio ECU/day)	-0.069	0.199
Air pollution costs (mio ECU/day)	-0.016	-0.016
% Change w.r.t. reference		
Welfare	-0.219	0.069
Cons. Surplus	-0.248	-0.011
Total tax revenue	-2.571	7.420
External costs excluding congestion	-4.802	-6.906
Tax revenue private transport	-13.507	39.015
Air pollution costs	-12.70	-12.71

* The change in welfare equals the change in consumer surplus minus the change in external costs (other than congestion) plus 0.06 times the change in total tax revenue.

The *cordon pricing* scenario reflects the situation where all commuters driving to the city centre pay an optimal congestion fee. Since the cordon is placed around the city centre, trips within the city centre are not charged. Cordon pricing is a realistic policy option: the technology required to charge drivers automatically when a cordon is passed is available and the cost of this technology is not prohibitive.

The instrument is not perfect: only trips passing the cordon are charged, inefficient parking charges remain in place, taxes are not adapted to environmental characteristics of cars, and public transport prices do not change.

It was shown in section 5 that, besides congestion externalities, imperfect parking charges are the main cause of inefficiency in the current transport situation in Brussels. We will analyse the impact of abolishing free parking. Whereas in the reference situation only 30% of all drivers pays for the resource cost of parking in the city centre, it is assumed that all drivers will incur this cost under *improved parking charges*.

Table 7 summarises the main effects of these three types of transport policy. The maximal welfare gain with respect to the reference situation is 1.3%, which is equivalent to approximately 90 ECU per capita on a yearly basis. Part of the gain derives from an important decrease in the damage from air pollution, accidents and noise. This damage decreases by 13.4%, or by 7.5 ECU per year per capita. Damage from air pollution diminishes with 12%, that of noise with 5%, and external accident costs decrease by 20%. Cordon pricing brings slightly more than half of the maximal attainable welfare gain. The decrease in the level of non-congestion external costs is lower, relatively. Charging all drivers for the resource cost of parking improves welfare by 0.42%, which is close to 1/3 of the maximal possible gain. The impact of cordon pricing on air pollution costs is small, as compared to the total welfare gain attained by this policy.

It should be noted that these transport policies require strong pricing measures. In the full external cost pricing, taxes on car use in the peak are increased by ca. 480%. Generalised prices increase by ca. 55%. In the cordon pricing scenario, the optimal increase of the user costs of a car in the peak is even higher because only the commuters can be taxed. In the "paying for parking" scenario, the non payers face an increase of users costs for car use of some 60%.

Table 7 Main effects of transport policies

	welfare gain (in Mio ECU/ day)	Traffic level index (passenger-kilometre)	change in external costs excluding congestion (mio ECU/day)	Change in air pollution costs (mio ECU/day)
Reference situation	0	100	0	0
Full external cost pricing	+0.703 (*100%*)	91	-0.058	-0.015
Cordon pricing	+0.368 (*52.3%*)	98	-0.018	-0.001
Parking charges	+0.231 (32.5%)	98	-0.019	-0.005

6.4 Policy comparison: global welfare impact and impact on non-congestion externalities

Table 8 shows that of the three groups of policies (transport, emission technology, fuel efficiency), the transport policies produce by far the best welfare results. This is due to the fact that they address directly the two most important sources of inefficiencies (excessive congestion in peak) and non-paid parking without negative side effects on the other sources of externalities. These policies are efficient because they use the price mechanism in a focussed way: via tolls in the peak period and by making car drivers pay for their parking place. A good index to measure the effect on congestion is the speed in the peak period. In the reference equilibrium this was reduced to 23 km/h. with our transport policies this speed could be increased significantly. As noted earlier, implementing these measures may be politically difficult, as they require huge increases in user costs for cars. Of course these conclusions hold only for the three transport policies that have been discussed here because one can find many examples of welfare reducing transport policies.

It is striking that the policy of full external cost pricing is also among the best to reduce the external air pollution costs. This need not always be the case. Given the structure of the external air pollution costs, the best policy is a policy that reduces the use of diesel cars and non-pooled cars in general. This is done in this scenario where the use of diesel cars is reduced by ca 22% (against 10% for petrol cars).

