

Final Report for Publication

TRENEN II STRAN

ST 96 SC 116

Project Coordinator:

Stef Proost, Kurt Van Dender, Centre for Economic Studies,
Katholieke Universiteit, Leuven, Belgium

Partners:

SESO, University of Antwerp, Belgium (B. De Borger)

CERTE, University of Kent at Canterbury, England
(R. Vickerman, J. Peirson)

Trinity College Dublin, Ireland (M. O'Mahony)

Vrije Universiteit Amsterdam, Netherlands
(J. van den Bergh, E. Verhoef)

TREC, Italy (R. Roson)

National Technical University of Athens, Greece (P. Kapros)

Project Duration:

15/04/1996 – 15/04/1998

July 1999

PROJECT FUNDED BY THE EUROPEAN
COMMISSION UNDER THE TRANSPORT
RTD PROGRAMME OF THE
4th FRAMEWORK PROGRAMME

Table of Contents

TABLE OF CONTENTS	2
PARTNERSHIP.....	4
EXECUTIVE SUMMARY	5
1. Urban Case Studies	7
2. Interregional Model.....	16
3. Performance and Optimal Use of Different Policy Instruments	20
4. Caveats and Directions for Future Research.....	21
OBJECTIVES OF THE PROJECT	22
SCIENTIFIC AND TECHNICAL DESCRIPTION	23
CHAPTER 1: AN INTUITIVE APPROACH TO THE TRENEN-MODEL	24
1. DIAGRAMMATICAL APPROACH	24
2. THE MODEL FLOW CHART.....	31
3. THE DIFFERENT TRENEN-MODELS.....	34
CHAPTER 2: A MATHEMATICAL DESCRIPTION OF THE TRENEN-MODEL	35
1. REPRESENTATION OF DEMAND AND SUPPLY	36
2. REPRESENTATION OF CONGESTION AND THE OTHER EXTERNALITIES	37
3. COMPUTATION OF THE MARKET EQUILIBRIUM	37
4. THE MAXIMUM AS A POLICY OPTIMISED MARKET EQUILIBRIUM	39
5. ECONOMIES OF DENSITY IN PUBLIC TRANSPORT	42
6. THE MARGINAL COST OF PUBLIC FUNDS.....	43
7. NON IDENTICAL INDIVIDUALS	44
8. CONSTRAINTS ON POLICY INSTRUMENTS	45
9. EXPLICIT NETWORK REPRESENTATION INSTEAD OF ONE LINK REPRESENTATION.....	45
10. THE USE OF THE MODEL FOR COMPARATIVE STATICS.....	45
CHAPTER 3: TRENEN II INTERREGIONAL: THEORY AND IMPLEMENTATION	46
1. TRANSPORT POLICIES IN A FEDERAL SYSTEM: A STRATEGY FOR ANALYSIS.....	46
2. STRUCTURE OF THE NUMERICAL OPTIMISATION MODEL	47
2.1. Structure of the demand side of the transport market	49
2.2. Structure of the supply side of the transport market	51
2.3. Externalities taken into account.....	52
3. SCENARIOS IN THE INTERREGIONAL MODEL	52
CHAPTER 4: OPERATIONALISATION OF THE MODEL CONCEPTS.....	55
1. DEMAND REPRESENTATION	55
2. SUPPLY REPRESENTATION.....	56
3. THE CONGESTION FUNCTION	59
4. THE MARGINAL COSTS OF PUBLIC FUNDS	59
4.1. The TRENEN approach in a general equilibrium context.....	59
4.2. Including the MCPF in the TRENEN approach.....	62
4.3. Empirical implementation of MCPF.....	63
5. SOFTWARE IMPLEMENTATION.....	64

CHAPTER 5: EXTERNAL COSTS OF TRANSPORT	66
1. THE MARGINAL EXTERNAL CONGESTION COSTS	66
2. THE MARGINAL EXTERNAL AIR POLLUTION COSTS	68
2.1. The marginal external air pollution costs of all transport modes except urban public transport	69
2.2. The marginal external air pollution costs of urban public transport	74
3. THE MARGINAL EXTERNAL ACCIDENT COSTS	74
4. THE MARGINAL EXTERNAL NOISE COSTS	78
4.1. Noise function	78
4.2. Monetary valuation	79
4.3. Results	80
5. THE MARGINAL EXTERNAL ROAD DAMAGE COSTS	81
CHAPTER 6: CASE-STUDIES	82
1. INTRODUCTION	82
2. URBAN CASE-STUDIES	83
3. INTERREGIONAL CASE-STUDIES	92
4. PERFORMANCE AND OPTIMAL USE OF DIFFERENT POLICY INSTRUMENTS	98
5. IMPLEMENTATION OF NEW PRICING POLICIES	99
5.1. Reliability of results	99
5.2. Implementation costs of road pricing	99
5.3. Use of congestion tax revenues	100
5.4. Who decides best on new prices ?	101
5.5. Safety and pollution policies	101
REFERENCES	103
ANNEX 1: LIST OF SYMBOLS	106
CHAPTER 1	106
CHAPTER 2	106
CHAPTER 3	107
CHAPTER 4	107
CHAPTER 5	108

Partnership

The TRENEN II STRAN Consortium consisted of:

Stef Proost (coordinator), Kurt Van Dender, Sara Ochelen, Edward Calthrop
Centre for Economic Studies, Katholieke Universiteit Leuven
Naamsestraat 69
3000 Leuven
Belgium
+ 32 16 32 68 01 (Stef Proost)
+ 32 16 32 66 55 (Kurt Van Dender)
+ 32 16 32 67 96 (fax)

Bruno De Borger, Christophe Courcelle, Didier Swysen
SESO, Universiteit Antwerpen
Prinsstraat 13
2000 Antwerpen
Belgium
+ 32 3 220 40 57 (Bruno De Borger)
+ 32 3 220 40 26 (fax)

Margaret O'Mahony, E. Gibbons, Q. Heaney
Trinity College Dublin
Dublin 2
Ireland
+ 353 1 677 30 72 (fax)

Pantelis Kapros, Stavroula Kavatza
National Technical University of Athens
Patisson42
106 82 Athens
Greece
+ 301 0384 37 22 (fax)

Roberto Roson
TREC
San Marco 3870
30124 Venezia
Italy
+ 39 41 257 83 65 (fax)

Roger Vickerman, John Peirson, Duncan Sharp
CERTe, Keynes College, University of Kent at Canterbury
Canterbury CT2 7NP
UK
+ 44 1 227 82 34 95 (Roger Vickerman)
+ 44 1 337 82 33 28 (John Peirson)
+ 44 1 227 82 77 84 (fax)

Jeroen van den Bergh, Erik Verhoef
Economic and Social Institute, Vrije Universiteit Amsterdam
De Boelelaan 1105
1081 HV Amsterdam
Netherlands
+ 31 20 444 60 97 (Jeroen van den Bergh)
+ 31 20 444 60 05 (fax)

EXECUTIVE SUMMARY

Objectives

The objective of the TRENEN II STRAN project is the development of strategic models for the assessment of pricing reform in transportation, and their application to the European Union. The strategic models are designed to analyse two types of policy problems. The first problem is to measure the gap between present and efficient prices across all modes. What prices are too low and what prices are too high compared to their marginal social cost? The second problem is to measure the potential of different types of pricing instruments to improve the pricing of transport. What can higher fuel excises achieve? Are parking charges and road tolls the best ways to make user prices correspond to marginal social costs? The answers go beyond theoretical principles. They take into account behavioural reactions, infrastructure capacity and interactions between modes. They integrate all external costs and they give information on the direction of pricing reform.

Model development

Two sets of models are developed: one for URBAN areas and one for INTERREGIONAL (or non-urban) transport. Both models use the same methodology. They represent the transport problem of a given zone as an equilibrium of a set of interrelated transport markets. One market corresponds to the use of a given type of vehicle (e.g., small gasoline car driven alone) at a particular period (peak or off peak) in that zone. Typically between 20 and 30 transport markets are distinguished for each zone. The equilibrium price on each market is expressed as a generalised cost (resource cost + tax + time cost). Using generalised costs as central price concept allows to study modal interactions resulting from changes in money prices and from changes in speed or quality of service.

Present taxes may or may not cover the marginal external costs (congestion, air pollution, accidents, noise and road maintenance). The main aim of pricing reforms is to adjust transport taxes in order to cover better the marginal external costs. In this way all transport users, when deciding on their mode of travel, will take into account all costs to society. This is more than an accounting exercise and requires a model for two reasons. First, all modes interact and some of the external costs (congestion) depend on the volume of traffic itself. This means that optimal taxes require an equilibrium computation including all modes simultaneously. Second, pricing instruments are in general imperfect and this

requires the trading off of welfare effects of too high or too low prices on different transport markets.

A final important element in the study of transport pricing reforms is the use of the transport tax revenues. The welfare effect of any change in revenues from the transport sector will crucially depend on the use of this revenue in other sectors. In the TRENEN models, the changes in the transport tax revenue are returned to the households. Their possible efficiency enhancing effect when used to reduce other taxes can be taken into account via a cost of public funds parameter.

The emphasis in the urban and interregional models is different. The urban models concentrate on urban modes (including walking and cycling), make a distinction between inhabitants and commuters and integrate parking costs and cordon tolling. The interregional models have tolled (highways) and untolled roads. An important part of the non-urban model is devoted to the freight transport modes. Moreover it can be used in a two country version where countries compete for tax revenue from international freight transport.

The models are used in 6 urban case studies and in 3 interregional case studies. Compared to existing detailed transport network simulation tools, the TRENEN models are very simple. The zone that is studied is assumed to be homogeneous so that its network capacity can be aggregated into one speed-flow relationship. Transport infrastructure capacity (road and tracks) is taken as given. Transport behaviour is represented by a nested CES utility function. Moreover, the model is static and takes infrastructure as given. The model computes counterfactual equilibria for the transport market. No adjustment path is given. The main advantages are the multi-modal character, the integration of passenger and freight transport, the representation of all relevant externalities and the capacity to compute welfare optimising values for the available policy instruments. This allows an economically consistent comparison of second best policy options. Experienced transport economists can implement and calibrate the model using a minimum of available data and resources. In contrast to most transport pricing case studies, all TRENEN case studies use a common approach for the measurement of internal and external costs and benefits. This is a prerequisite for an analysis of policy proposals at the EU level.

In the next sections, we summarise the main findings of the case studies. Each case study consists of two parts. First there is an analysis of a reference equilibrium that corresponds to the expected situation for 2005 with unchanged pricing policies. This analysis is the result of calibrating a TRENEN model to the observed transport price and volume data in a given zone. Next, the calibrated model is used to test several common scenarios of pricing reform. These common scenarios include cordon pricing in urban areas and tolls on

motorways, resource cost pricing of parking and regulation of emission characteristics of vehicles. For the analysis of the pricing reform scenarios, two benchmarks are used: the reference scenario with unchanged policies and the optimal pricing scenario where perfect pricing instruments are assumed.

1. Urban Case Studies

Transport demand

Four types of representative consumers are distinguished by two criteria. First, a driver may pay for parking at the trip destination or not, and, second, individuals may be commuters or inhabitants. Each representative urban consumer is given the following 20 or so transport options: they can forego their trip or not, they can travel in peak or off peak, use motorised transport or not, use private transport or transit, opt for solo driving or car pooling, use a small or a large car, use a petrol or a diesel engine. Moreover within transit they may have the choice between bus and rail (underground, light rail, tram).