Table 8 Comparison of policy types: impact on welfare and on non-congestion external costs

	Change in Welfare (mio ECU/day)	Change in ext. air poll. Cost (mio ECU/day)	total passenger car units per day (index)	speed of cars in peak
Reference			100	23
Full ext. cost pricing	+0.703 (100%)	-0.015	78	40
Cordon pricing	+0.368 (52%)	-0.001	89	33
Parking charges	+0.231 (32%)	-0.005	95	26
Improved Emission Technology (consumer paid)	-0.003 (-0%)	-0.006	100	23
Improved Emission Technology (gov’t paid)	-0.013(-0%)	-0.006	100	23
Improved Fuel efficiency (regulation)	-0.120 (-17%)	-0.016	98	24
Improved Fuel efficiency (via fuel tax)	+0.038 (+5%)	-0.016	95	26

When we consider the two other types of policies, one observes that the policy that uses the tax instrument (fuel efficiency) or makes car users pay for the investment (emission technology) gives better results than when the government foregoes tax revenues. The principal reason for this is the large external costs in the reference equilibrium for car transport. Any policy that increases tax levels on car use will then perform better than a policy that makes car use even less expensive (government paid improved emission technology).

One may wonder why the improved emission technologies perform rather poorly in terms of air pollution reduction. There are two reasons. A first reason is that the foreseen technical improvements address pollutants like VOC, NOx and CO but to a much smaller extent the more damaging particles. The second reason is that after the introduction of the pre-heated three way catalytic converter, one has probably reached the zone of increasing marginal abatement costs.

In comparing the effects of pricing (transport) policies and regulation (air quality) policies in table 10, one has to bear in mind that the results of pricing measures give gross benefits while these for regulation measures are net benefits. In the latter, the cost of the policy change in terms of resource costs is taken into account (not any other cost aspects, e.g. administration and enforcement costs of the regulation). The situation is different for pricing measures. First, cost estimates of the various pricing measures are hard to come by. The estimates that are available suggest that automated congestion toll mechanisms yield substantial net benefits (see, for example, MVA Consultancy 1995)). Second, there is no theoretical reason why all pricing policies – even if costless to implement – would yield welfare gains.

The welfare outcomes of these exercises depend, amongst others, on the weights given to the different welfare components. Damage from air pollution, accidents and noise has the same weight as consumer and producer surplus. Tax revenues receive a higher weight, because it is assumed that extra transport tax revenue is used to decrease labour taxes, such that the overall degree of tax distortion in the economy is decreased. The weights used in this paper are normative, in the sense that distributional issues are absent: the objective is efficiency. Modelling experiments suggest that efficient pricing can be distributionally neutral, if combined with appropriate revenue redistribution mechanisms.

The results also depend on the quality of the data. We are reasonably confident with respect to the price, tax, resource cost and quantity data used for the reference equilibrium. Cost estimates for improved emission technology and for increased fuel efficiency are, almost by definition, more uncertain. If the resource cost of fuel efficiency improvement is much lower than estimated here, then fuel efficiency regulation might be beneficial. If this were the case, however, the regulation would probably be superfluous, because producers would have incentives to provide vehicles at as low a user cost as possible given available technology. Strengthening of this incentive structure is probably a more useful policy, also from a dynamic point of view, than introducing regulations. This is the fundamental message from the fuel efficiency exercise in this paper.

7. Conclusions

We have compared welfare changes and air pollution reductions achieved by various types of urban transport policy, by regulation of emission technology and by regulation of fuel efficiency.

The general findings are that:

- Regulation policies on emissions or on fuel efficiency do not cause large shifts in total travel by private vehicles. These policies may achieve substantial reduction of urban air pollution, but their effectiveness does not depend on reduction of automobile travel. Congestion externalities are hardly affected by environmental policies.
- Regulation policies for emissions may also have reached the zone of increasing marginal abatement costs and this can make them less effective in welfare terms.
- Transport policies do cause large shifts in modal and time distribution of urban traffic. Through the impact on traffic demand, these policies have important beneficial environmental effects as well.
- The comparison of transport policies and air pollution regulation measures confirms that large welfare gains will be obtained through policies which focus on the dominant inefficiences in current urban transport markets (congestion, provision of free parking space).