Price and cost concepts used

For these 20 transport markets, data are collected on resource costs, taxes and external costs in the reference situation. Resource costs plus taxes minus subsidies, and own time costs constitute the *generalised price of transport* that consumers will take into account when making choices.

For private transport the *resource costs* include the per kilometre cost (excluding taxes) of a car, maintenance, fuel and parking. For public transport, a linear cost function is used. There is a fixed cost and two variable costs. The variable cost per transit passenger kilometre in the peak period is based on a fixed occupancy rate and contains the capacity costs of the carriages or busses. In the off peak, the marginal resource cost per passenger kilometre is again based on a fixed but lower occupancy factor and includes only fuel, maintenance and labour costs of drivers. For transit, a Mohring effect is included by making the waiting time (component of generalised price) a function of the frequency of service, that is itself a function of total demand for transit.

Four types of *external costs* are computed for every transport mode. The external congestion cost is represented implicitly in the model via the time component in the generalised price. The estimates of the marginal external air pollution cost are based on EXTERN-E information. These costs include greenhouse gas damage, ozone damage and most other conventional air pollution damage. The noise damage estimates are based on

hedonic price information from the housing market. The external marginal accident costs consist of the average accident costs not covered by insurance payments. An important assumption here is that the average accident risk does not increase when a vehicle is added to the road. Original empirical work for London has shown that the relation between average accident risks and volume of cars can be decreasing as well as increasing. Table 1 gives, as illustration, the external costs in the reference equilibrium for Brussels for diesel and gasoline cars. Note the dominant role of congestion as external cost in the peak period and the important air pollution cost of diesel.

Table 1: Marginal external costs 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
<i>Total</i>	<i>1.895</i>	<i>0.047</i>	<i>1.932</i>	<i>0.068</i>

Inefficient urban transport prices in the reference equilibrium

Table 2 supplies some key characteristics of the case studies for *Amsterdam*, *Athens*, *Brussels*, *Dublin* and *London* for the year 2005¹. Figures 1 and 2 give generalised prices and generalised marginal social costs for the peak and off peak period of a small petrol car driven alone by an inhabitant who does not pay for his parking at destination. The generalised price (left block for every city) includes the resource costs (except parking), taxes and own time costs. The generalised marginal social cost (right block) includes resource costs, parking resource costs, own time costs and marginal external costs. Congestion shows up as an increased time cost per kilometer. Figures 3 and 4 show the same type of information for transit per bus in the peak and the off peak. Subsidised consumer prices (variable costs not covered) appear as negative elements in the consumer price block diagrams. All price and cost information is expressed in ECU per passenger kilometer².

¹ Results for Bologna are not presented here because for that city the transport flows were aggregated for the whole province and the peak and off-peak periods were defined such as to have identical traffic levels. This makes that one of the major externalities is assumed away so that these results are not comparable with the other case studies.

² 1 ECU = 1 EURO = 1,15 US dollar on Jan 4,1999.

Comparison across case studies shows that per kilometre resource costs (vehicle costs, maintenance costs and fuel costs) are quite similar in all cities considered. Parking costs and time costs differ strongly. Parking costs are highest in the most densely populated cities (Athens, London) and in Amsterdam (due to strict parking supply policies). The share of drivers with access to free parking was estimated at 70% for all cities except Amsterdam (30%), where a strict parking policy is implemented in the reference situation (30% non payers). Parking costs are a substantial part of total trip costs in all cities considered. Time costs are the result of transport demand and supply conditions in the reference situation. The road networks (capacity and utilisation) in the different cities differ strongly leading to different average speeds.

Table 2: Characteristics of Case Studies

	Potential Transport users	% inhabitants	% free parking	Peak speed Km/h	Offpeak speed Km/h
Amsterdam	492 192*	70	30	13	35
Athens	4 500 000	89	70	11	25
Brussels	1 585 474	59	70	23	49
Dublin	1 260 000	21	70	19	35
London	7 498 576	89	70	27	33

*actual users

When transport prices are efficient, the consumer price should equal the marginal social cost¹. Figure 1 shows that peak car use covers only one third to half of its full marginal costs. There are two main sources of discrepancies: unpaid parking and important external congestion costs. Unpaid parking² distorts prices in the peak and off peak. Its importance varies across cities: parking costs are much higher in London and Amsterdam than in Brussels and Dublin. The external costs shown in the figures cover congestion, air pollution, accidents and noise.

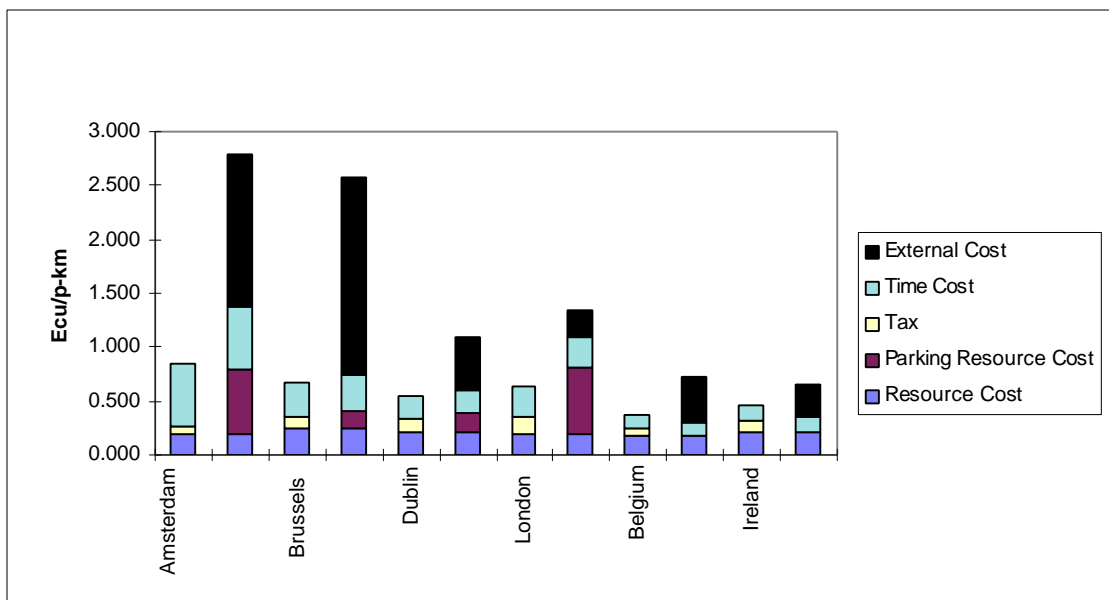
¹ This is the partial equilibrium result when no account is taken of the way in which tax revenues are used. Results from the interregional model follow this approach. In the urban model, it was assumed that tax revenues are used very efficiently, such that optimal transport taxes exceed marginal external costs.

² Unpaid parking is called an unpaid resource cost rather than an external cost. In the case of free parking for shopping and employer provided parking, households do not take this cost into account in their trip decision and mode choice. Ultimately the resource cost of free parking is paid by all households through higher product prices or lower wages.

External congestion costs are high in the peak period and small (except in London) in the offpeak. The estimation of marginal external congestion costs depends crucially on the slope of the aggregate speed-flow relationship. The figures show important differences in marginal congestion costs between urban areas. These can not be explained easily (smaller in London than in other areas)¹. Figure 2 shows that pricing of off peak car use is much more efficient except for the parking resource costs.

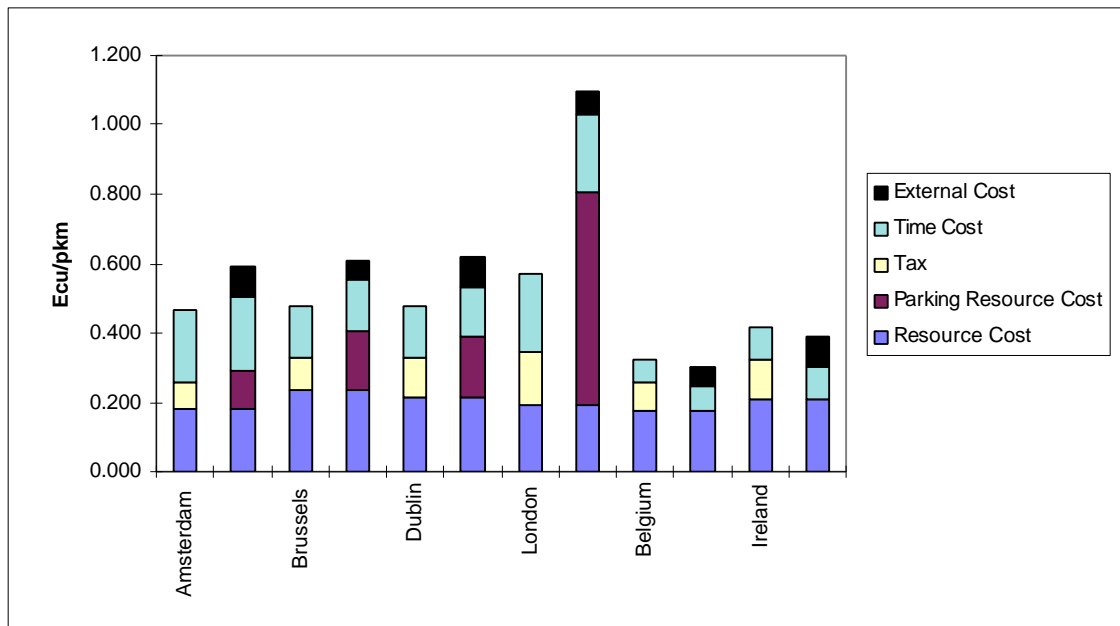
Taxes are more or less equal in peak and off peak periods at present. This shows that structure and level of prevailing transport taxes in European cities are not adequate for an efficient internalisation of marginal external costs.

Figure 1: Peak car reference prices and costs (expected for 2005)



¹ Part of the differences is correlated with the size of the area studied. The London network (Greater London Region) is (a) on a larger scale *and* (b) includes a much higher share of high capacity roads than the Brussels network (Brussels Region *without* principal ringroad). Factor (a) explains the relatively low time cost in London for the peak period. Factors (a) and (b) lead to low marginal external costs in London and high marginal external costs in Brussels and Amsterdam (high marginal external costs may be caused by a large number of transport users, and/or a large sensitivity of travel speed for changes in traffic volume).

Figure 2: Off-peak car reference prices and costs



Figures 3 and 4 show that urban transit (here we confine ourselves to busses) also generates external costs but that prices are for these modes much better in line with social costs. In London, where subsidies for public transport are much lower, prices tend to exceed marginal social costs.

Figure 3: Peak bus reference prices and costs

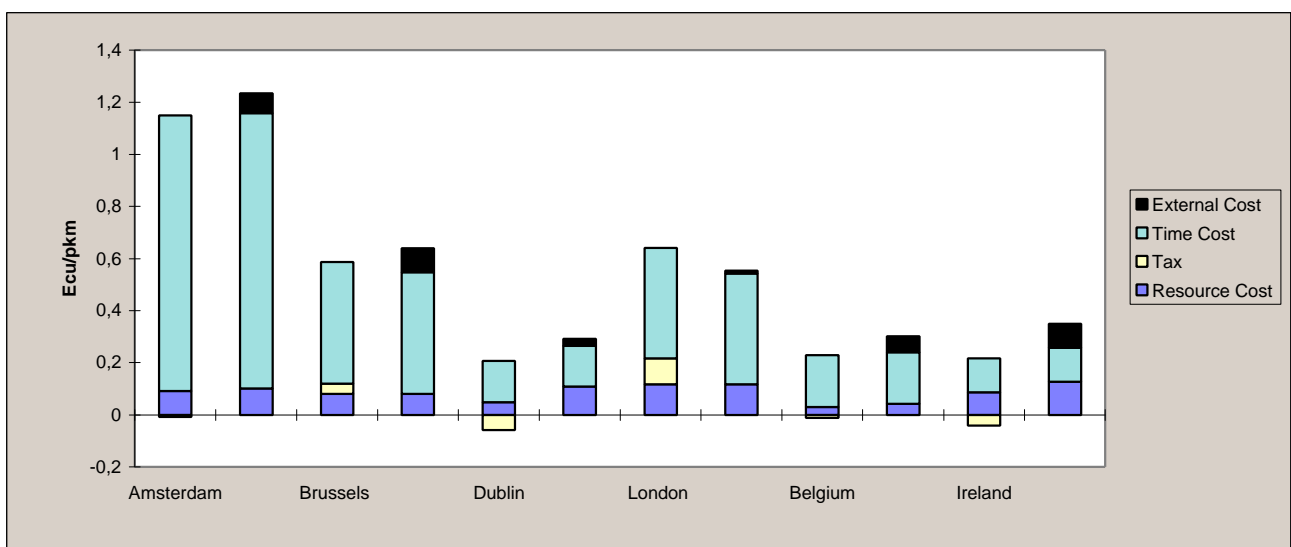
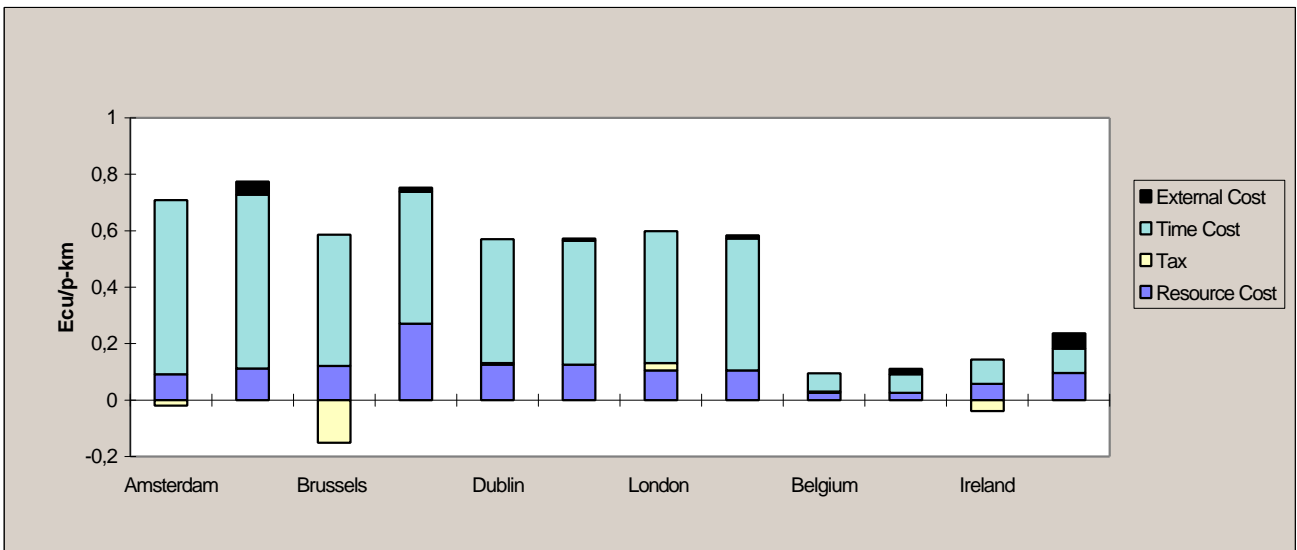


Figure 4: Off peak bus reference prices and costs



Urban transport pricing policies

Table 3 presents the different transport pricing policies that are analysed. Table 4 presents welfare impacts of these alternative transport pricing policies. Welfare summarises the impacts on consumer and producer surplus, on government revenue and on external costs. Welfare is measured in terms of generalised income: money budget plus value of leisure time .

Table 3: Description of common scenarios

scenario	existing taxes and subsidies that are abolished	policy instruments used
Optimal pricing (benchmark)	all abolished	taxes and subsidies can be differentiated by veh km or pass km according to mode, type of vehicle, time of the day
Cordon pricing	all subsidies to public transport except for fixed cost	1 cordon that is optimally differentiated between peak and off peak public transport prices are equal to marginal resource cost
Uniform pricing	fuel taxes	fuel taxes are increased to a common EU level (0.5 ECU/l per gasoline and 0,393 ECU/l of diesel) this implies small increases in most countries except for a larger increase in Greece)
Cordon pricing + parking charges	all subsidies to public transport except for fixed cost subsidies to parking	1 cordon that is optimally differentiated between peak and off peak public transport prices are equal to marginal resource cost
Uniform pricing + parking charges	fuel taxes subsidies to parking	fuel taxes are increased to a common EU level (0.5 ECU/l for diesel), this implies small increases in most countries except for a larger increase in Greece parking charges equal to resource costs
Emission technology regulation for cars (results not shown in table 4)	existing technology regulation for cars	more expensive but cleaner emission technologies reduction of emissions (except CO ₂) of some 50%
Optimised public transport prices (results not shown in table 4)	existing subsidies and taxes on public transport	public transport prices can be fixed optimally in peak and off peak

Table 4: Welfare Impact of Alternative Policy Measures: maximal potential gain (%) and share of maximal gain

	welfare gain as % of generalised income	expressed as % of maximal gain			
	Optimal pricing	Optimal pricing	Cordon pricing	Cordon + parking charges	Uniform pricing
Amsterdam	1.29	100%	18%	76%	3%
Athens	1.70	100%	15%	67%	16%
Brussels	0.89	100%	44%	59%	8%
Dublin	0.48	100%	53%	65%	6%
London	1.04	100%	13%	87%	0%

As can be seen from table 4, large potential welfare gains can be achieved in most cities if theoretically optimal prices can be implemented. This is a benefit estimate before implementation costs. Moreover the estimates assume that the increases in net tax revenue from the transport sector generate a net benefit of 7% by using it to reduce existing distortionary labour taxes.

In the optimal pricing scenario peak car money prices increase strongly (+100% to +250%) to cover resource costs of parking and to cover marginal external costs. Optimal prices are typically somewhat larger than marginal resource costs plus external costs because we assume that revenues can be used to reduce distortionary labour taxes. The marginal external congestion cost that is charged in the optimum is only one third to one half of the external congestion cost measured in the reference equilibrium. *The pricing inefficiencies measured in the reference equilibrium (figures 1 to 4) are therefore an insufficient guide to optimal prices.* Note also that there is no need to discriminate between pooled and non pooled cars. Off peak money car prices increase also (+60% to + 180%) to cover resource costs of parking and the different external costs. Moreover, optimal vehicle use prices are higher for diesel cars because of their higher external health damage costs. Finally it is optimal to impose the use of cleaner vehicles (less conventional emissions) in urban zones, certainly for diesel cars.

The strong increase of car user prices goes together with an important adjustment of the public transport prices. For use of busses in the peak period, optimal prices increase by 23 to 424% as subsidies are now replaced by taxes to cover the variable resource cost and the external costs. For urban rail services price increases are smaller as their external costs are

smaller. Off peak prices for busses increase strongly when there were high subsidies in the reference situation.

The drastic price changes generate only relatively small reductions in the total volume of transport. There are two reasons for this. First, passenger transport is price inelastic. Secondly higher money prices are compensated partly by reduced time costs. The total volume across all modes and measured in passenger kilometre, declines by 7 to 14%. Peak car use declines by 20 to 33% and off peak car use by 8 to 41%. Off peak car use decreases will be particularly high where there is unpriced congestion and unpaid parking.

The optimal volume of peak public bus transport is higher in most cities (up to 34%) except in one city (Dublin) where there are excessive subsidies in the reference. Off peak public transport use increases in the reference. Off peak public transport use increases strongly in some cities (53 to 84%) and decreases in those where subsidies were too high. Volumes of urban rail transport increase everywhere. *For urban areas, the optimal pricing scenario generates an important net increase in tax revenues* (all taxes minus all subsidies to public transport). Households will therefore only experience a net welfare increase when the returned tax revenue is also taken into account. A mix of instruments will be needed to approach this optimal pricing scenario.

One of the obvious policy mixes is to keep all taxes at their present level and add a cordon toll (differentiated between peak and off peak) together with resource pricing for public transport. This is the *cordon pricing scenario* described in table 3 and reported in table 4. The placement of the cordon will determine its effectiveness. The higher the proportion of commuters that are affected by the tolls, the more effective will be the cordon pricing. This is the reason why cordon pricing is rather effective in Brussels and Dublin. The optimal cordon tolls are high: money price increases for commuters in the peak between 90 and 248%. The overall effectiveness of the scenario is limited because the congestion externality can only be corrected for part of the car users. In fact the inhabitants even increase their peak car use because they are attracted by the higher speed. Moreover the free parking problem and the misuse of diesel cars in urban areas is not corrected in this scenario.

Adding to the *cordon pricing scenario* the *pricing of parking at resource cost* improves strongly the overall efficiency. Particularly in those cities where the parking costs are high. This mix of instruments is not yet perfect because the external congestion cost of the inhabitants is not directly addressed. Moreover the external air pollution costs are not minimised.

The *uniform pricing scenario* shows that a small increase of fuel taxes is not effective at all to cope with the different pricing inefficiencies. Of course one could try higher increases,

this could reduce peak traffic levels and off peak traffic levels and reduce the use of diesel cars. This instrument has some effectiveness in urban areas but will at the same time discourage off peak non urban peak car use too much. Moreover it will spur excessive efforts to increase the fuel efficiency of cars. These efforts will be cost-effective for consumers but not for society because the consumer price of fuel exceeds the resource cost plus the marginal air pollution cost of fuel.

Adding parking *resource pricing to the fuel price instrument* improves the efficiency greatly in these cities where unpriced parking is the biggest problem.

With respect to the *regulation of emission technology of cars*, it can be shown that this measure on its own can *maximally* achieves 4.5% of the maximum welfare gain. Detailed analysis of this policy option shows zero or slightly negative welfare effects for Brussels. While it can be interesting to impose stricter emission regulations for cars in large urban areas (certainly for diesel cars), this policy addresses only one of the minor pricing inefficiencies found in urban transport markets.

2. Interregional Model

The interregional model focuses on passenger and freight transport simultaneously. In terms of volume, freight transport can be as important as passenger transport. We discuss first the inefficiencies in passenger transport.

Passenger transport

Interregional passenger transport pricing inefficiencies are in general less important than in the case of urban transport. This becomes clear from inspecting the right hand part of figures 1 to 4 where results for non-urban transport in Belgium and in Ireland are presented. As in the case of urban transport, we focus on the differences between the generalised price and the generalised marginal social cost for two typical modes (small gasoline car and bus) in the peak and off peak period.

Prices of peak period car use do not cover marginal external congestion costs. The congestion cost itself is however smaller than in urban areas. In the off peak period, cars pay slightly more than their marginal social cost. Public transport pricing inefficiencies exist but are less important per kilometre than in urban markets. Non-urban bus transport is heavily subsidised and underpriced in both cases.