There are many caveats in this analysis. One of the important limitations is that it has been limited to only one urban area while many policy measures can only be taken on a more global scale. Their assessment therefore requires an analysis using the same methodology and applied to a representative sample of European urban and non urban areas.

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Appendix 1 Detail on computation of emission factors for standard cars, cars with improved emission technology and cars with improved fuel efficiency

TRENEN can distinguish between two types of passenger car technology. We have defined cars with standard and improved emission technology for the exercise in section 6.1. For section 6.2, cars with normal and increased fuel efficiency were introduced. This fuel efficiency is for cars with standard emission technology. We can not distinguish according to emission technology and fuel efficiency simultaneously.

The emissions for passenger cars with *standard emission technology and improved emission technology* were calculated as follows:

- From ExternE (1997) we take emissions per vehicle kilometre for the newer cars in the 1996 car stock. For petrol cars, EURO2 cars were used, for diesel cars, the 90'ies diesel was taken. Table 1 gives the ExternE values. Interregional values are for the Stuttgart-Mannheim drive, urban values for Stuttgart conditions.

Table A.1.1 ExternE emissions for urban and interregional passenger car traffic, g/vkm (CO2: kg/vkm)

		NOx	CO2	VOC	CO	PM	SO2
Interregional	Petrol	0.24	153.4	0.044	0.609	0.005	0.013
	Diesel	0.478	120.3	0.049	0.293	0.055	0.117
Urban	Petrol	0.22	191.6	0.252	2.65	0.009	0.018
	diesel	0.587	137.8	0.138	0.83	0.084	0.15

Source: External costs of transport in ExternE, technical final report, 1997, 71

- Conversion to 2005 emissions was done by applying Auto-Oil I scenarios on emission reductions to the ExternE values for 1996. TRENEN URBAN distinguishes standard and improved technology for 2005. Standard technology is assumed to coincide with Auto-Oil Scenario II, improved technology with Scenario III. Auto-Oil I provides estimates of the extra cost of both types of technology. Table 2 gives the emission reductions used.

Table A.1.2 Auto-Oil I emission reductions for 1996 2010

		NOx	CO2	VOC	CO	PM	SO2
Scenario II	Petrol	40%	-	40%	30%	0	-
	Diesel	35%	-	20%	40%	35%	-
Scenario III	Petrol	65%	-	65%	45%	0	-
	diesel	30%	-	30%	50%	50%	-

Source: EC doc II/576/95-EN, 8

- The average urban and interregional emission factors are adapted to the different TRENEN case studies by using ExternE (1997, 102) ratio's for different cities and regions.
- The resulting emissions still need to be adapted to the TRENEN model structure. Disaggregation to large and small cars, to occupancy rate and to peak-offpeak traffic is based on the VIA ratios for these criteria. These VIA ratios were derived from the VIA deliverables to the TRENEN I project. This finally results in the values of table A.1.3.

Table A.1.3 Emissions of Standard and Improved Emission Technology Passenger Cars (gram/vkm, CO2: kg/vkm)