Three policy scenarios have been examined for the interregional passenger and freight transport.

Table 5: Definition of common policy scenarios for non-urban zones

scenario	existing taxes subsidies abolished	policy instruments used
Optimal pricing (benchmark)	all abolished	taxes and subsidies can be differentiated by vehkm, passkm or tonkm according to mode of vehicle and time of the day
Congestion pricing	public transport subsidies on variable costs are abolished public transport priced at resource cost	toll differentiated between peak and off peak period on highways (Belgium) and all roads (Ireland)
Uniform pricing	fuel taxes	fuel taxes are increased to a common EU-level (0.5 ECU/l for gasoline and 0.393 ECU/l for diesel), this comes down to small increases in most countries. Additional fee of 1000 ECU/year for trucks and 100 ECU for cars for the use of highways.

Table 6: Welfare Impact of Alternative Policy Measures: maximal potential gain (%) and share of maximal gain

	Potential welfare gain (% of total generalised income)	Optimal Pricing	Congestion Pricing	Uniform Pricing
Belgium	0.80%	100%	83%	8.5%
Ireland	0.29%	100%	59%	-1.2%

In the optimal pricing scenario, the correction of the pricing inefficiencies requires increases in the money-prices for peak car transport of 35 to 45% that lead to volume reductions in the peak of about 10%. Off peak prices have to decrease by 5 to 10%. The maximal welfare gains that can be achieved by better pricing policies are substantial. In the optimal pricing scenario, the overall volume of transport (passkm) does almost not decrease (- 2%). There are however important shifts away from peak car use to off peak car public transport. The volume of off peak transit decreases because the very high subsidies to cover variable costs are abolished in the optimal pricing scenario.

For the non urban zones considered, optimal pricing yields substantial increases in net revenues (taxes-subsidies). The increase is smaller for passenger transport (+25% to +29%) than for freight transport (+233% and more).

In the congestion pricing scenario, the money price of peak car transport is raised by 35 to 40% and this allows to obtain an important part of the welfare gain. In this scenario, public transport is priced at resource cost so that also the inefficient part of the subsidies is corrected.

In the uniform pricing scenario, the price increase is not differentiated between peak and off peak car use so that the welfare effects are at best small.

Freight transport

The existing pricing inefficiencies in freight transport are shown in figures 5,6 and 7. For trucks, the prices are smaller than the marginal social costs in the peak period . The major external cost is again congestion. When subsidies are not excessive, as they are in Ireland, the prices of rail are closer to the marginal social cost. Because external costs of inland waterways are small, prices and marginal social costs are roughly in line with each other.

Figure 5: Peak truck reference prices and costs

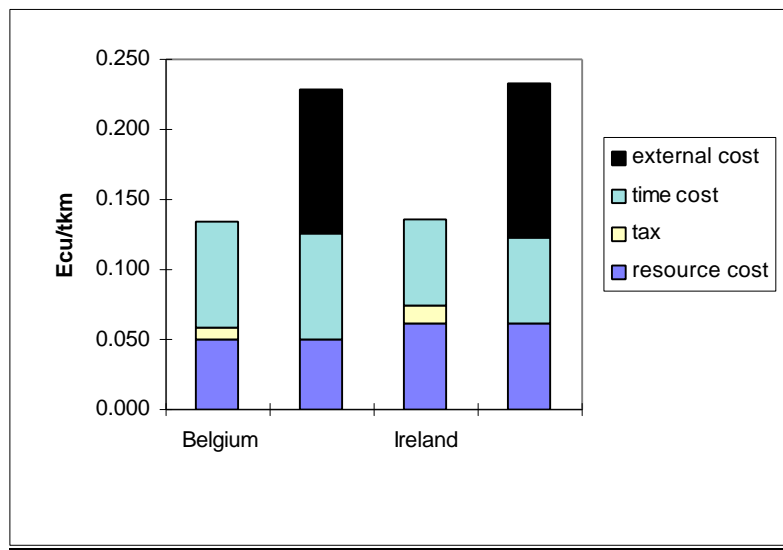


Figure 6: Off-peak truck reference prices and costs

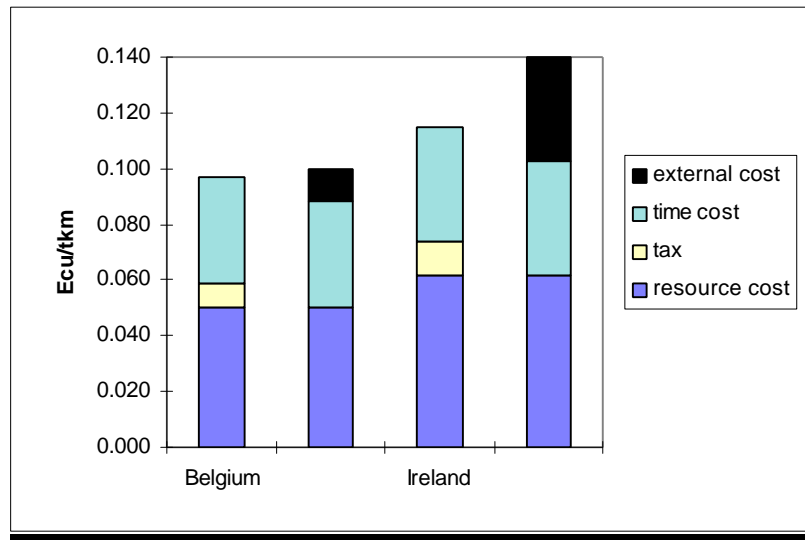
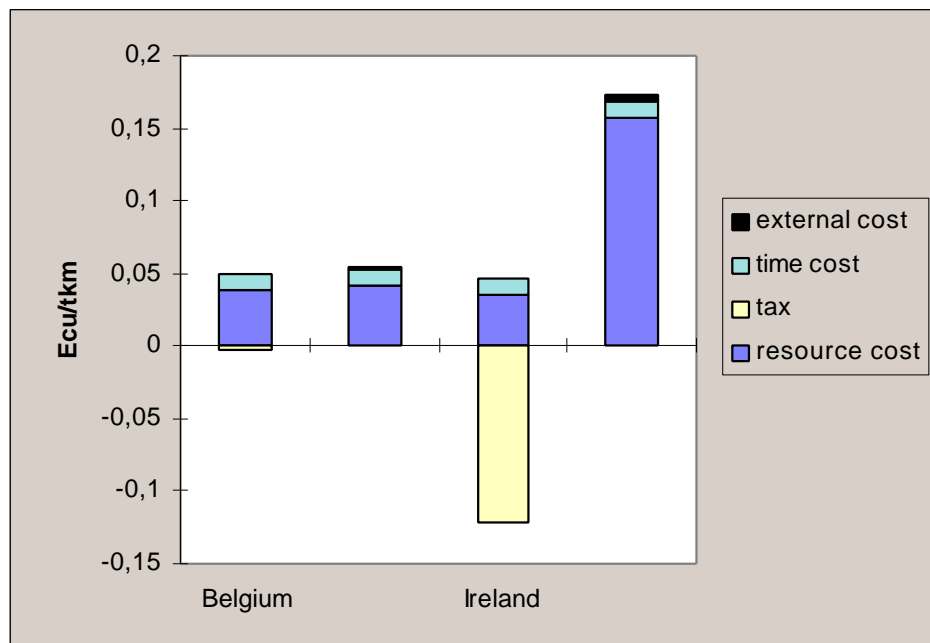


Figure 7: Rail reference prices and costs



Optimal pricing of trucks requires money price increases of 63 (Belgium) to 100% (Ireland). Off peak prices are raised by 7 to 36%. Prices of rail services increase too by 15% (Belgium) to 350% (Ireland). No major price change is required for inland waterways in Belgium. These price changes cause an overall decrease of freight transport volume of 4 (Belgium) to 7% (Ireland). The share of rail decreases and the market share of inland waterways increases in Belgium.

Congestion pricing on motorways can be an effective way to control external congestion costs in interregional transport. Raising fuel prices, even in a harmonised way over Europe is not very efficient because off peak passenger and off peak truck consumer prices are not systematically lower than the marginal social cost.

3. Performance and Optimal Use of Different Policy Instruments

The case studies reported do not cover the whole of the EU and their results depend on the very simple model structure and the many assumptions on resource costs, external costs and transport behaviour. Nevertheless the case studies have allowed to advance some working conclusions on the relative performance of different policy instruments. We start with the effects of the simplest policy instruments, ending with the more sophisticated ones.

- parking policies

Making all road users pay for the resource cost of their parking place plus an extra charge can be a very effective instrument. It corrects the parking inefficiency and reduces at the same time the congestion externality. This achieves between 30% and 65% of all potential welfare gains in urban areas.

- improved car emission technologies

Using taxes or standards to favour the introduction of cleaner cars is an important instrument for urban areas, in particular for limiting the emissions of diesel cars. The investment in cleaner cars is not necessarily justified in non-urban areas. This instrument can be responsible for between 1 and 4% of maximal potential welfare gains.

- fuel tax policies

Higher fuel excises could reduce car traffic in urban areas and in non urban areas in the peak. For this reason, fuel tax instruments can be effective. They also reduce non-urban passenger and freight road transport in the off peak period and this is not necessarily justified. Increased fuel excises are therefore not a good instrument to improve pricing on transport markets. The fuel price instrument is flawed because of two additional problems. First, fuel prices cannot be differentiated strongly between countries without stimulating important tax evasion efforts by international transport. Second, too high fuel excises stimulate the use of excessively fuel efficient cars and trucks, which is another form of inefficient tax evasion. This tax evasion is inefficient because, given present levels of fuel excises, the marginal cost of avoiding fuel consumption has become much higher than the marginal social cost of fuel use.

- reduced subsidies to public transport

Once one can correct the pricing of car transport, it is no longer justified to set tariffs much below the marginal social cost for public transit. Optimal transit prices differ between peak and off peak periods and should cover also the marginal external costs.

- simple congestion pricing

The simplest congestion pricing is cordon pricing in urban areas and congestion pricing on interregional highways. If this can be combined with an elimination of subsidies for variable costs of public transport, important welfare gains are possible. For urban areas these gains vary from 16% to 60% (depending on the location of the cordon) and for interregional transport between 60% and 83% of the potential maximal welfare gains.

4. Caveats and Directions for Future Research

The main contribution of using highly simplified models is to advance a direction of reform that is internally consistent. Of course, using simple models to simulate important changes comes at a cost. Therefore the results need confirmation by application to a larger part of the EU and by verifications with more detailed models and experiments. Network models can provide the necessary spatial disaggregation; dynamic models are well suited to study in more detail the optimal transition to better pricing instruments. Moreover, in the simulation results no account has been taken of the transaction costs of new pricing methods like road pricing and of the enforcement costs of pricing of parking.

The modelling methodology used has allowed us to pay special attention to the use of the transport tax revenues. It has been demonstrated that the way transport tax revenue is used co-determines the optimal tax rates. It is only when the tax revenue can be used for a reduction of existing labour taxes that transport taxes equal to or higher than the marginal external costs can be an optimal policy. When transport taxes are used differently the optimal taxes are lower than the marginal external costs.

Finally, urban and non-urban trips should better not be analysed independently as non-urban trips can have urban destinations and vice-versa.