	NOX	CO2	VOC	CO	PM	SOX
PK.AL.GS.SM.ST	0.108	0.199	0.1702	2.0035	0.0078	0.027
PK.AL.GS.BG.ST	0.152	0.268	0.2397	2.9173	0.0078	0.027
OF.AL.GS.SM.ST	0.0961	0.169	0.1385	1.2388	0.0078	0.027
OF.AL.GS.BG.ST	0.1332	0.208	0.195	1.8084	0.0078	0.027
PK.PO.GS.SM.ST	0.1193	0.214	0.1819	2.1045	0.0078	0.027
PK.PO.GS.BG.ST	0.1658	0.281	0.2542	3.0389	0.0078	0.027
OF.PO.GS.SM.ST	0.1043	0.179	0.1469	1.3013	0.0078	0.027
OF.PO.GS.BG.ST	0.1421	0.218	0.2057	1.9114	0.0078	0.027
PK.AL.GS.SM.IM	0.0629	0.199	0.0989	1.5758	0.0078	0.027
PK.AL.GS.BG.IM	0.0887	0.268	0.1402	2.2991	0.0078	0.027
OF.AL.GS.SM.IM	0.056	0.169	0.0808	0.9741	0.0078	.027
OF.AL.GS.BG.IM	0.0776	0.208	0.1138	1.423	0.0078	0.027
PK.PO.GS.SM.IM	0.0696	0.214	0.1055	1.6522	0.0078	0.027
PK.PO.GS.BG.IM	0.0967	0.281	0.1484	2.3876	0.0078	0.027
OF.PO.GS.SM.IM	0.0609	0.179	0.0857	1.0219	0.0078	0.027
OF.PO.GS.BG.IM	0.0829	0.218	0.1204	1.4994	0.0078	0.027
PK.AL.DI.SM.ST	0.311	0.179	0.1165	0.4311	0.0809	0.1391
PK.AL.DI.BG.ST	0.4983	0.221	0.2486	0.8752	0.1324	0.1733
OF.AL.DI.SM.ST	0.243	0.131	0.0699	0.3396	0.0503	0.1016
OF.AL.DI.BG.ST	0.3528	0.166	0.1243	0.7315	0.0772	0.1294
PK.PO.DI.SM.ST	0.3188	0.189	0.1165	0.4441	0.0834	0.1476
PK.PO.DI.BG.ST	0.5122	0.234	0.2486	0.8752	0.1361	0.1829
OF.PO.DI.SM.ST	0.2491	0.138	0.0699	0.3657	0.0576	0.1080
OF.PO.DI.BG.ST	0.3637	0.176	0.1243	0.7184	0.0809	0.1380
PK.AL.DI.SM.IM	0.2393	0.179	0.102	0.498	0.0625	0.1391
PK.AL.DI.BG.IM	0.3833	0.221	0.2175	0.498	0.1022	0.1733
OF.AL.DI.SM.IM	0.1869	0.131	0.0612	0.498	0.0388	0.1016
OF.AL.DI.BG.IM	0.2714	0.166	0.1088	0.498	0.0596	0.1294
PK.PO.DI.SM.IM	0.2452	0.189	0.102	0.498	0.0634	0.1476
PK.PO.DI.BG.IM	0.394	0.234	0.2175	0.498	0.1041	0.1829
OF.PO.DI.SM.IM	0.1916	0.138	0.0612	0.498	0.0445	0.1080
OF.PO.DI.BG.IM	0.2797	0.176	0.1088	0.498	0.0625	0.1380

Legend
PK peak period, OF offpeak period
AL occupancy rate 1, PO occupancy rate 2.5
GS petrol car, DI diesel car
SM small car, BG large car
ST standard 2005 technology, IM improved emission technology

- Valuations were derived from ExternE results. For CO2, the maximum of the ExternE range was used.

Computation of emissions from passenger cars with *increased fuel efficiency* starts from emission factors for cars with standard emission technology, and assumes a direct proportional link between fuel consumption and emissions. Table A.1.4. shows fuel consumption for both fuel efficiency levels, table A.1.5. gives emission factors.

Table A.1.4 Fuel Consumption for old and new cars (litre/100km, for Brussels 2005)

	Unregulated		Regulated	
	Petrol	Diesel	Petrol	Diesel
Peak, occ.1, small	7.118	5.167	4.583	4.480
Peak, occ.1, large	9.602	6.421	6.182	5.567
Peak, occ.2.5, small	7.692	5.472	4.952	4.745
Peak, occ.2.5, large	10.040	6.774	6.464	5.874
Offpeak, occ.1, small	6.052	3.766	3.896	3.265
Offpeak, occ.1, large	7.438	4.818	4.789	4.178
Offpeak, occ.2.5, small	6.394	3.987	4.117	3.457
Offpeak, occ.2.5, large	7.793	5.114	5.017	4.434
Average	7.766	5.190	5.000	4.500