OBJECTIVES OF THE PROJECT

The objective of the TRENEN II STRAN project has been to

- develop a set of strategic models for transport policy assessment in the field of taxation, pricing and regulation;
- to apply these models in case studies, for analysis of different transport pricing policy proposals with a European dimension.

The objective was reached through the following steps:

- Theoretical development and implementation of the TRENEN II URBAN and TRENEN II INTERREGIONAL models that compute optimal transport taxes. The software tools (TRENEN II URBAN and TRENEN II INTERREGIONAL) were developed on the basis of the TRENEN I results (JOULE programme, 01/94 – 12/95). Both models have been substantially modified and extended.
- Study of transport policy proposals and definition of policy packages for analysis. A policy package is defined as a set of policy instruments.
- Preparation of data inputs for the case study work. Data were constructed for internal and external costs of land transport.
- Model implementation and coordinated case studies for:
 - Non-urban areas in: Belgium, Ireland, Italy
 - Cities: Amsterdam, Athens, Bologna, Brussels, Dublin, London.
- Comparative analysis of the case study results for a number of common policy packages.

Scientific and Technical Description¹

The scientific and technical description of the project starts with an introductory chapter that explains the modelling approach using graphical illustrations, a model flow chart, and an explanation of the different versions of the TRENEN-model. The second chapter explains the mathematical structure of the TRENEN-URBAN model and may be less accessible for non transport economists. Chapter 3 explains the structure of the TRENEN-INTERREGIONAL model. Chapter 4 and 5 discuss the estimation of internal and external costs. Chapter 6 discusses briefly the results of the case studies.

¹

We benefited from useful comments on our deliverables by C. Sikow-Magny and by C. Nash and the other CAPRI-consortium members.

CHAPTER 1: AN INTUITIVE APPROACH TO THE TRENEN-MODEL

Two complementary approaches are used to explain the basic idea underlying the model. The first is based on a demand and supply diagram for one transportation market (section 1), the second on a model flow chart (section 2). In the third section we survey the different model versions that exist as well as their software implementation.

1. Diagrammatical Approach

The transport sector is an important cause of external costs specific to transportation like congestion and accidents, but also of other external costs like air pollution. Those problems are often tackled by piecemeal policies and technologies treating one problem domain at a time. There is a need for integration of these policy actions in a consistent framework. A way to integrate these considerations is to use equilibrium models for the transport market in which external cost aspects are integrated.

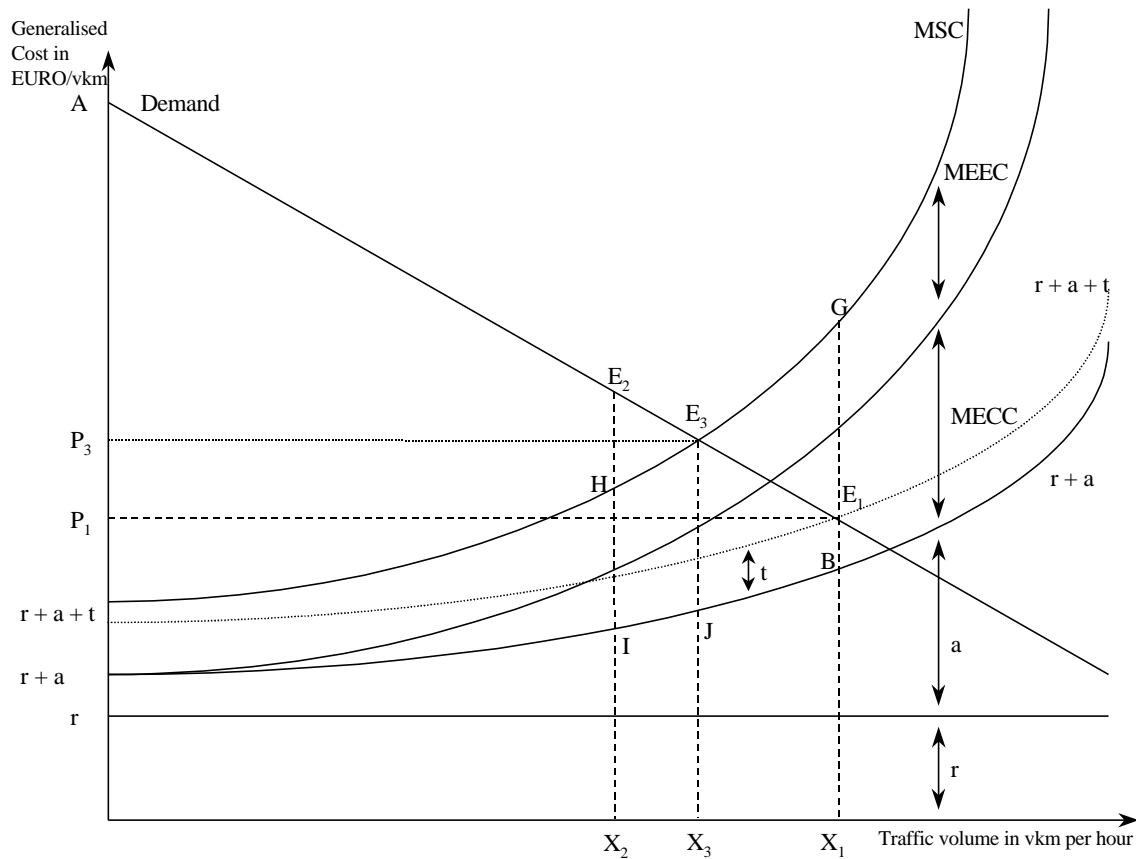
The basic idea of the TRENEN model is to look for the optimal combination of price and regulatory policies in the transport and environment domain via the optimisation of a welfare function. This optimum will be implemented as a market equilibrium with different types of taxes, public transport prices and environmental standards. This can best be illustrated by using a figure with only one transportation market.

Consider the market for car km on a specific road link between two cities as depicted in Figure 1.1. This figure represents the market for car km in one particular period (peak) with one particular type of car (small petrol car with catalytic converter) on a road infrastructure with given capacity.

On the horizontal axis we represent the volume of car use (vehicle kilometre per hour). On the vertical axis we represent the generalised cost of car use. This generalised cost will equal the sum of the money cost (EURO/vehicle kilometre) paid by the car user plus the time cost needed per car kilometre.

The *demand function* expresses the marginal willingness to pay to use a car at each volume of car-kilometres, the surface under the curve is thus a measure of the total benefits of car use: at a very high price only the strictly necessary car km would be demanded - as generalised costs drop, more and more households are ready to use the car for all types of purposes.

Figure 1.1: A transport market



In this market, the equilibrium volume of car use will be determined by the generalised cost of car use. Take any point on the vertical axis, the corresponding volume of car use on the horizontal axis is given by the demand curve: at this level of car use, the marginal willingness to pay of the last car user equals the generalised cost. Obviously, the volume of car use depends on many other elements as there are: prices, speeds and quality of other modes, location, income, composition and social attitudes of the household. In the TRENEN-model approach the effect of prices, speeds and quality of the other modes and of income variations is taken into account by shifts in the demand function. In our graphical example with only one mode, these interactions are not represented but they are present in the model. The location, composition and social attitudes are exogenous in the TRENEN-model approach.

In order to determine the equilibrium volume of car use we need to determine the *generalised private cost of car use*. The generalised private cost of car use consists of three elements: the resource costs, the taxes or subsidies and the average time cost. The resource costs equal the marginal production costs of the different inputs needed to use a car: fuel cost, maintenance cost, tyres and physical vehicle depreciation. It is represented by the line r in Figure 1.1. The average time costs are represented by the curve $r+a$. The average time cost increases when the volume of car use increases due to congestion: speeds drop and all drivers have higher time costs. When we add taxes on car use (aggregate of taxes on fuel, maintenance, registration, etc.) we obtain the *private cost of car use* (dotted line t). In figure 1.1, this means that the equilibrium volume of car use is X_1 and the generalised price equals P_1 . This is the equilibrium we observe.

External costs

There are external costs in this equilibrium. External costs are costs that are generated by a car user and that are not paid by him. The first externality is the marginal external congestion cost. The marginal external congestion cost is the cost of the additional time losses imposed by one extra car user on others.

This cost (MECC in Figure 1.1) is steeply increasing when we reach the capacity of the road network because of two reasons. First, adding one car decreases more and more the speed. Secondly, when there are more cars on the road, the decrease in speed will affect more cars. The marginal external congestion cost in Figure 1.1 corresponds to the increase in slope of the average time cost curve times the volume of car use. It is important to recognise that, although every car user experiences congestion (higher time costs) himself, he does not pay for the time losses caused to other car users (the external part of the congestion costs).

We add a second external cost on top of external congestion costs: this can be air pollution, noise, accidents etc. (distance MEEC in Figure 1.1).

The *total marginal social cost* of car use is now given by the sum of resource costs, average time costs, external congestion costs and other external costs (excluding taxes that are a private cost but no cost at the level of society). This marginal social cost includes all costs of car use. The optimal volume of car use would be reached when the willingness to pay for the car use equals at least this social marginal cost. This means in Figure 1.1 that X^3 is the optimal volume of car use. The corresponding optimal generalised price equals P_3 . This equilibrium can be reached by using an optimal tax E_3J . This tax equals the difference between the marginal social cost and the private cost of car use (before taxes). The welfare gain of implementing this optimal tax equals the area E_3GE_1 : the excess of

social marginal costs over the private value of car transport to the user (given by the demand function).

Computing optimal prices

In the TRENEN-model the objective is to compute optimal prices like the distance E_3J . This is done by starting from a reference point like E_1 and by comparing for this volume the level of the private marginal cost with the social marginal cost. If there is a discrepancy (like GE_1 in Figure 1.1), the model is used to look for the optimal tax E_3J .

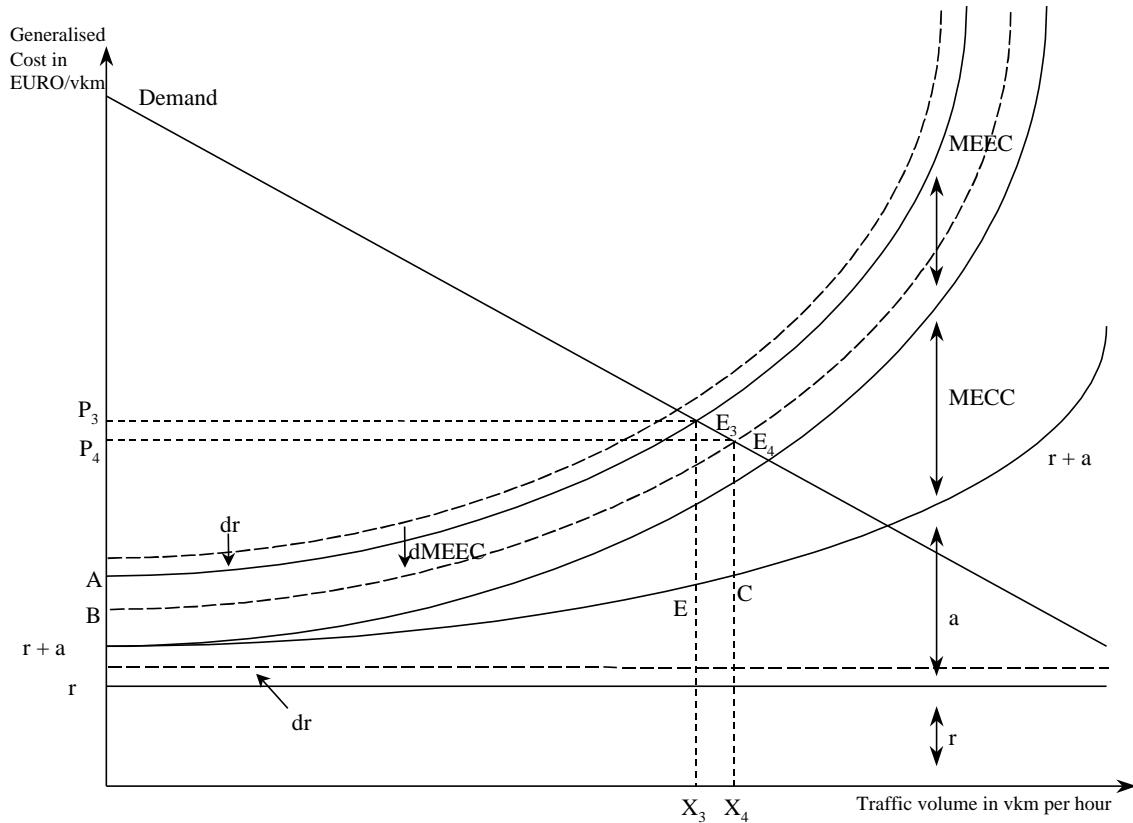
In order to do this the model needs four types of information: the observed volume and composition of private cost in the reference equilibrium, the slope of the demand function, the slope of the private cost function before taxes and finally the magnitude and slope of the marginal external costs.