Table A.1.5 Emissions of Normal and Increased Fuel Efficiency Passenger Cars (gram/vkm, CO2: kg/vkm)

	NOX	CO2	VOC	CO	PM	SOX	
PK.AL.GS.SM.NF	0.108	0.199	0.1702	2.0035	0.0078	0.027	
PK.AL.GS.BG.NF	0.152	0.268	0.2397	2.9173	0.0078	0.027	
OF.AL.GS.SM.NF	0.0961	0.169	0.1385	1.2388	0.0078	0.027	
OF.AL.GS.BG.NF	0.1332	0.208	0.195	1.8084	0.0078	0.027	
PK.PO.GS.SM.NF	0.1193	0.214	0.1819	2.1045	0.0078	0.027	
PK.PO.GS.BG.NF	0.1658	0.281	0.2542	3.0389	0.0078	0.027	
OF.PO.GS.SM.NF	0.1043	0.179	0.1469	1.3013	0.0078	0.027	
OF.PO.GS.BG.NF	0.1421	0.218	0.2057	1.9114	0.0078	0.027	
PK.AL.GS.SM.IF	0.0696	0.1282	0.1096	1.2903	0.005	0.0174	
PK.AL.GS.BG.IF		0.0979	0.1726	0.1544	1.8787	0.005	0.0174
OF.AL.GS.SM.IF	0.0619	0.1088	0.0892	0.7978	0.005	0.0174	
OF.AL.GS.BG.IF		0.0858	0.1340	0.1256	1.1646	0.005	0.0174
PK.PO.GS.SM.IF		0.0768	0.1378	0.1171	1.3553	0.005	0.0174
PK.PO.GS.BG.IF	0.1068	0.1810	0.1637	1.9571	0.005	0.0174	
OF.PO.GS.SM.IF		0.0672	0.1153	0.0946	0.8380	0.005	0.0174
OF.PO.GS.BG.IF	0.0915	0.1404	0.1325	1.2309	0.005	0.0174	

PK.AL.DI.SM.NF	0.311	0.179	0.1165	0.4311	0.0809	0.1391
PK.AL.DI.BG.NF	0.4983	0.221	0.2486	0.8752	0.1324	0.1733
OF.AL.DI.SM.NF	0.243	0.131	0.0699	0.3396	0.0503	0.1016
OF.AL.DI.BG.NF	0.3528	0.166	0.1243	0.7315	0.0772	0.1294
PK.PO.DI.SM.NF	0.3188	0.189	0.1165	0.4441	0.0834	0.1476
PK.PO.DI.BG.NF	0.5122	0.234	0.2486	0.8752	0.1361	0.1829
OF.PO.DI.SM.NF	0.2491	0.138	0.0699	0.3657	0.0576	0.1080
OF.PO.DI.BG.NF	0.3637	0.176	0.1243	0.7184	0.0809	0.1380
PK.AL.DI.SM.IF	0.2696	0.1552	0.1010	0.3738	0.0701	0.1206
PK.AL.DI.BG.IF	0.4320	0.1916	0.2155	0.7588	0.1148	0.1503
OF.AL.DI.SM.IF	0.2107	0.1136	0.0606	0.2944	0.0436	0.0881
OF.AL.DI.BG.IF	0.3059	0.1439	0.1078	0.6342	0.0669	0.1122
PK.PO.DI.SM.IF	0.2764	0.1639	0.1010	0.3850	0.0723	0.1280
PK.PO.DI.BG.IF	0.4441	0.2029	0.2155	0.7588	0.1180	0.1586
OF.PO.DI.SM.IF	0.2160	0.1196	0.0606	0.3171	0.0499	0.0936
OF.PO.DI.BG.IF	0.3153	0.1526	0.1078	0.6229	0.0701	0.1196

Legend PK peak period, OF offpeak period
AL occupancy rate 1, PO occupancy rate 2.5
GS petrol car, DI diesel car
SM small car, BG large car
NF normal fuel efficiency, IF improved fuel efficiency