Computing point E_3 for one market is not difficult and a graphical tool could do the job. In general a model is needed because of three types of complications: the simultaneous choice of emission standards for vehicles, the interaction between different transport modes and the constraints on the choice of policy instruments.

Emission standards and optimal pricing

Externalities as air pollution are mostly addressed via standards and taxes. In our simple model with only one type of cars we can illustrate the interaction of emission standards and pricing policies in Figure 1.2. Assume that we start with an optimal tax per vehicle kilometre and that we are in equilibrium E_3 . In this equilibrium the optimal tax includes a charge equal to the marginal external air pollution cost MEEC. Assume now that there is a choice between a standard car and a clean car. If the tax cannot be tailored easily in function of the emission characteristics of a car, an emission standard can be an interesting policy instrument. An emission standard for cars means, in terms of Figure 1.2, that the resource cost of a car increases (dr) but that this allows a decrease of the external air pollution costs that is larger than the increase in resource costs. This makes the emission standard interesting. It is important to see the interaction between standards and optimal pricing of car use. If a standard is imposed, the optimal tax on car use will change because of two reasons. First the remaining pollution level per car kilometre will decrease. Second, the net effect of the increased resource cost and decreased external pollution cost (and tax) will be a larger volume of car use (larger than X_3) and this means an increase in the external congestion cost component of the tax so as to arrive in E_4 . From this illustration it is clear that there is a need for a simultaneous choice of road-use taxes and emission standards.

Figure 1.2: Interaction of emission standards and pricing policies



Optimal pricing with several modes.

When several modes compete for the same trip, optimal taxes need to be coordinated. The interactions to be taken into account are illustrated in Figure 1.3. We start in Panel A of this figure with a given volume of car use X_1 that is too large: there is an important marginal external congestion cost ($A E_1$). In Panel B we have a rail service where the price equals the marginal variable cost r . The equilibrium is E_2 . We can simulate the effects of a subsidy s to rail in Figure 1.3. The subsidy decreases the price of the rail mode to $r-s$. This will make the demand curve for car use shift to the left (D'): for the same generalised cost of car use there will be less car users because some of them prefer the train. When taxes on the car market remain unchanged (to keep it simple we have assumed no taxes here), the external congestion cost decreases to BE_3 . Because the equilibrium volume of car use decreases to X_3 there will be a decrease of the generalised cost of car use (the average time cost decreases). The decrease in the generalised cost of car use will produce a shift to the left of the demand function of rail use (D'). The ultimate equilibrium is E_3 for

car use and E_4 for rail use.

In order to compute the net welfare gain of this subsidy one needs to balance the welfare loss on the rail market with the welfare gain on the car market. There is an efficiency loss on the rail market because some users now make trips that do not cover the marginal resource cost of rail trips. There is a welfare gain on the peak car market because the number of car trips for which the willingness to pay is lower than the social marginal cost has been reduced. Summing up, a subsidy to public transport can be justified when the peak car use does not pay for its marginal social cost. To determine the optimal second best subsidy on rail or busses one needs information on the cross-price subsidies, on the own price subsidies as well as on the marginal resource cost and the external costs of private and public transport.

Figure 1.4 illustrates another reason why we need to treat several transport markets simultaneously. In Figure 1.4 we illustrate the computation of an optimal tax on car use when peak and off peak car use can not be taxed separately. The optimal tax has to be chosen such as to minimise the total inefficiency loss in the peak period (tax too low; area ABE_3) and in the off-peak period (tax too high; area E_4DC).

The TRENEN-model has been designed to help solving the optimal pricing problems that have been shown in figures 1.1 to 1.4.

Figure 1.3: Interaction of transport modes

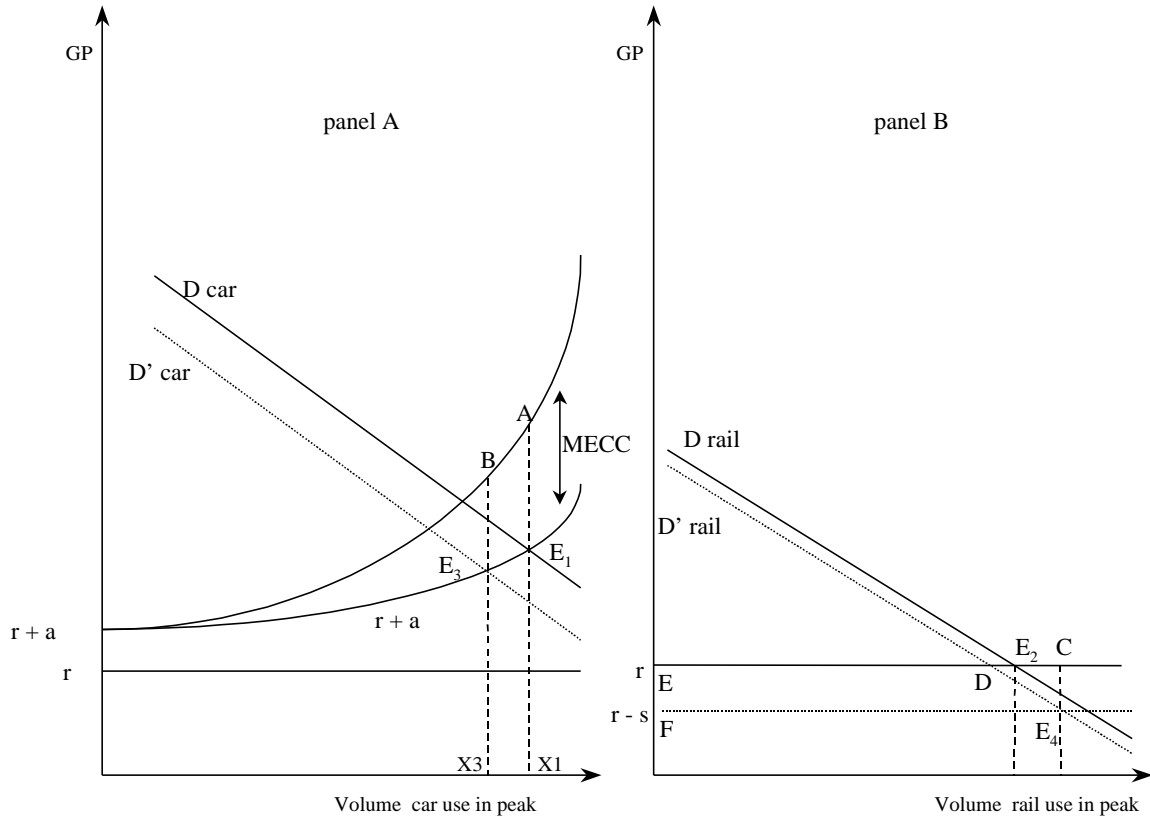
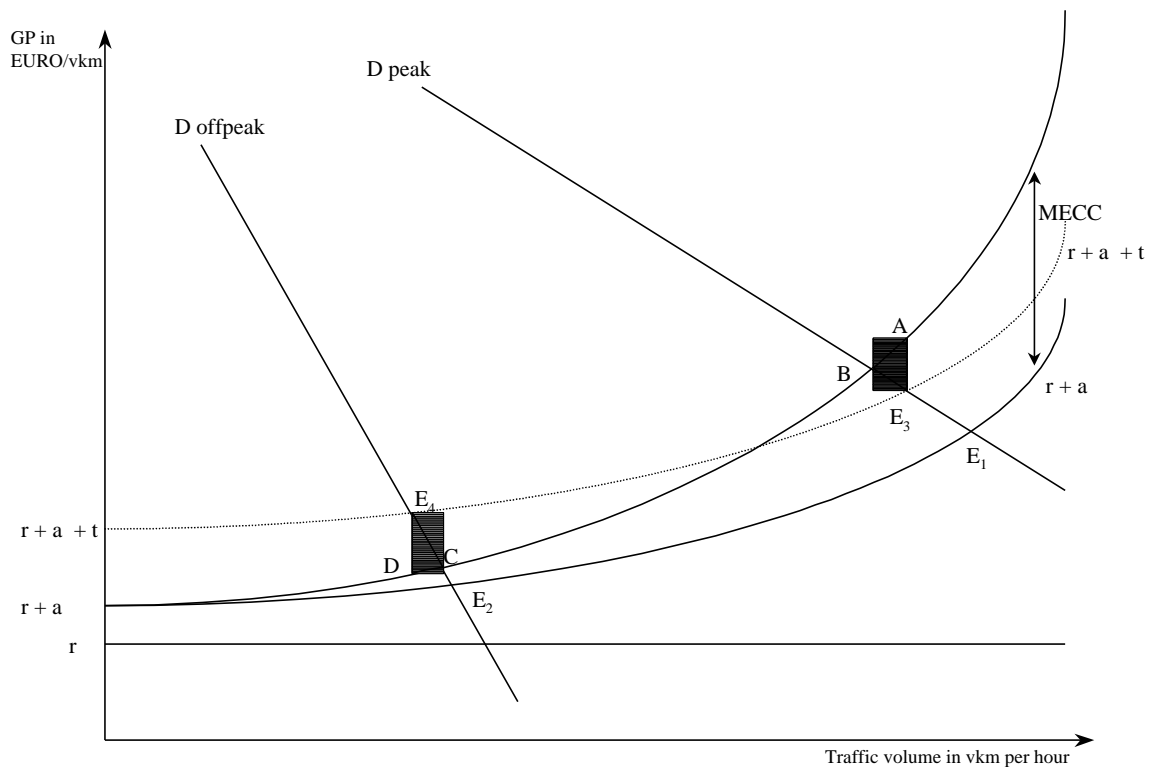


Figure 1.4: Constraints on instruments



2. The Model Flow Chart

Figure 1.5 shows the principal components of the TRENEN model. It contains three parts: a demand part, a supply part and an equilibrium price module.

We start with the *demand part* at the left hand side of Figure 1.5.

A representative household has different transportation options:

- it can vary overall demand for transportation, i.e. choose between transport and other goods in maximising the utility level;
- choose the moment of the day for its travel;
- choose between motorised and non motorised transport ;
- choose between two modes in order to full-fill its transportation needs: private or public mode;
- and more specifically between metro or tram and bus, and on the private side: solo driving or shared driving (car pool);
- if the car mode is chosen, different sizes of vehicles are available;
- and finally there is a choice between several types of fuel, here diesel and petrol.

In the demand part, consumers will choose between alternative types of transportation on the basis of their subjective preferences and on the basis of the relative prices of the different transport alternatives supplied to them. The transport goods consumed will have the dimension vehicle kilometre in a specific type of vehicle (large, small car or public transport).

We can make a similar reasoning for freight transport. A representative producer has in its decisions to produce a given output, the choice between:

- using more freight transport or more other inputs (labour, capital);
- using private or public transport
- using trucks in the peak or off-peak
- etc.

The *supply part of the model* (right hand side of Figure 1.5) represents the activities and choices made by the producers of cars and the suppliers of other inputs like fuels, car maintenance etc. Choices in the supply part of the model will be taken on the basis of maximum profit subject to government regulation on the technology and equipment of vehicles. With perfect competition among the suppliers, the supply will deliver at marginal resource costs plus producer taxes, so in the absence of producer taxes, producer prices will equal the least cost combination of marginal resource costs. If there is no pollution regulation or taxation, suppliers will typically supply vehicle kilometres with dirty cars.

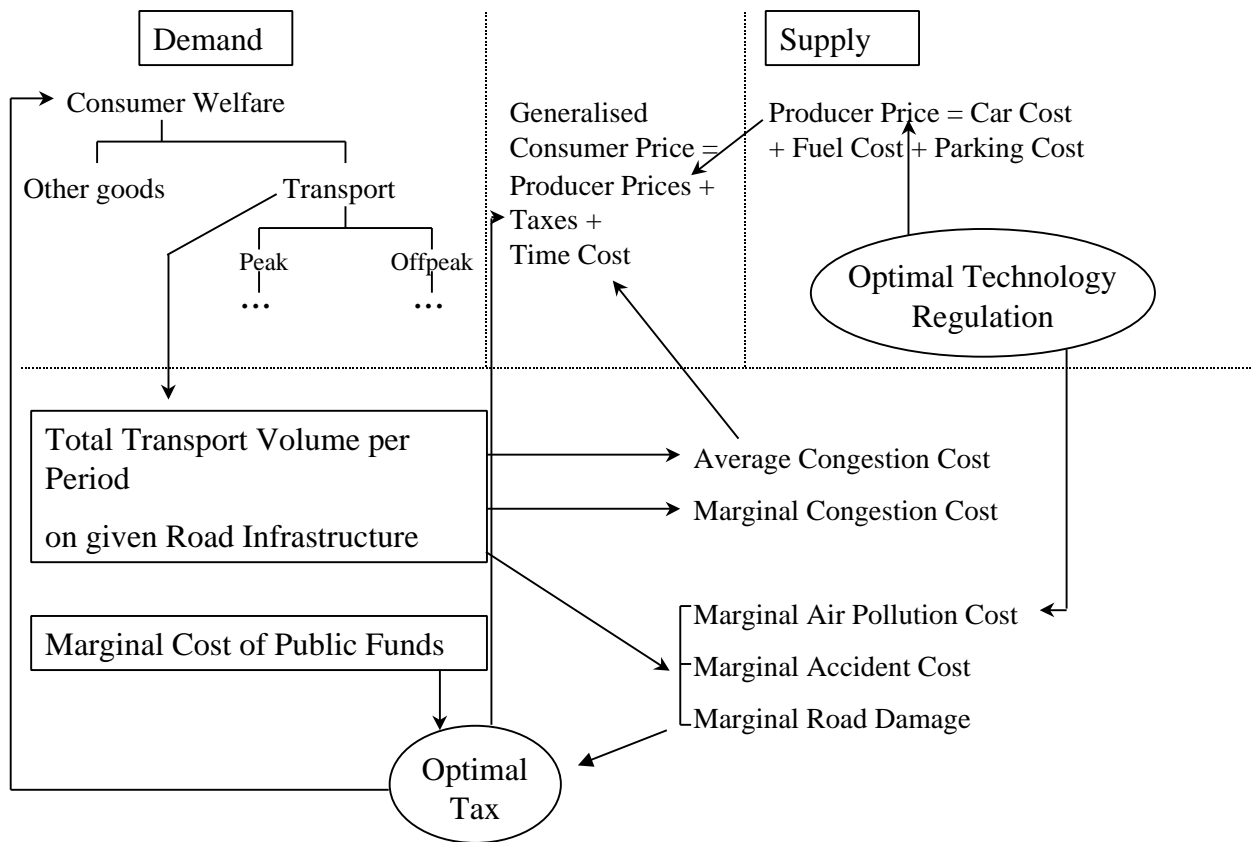
TRENEN is a static model that optimises pricing for a given infrastructure. Therefore the supply of infrastructure is not included in the model.

In the *equilibrium price module* (middle and lower part of Figure 1.5) generalised prices are computed for the different types of transportation modes. The generalised price is 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 that will be a function of the total volume of traffic in equilibrium; this transportation time contains the average congestion cost;
- a tax (or subsidy) that has two functions: to raise tax revenue or subsidise certain modes of transportation and secondly to correct for certain external costs like air pollution, marginal congestion costs etc. This tax is differentiated for the different types of transport goods. The magnitude of the taxes is determined by the marginal cost of public funds (the benefit of raising tax revenue in the transport sector equals the cost of public funds raised in other sectors) and by the level of the marginal external costs.

Besides taxes, the policy maker can also impose certain *environmental regulations* under the form of ad hoc constraints on the supply part of the model: minimum energy efficiency, banning certain types of fuels etc. This will increase the producer price but will decrease the external effects associated to vehicle use.

Figure 1.5: TRENEN-model flow chart



3. The Different TRENEN-models

Several types of TRENEN-models have been developed. They all use the same principles but are adapted to the question one wants to answer:

<p>TRENEN-URBAN:</p> <hr/>	<p><u>focus</u> on representation of passengers transport in urban areas, distinction between commuters and inhabitants and between those who have and so not have not access to free parking.</p> <hr/> <p>Versions: 0. Basic</p> <ol style="list-style-type: none"> 1. Model with two government levels 2. Model with explicit transport network
<p>TRENEN-INTERNATIONAL:</p> <hr/>	<p><u>focus</u> on interregional passenger transport and freight transport, tolled and untolled roads, freight transit transport</p> <hr/> <p>Versions: 0. Basic with one country model</p> <ol style="list-style-type: none"> 1. Two country model where two country governments take each their own policy decisions

Only the basic versions of the 2 TRENEN-models are operational and can be transferred. The other versions are to be considered as research tools.

CHAPTER 2: A MATHEMATICAL DESCRIPTION OF THE TRENEN-MODEL

This section describes a simplified version of the TRENEN-URBAN model. The TRENEN-interregional model has a similar structure. The major differences with the TRENEN-URBAN model will be explained in Chapter 3.

Assume N identical individuals and $i=1,\dots,I$ different passenger transport demand categories (use of bus, small car, large car, etc.). Each mode can be produced by $j=1,\dots,J$ supply technologies (e.g. for i = small car we could have small car without or with catalytic converter ($j=1$ or 2)). Similarly there are $f=1,\dots,F$ different freight transport demand categories, satisfied by J different supply categories. Individual passenger transport demand for a certain type i of transport equals x_i and is satisfied by a total supply of J different car technologies z_{ij} . Freight demand using mode f is denoted x_f and can be satisfied by j technologies (z_{fj})¹. C (element c) denotes the set of consumer goods.

The policy maker maximises the sum of consumer surpluses of passenger and freight transport users, producer surpluses of the suppliers of transport, and the tax revenue weighted by the marginal cost of public funds, minus external costs. Government selects taxes (by setting the consumer and producer prices) for all transport goods and determines, through regulation, the types of transport technologies to be used to satisfy demand for each mode.

This is the traditional formulation for a regulatory problem with perfect information for the policy maker: the policy maker knows the demand functions and the marginal costs of the different supply options, and fixes the equilibrium by setting consumer prices and regulating supply. Tax revenues are returned to the consumers. Tax revenues receive, via the marginal cost of public funds parameter, a larger weight than consumer and producer welfare because it is costly to collect tax revenue. Using a marginal cost of public funds approach is preferable to the use of an absolute budget constraint for the public transport authority because the implicit marginal cost of this constraint is unknown beforehand and can diverge strongly from the cost of collecting public funds on other markets (see LAFFONT and TIROLE (1994)). Moreover the marginal cost of public funds parameter allows to take into account the welfare effects of alternative ways of using the tax revenue.

¹

The notation of indices is as follows: i and k are used to denote the different passenger transport modes, f and g denote the different freight transport modes and l denotes both passenger and freight transport modes. The type of technology is indexed with j .

This is a partial equilibrium approach in the sense that the feedbacks on non-transport markets are neglected. More specifically, prices on other markets, including the price of inputs for transport, are fixed, tax revenue is returned in a lump sum way¹, and the valuation of externalities only depends on changes in the transport market.

1. Representation of Demand and Supply

Demand functions are defined as a function of the generalised price of transport: the cost of transport consists of a money cost (the public transport fare or the expenditures for the use of a car, q_i) and a time cost (the time necessary for the trip, t_i , times the value of time, ρ_i). This time may depend on the mode of transport (passenger or freight, car or public transport) and on the discomfort of the users (a minute lost in the morning peak has a higher subjective value than a minute lost during a shopping trip in the afternoon).

The generalised price for a passenger km with modus i is thus defined as:

$$\text{generalised price}_i = q_i + \rho_i t_i \quad (1)$$

The use of generalised prices is a shortcut for a more elaborate model with endogenous values of time. This is justified as long as values of time do not change between two equilibria. The generalised price plays an important role in the model: travel times are endogenous, as they depend on the level of congestion of the transport mode used.

Consumer surpluses are no longer unique in the case of interdependent demand functions for transport. Therefore, we use the indirect utility function $V(\text{income}, q_i + \rho_i t_i, \dots)$, function of generalised prices and income, divided by the marginal utility of income in the reference equilibrium μ_r as welfare measure for the consumers of transport. The consumer surplus of freight transport demand is given by the cost function of a unique producer. The indirect utility function and the cost function implicitly define demand for transport.

The supply side representation is simple. The producer price per vehicle km with mode i is p_i . The marginal resource costs of supplying vehicle km with mode i and technology type j are taken constant and equal rc_{ij} .

¹

We do not model explicitly the effects of recycling the tax revenue on other markets. However, the marginal cost of public funds parameter we can take into account the efficiency losses or gains on other markets due to the recycling decision (see section 4 in Chapter 4).

2. Representation of Congestion and the other Externalities

We assume that some transport modes share a common infrastructure of fixed capacity. The unit time t_i for a passenger km using mode i will depend on the total traffic volume sharing the road network. With:

set S_i denoting the group of (passenger and freight transport) modes that use the same infrastructure (e.g. cars, trucks and public busses in the peak period),

m_i the contribution of mode i to the overall congestion (e.g. a bus with 40 people adds per person less to congestion than a car with 1 person),

the general form of the congestion function is¹:

$$t_i = T_i \left(\sum_{l \neq f \in S_i} m_l N x_l + \sum_{f \in S_i} m_f x_f \right) \quad (2)$$

Marginal external costs ec_{ij} other than congestion can be a function of any of the variables of the model. For simplicity they are taken as constant per vehicle km. These external costs depend on technology used (e.g. the polluting emissions of a car depend on the pollution abatement equipment j).

3. Computation of the Market Equilibrium

We compute a market equilibrium by maximisation of the following welfare function:

$$\begin{aligned} \text{MAX} \frac{N}{m_r} V \left[q_0, q_i + r_i t_i; (i = 1, \dots, I), Y + \frac{1}{N} \sum_{l,i} (p_l - rc_{li}) z_{li} + \frac{1}{N} \sum_f (q_f - p_f) x_f + \sum_i (q_i - p_i) x_i \right] \\ - C \left(q_f + r_f t_f; f = 1, \dots, F \right) + I \sum_i (q_i - p_i) N x_i - \sum_{l,i} (ec_{li} z_{li}) \end{aligned} \quad (3)$$

The first term measures utility as a function of generalised prices and income. Income consists of exogenous income (Y), profits from the transport supply industry and returned tax revenue from freight and passenger transport. Utility is converted into income terms by dividing it by the marginal utility of income (μ_r) in a reference situation. Prices of non-transport goods q_0 remain fixed. The second term measures the producer surplus of freight transport users. The third term measures the marginal cost of public funds minus one (λ).

¹ The same function can be written for the unit time t_f for a freight km using mode f :

$$t_f = T_f \left(\sum_{l \neq f \in S_f} m_l N x_l + \sum_{g \in S_f} m_g x_g \right)$$

No extra value was attributed to the tax revenue raised on freight demand because, in general production efficiency is desirable (DIAMOND and MIRRLEES (1971)). The last term measures the total external cost damage excluding the congestion cost. The external congestion cost is implicitly represented in transport time costs which are included in the generalised prices.

The objective function is maximised with respect to p_i , q_i and z_{ij} , subject to the following constraints:

$$\sum_j z_{ij} \geq N x_i \quad \forall i \quad (4)$$

$$\sum_j z_{fj} \geq x_f \quad \forall f \quad (5)$$

$$p_l \geq r c_{lj} \quad \forall l, j \quad (6)$$

In addition we require that all variables take positive values. The first two constraints state that demand has to be satisfied by the sum of the technologies supplied¹. The third constraint states that producer prices are larger than the marginal resource costs, which is justified by incentive compatibility constraints for producers. Subsidies to private or public transport are represented by a producer price larger than the consumer price.

We assume that this objective function is well-behaved, that the maximum problem has a solution. A unique solution is not guaranteed². We use Lagrange multipliers α_i , α_f for the first set of constraints and γ_{ij} for the second set of constraints, and look for an optimum with respect to the control variables q_i , q_f and $z_{i+f,j}$. This implies that the demand levels x are controlled indirectly via the consumer prices q so that all optima of the model are by construction consumer optima (passenger transport) or cost optima (freight transport). Taxes on consumer goods are implicitly determined by the difference between q and p . The optimum will satisfy the complementary slackness conditions associated to (4), (5) and (6) as well as the following first order Kuhn Tucker conditions for an interior optimum (x_{kq_i} represents the derivative of x_k with respect to the consumer price of good i and μ stands for the marginal utility of income in the new equilibrium):

¹ The supply of transport has to be corrected for the occupancy rate in order to match the demand of passenger km.

² Optimal tax problems can have local maxima (Diamond and Mirrlees (1971)). In the model applications we experienced no problems as we always start from a feasible reference situation.

$$\begin{aligned}
& - \frac{\mathbf{m}}{\mathbf{m}_i} N x_i - N \frac{\mathbf{m}}{\mathbf{m}_i} \sum_{l \neq f \in S_i} \mathbf{r}_l x_l t_{lq_i} - \sum_{f \in S_i} \mathbf{r}_f x_f t_{fq_i} \\
& + \frac{\mathbf{m}}{\mathbf{m}_i} N x_i + N \frac{\mathbf{m}}{\mathbf{m}_k} \sum_k (q_k - p_k) x_{kq_i}
\end{aligned} \tag{7}$$

$$+ \mathbf{I} N x_i + \mathbf{I} \sum_k (q_k - p_k) N x_{kq_i} + \sum_k \mathbf{a}_k N x_{kq_i} = 0$$

$$\begin{aligned}
& - N \frac{\mathbf{m}}{\mathbf{m}_f} \sum_{l \neq f \in S_i} \mathbf{r}_l x_l t_{lq_f} - \sum_{f \in S_i} \mathbf{r}_f x_f t_{fq_f} + \frac{\mathbf{m}}{\mathbf{m}_g} \sum_g (q_g - p_g) x_{gf}
\end{aligned} \tag{8}$$

$$+ \frac{\mathbf{m}}{\mathbf{m}_f} x_f - x_f + \sum_g \mathbf{a}_g x_{g_f} = 0$$

$$\frac{\mathbf{m}}{\mathbf{m}_i} (\sum_j z_{ij} - N x_i) - \mathbf{I} N x_i - \mathbf{g}_{ij} = 0 \tag{9}$$

$$\frac{\mathbf{m}}{\mathbf{m}_f} (\sum_j z_{ff} - x_f) - \mathbf{g}_{ff} = 0 \tag{10}$$

$$\frac{\mathbf{m}}{\mathbf{m}_l} (p_l - rc_{lj}) - ec_{lj} - \mathbf{a}_l = 0 \tag{11}$$

4. The Maximum as a Policy Optimised Market Equilibrium

It can be shown that the solution to this maximisation problem corresponds to a market equilibrium where:

- government regulates the supply technologies to be used,
- producers maximise profits, taking prices as given,
- consumers select their preferred consumption bundle given the consumer prices, and
- government combines regulations and consumer taxes to maximise overall welfare.

Given the construction of the objective function, all solutions are optimum budget allocations or minimum cost allocations for given generalised prices. Assume

provisionally that there is no excess supply at the optimum, because this would constitute a pure loss at least equal to the resource cost. This implies via the complementary slackness condition associated to (4) that $\alpha_i > 0$. For each final transport good k at least one technology g is used such that $z_{kh} > 0$. This implies through (11) that for whatever technologies g and h used in the optimum to satisfy demand k , we must have:

$$rc_{kl} + ec_{kl} = rc_{kn} + ec_{kn} \quad (12)$$

Consequently in each welfare optimum the sum of resource costs and external costs determines which technologies should be used. Hence, choice of technology does not depend on any other parameter (not on λ , in particular).

Because the producer price p_i is identical for g and h and because the producer only has to pay for resource costs, a cost minimising producer would not necessarily select the socially optimal technology. Therefore, we need to introduce the regulation of the type of technology to be used, as a policy instrument¹. In the optimum and for normal values of $\lambda > 0$, producer prices will, for all technologies used, always be equal to the resource costs. To see why, assume that prices are higher than the resource costs. Then the government can increase its tax revenue at the expense of the lower valued producer surplus by keeping constant q but lowering p until it reaches the resource costs. We conclude that, in the selected optimum, producer prices equal the lowest marginal resource costs of the set of technologies allowed by the policy maker. This corresponds to the outcome of a perfectly competitive market with regulations on the type of transport technologies that can be used.

For the interpretation of the optimal tax rules it helps to restrict the analysis first to the case where demand for each transport good only depends on its own price. Using (7) and (11) we obtain for the optimal tax on passenger transport:

$$\left[t_k - \frac{tmcong_k + ec_k}{(1 + \mathbf{1} \mathbf{m}_t / \mathbf{m})} \right] \frac{E_{kk}}{q_k} = - \frac{\mathbf{1} \mathbf{m}_t / \mathbf{m}}{1 + \mathbf{1} \mathbf{m}_t / \mathbf{m}} \quad (13)$$

where $tmcong_k$ is the total marginal congestion cost of increasing the use of passenger transport mode k (T_{ii} and T_{ff} represent the derivative of unit transport time of respectively

¹

In an alternative model set-up, not discussed here, the policy maker could replace the technology regulations by a tax on producers or on consumers in function of the type of technologies that are used. The choice between regulation, taxing externalities at the stage of producers or at the stage of consumers is not important in this model where the policy maker is perfectly informed and disposes on perfect policy instruments.

passenger and freight transport with respect to the total volume of transport and m_k the contribution of mode k to congestion):

$$tmcong_k = m_k [N \sum_{ie S_k} r_i x_i T_{ii} + \frac{m}{m(0)} \sum_{fe S_i} r_f x_f T_{ff}] \quad (14)$$

When there are no external effects, (13) becomes the familiar Ramsey expression where taxes are inversely proportional to the own price elasticity. The general level of taxes on consumer goods will increase when the shadow cost of public funds λ increases. The term $\mu(0)/\mu$ is an approximation term with a value close to 1.

Consider now the case with external costs. The external congestion cost of an increase of passenger transport of type k is defined in (14) and consists of the value of the time losses for all transport users (passengers and freight). In (13), taxes become Pigouvian taxes when $\lambda=0$.

When λ increases, the externality part of the optimal tax decreases below the pure Pigouvian component and the Ramsey component increases. Intuitively a higher λ means that the second role of the tax (to raise revenue) becomes more important and that therefore the policy maker can afford less tax differentiation aimed at environmental protection as this counteracts the revenue raising objective of the tax system. This trade-off has been studied by BOVENBERG and DE MOOIJ (1994) and BOVENBERG and GOULDER (1996) in a general equilibrium context. They pointed out that, in the absence of feedbacks from the externality on the consumption of taxed goods, a higher cost of public funds will in general imply lower rather than higher externality taxes. This contradicts the popular second dividend hypothesis where higher environmental taxes were meant to lower labour taxes.

This reasoning can be transplanted to our partial equilibrium model with two qualifications. First, we deal with congestion and this is a type of externality that feeds back on the consumption of taxed goods. MAYERES and PROOST (1997) have shown that this requires a complex correction of the externality term so that only empirical studies can bring about conclusions on this point. Second, in a partial equilibrium approach, no account is taken of the use of the tax revenue and its ultimate effect on the cost of public funds. This procedure is only justified if the variations in tax revenues studied with the transport model can be considered as marginal.

When we consider the cross price effects between passenger transport goods, existing price distortions for complements and substitutes have to be taken into account. Cross price effects become very important when there are restrictions on the taxation of certain modes

(e.g. car use in the peak period). In this case there are large distortions between the social cost and the price of that mode and this can require important deviations from social cost pricing for substitute modes (e.g. subsidies for public transport).

Restricting ourselves to the case without cross-price effects for optimal taxes on freight transport, (8) and (11) imply:

$$[t_f - tmcong_f - \mu(0)/\mu ec_{ff}] \frac{E_{ff}}{q_f} = (\mu(0)/\mu - 1) \quad (15)$$

When the $\mu(0)/\mu$ approximation is perfect, we have pure Pigouvian taxes that preserve production efficiency, as advocated by DIAMOND and MIRRLEES (1971). The difference between (15) and (13) lies in the λ : public revenue considerations are absent when setting indirect taxes to firms.

Optimality conditions (12), (13) and (15) will be driving all model results shown later. The basic model shown here can be extended in several ways. We will discuss briefly three additional features that have been introduced in the empirical model (sections 5, 6 and 7).

5. Economies of Density in Public Transport

In the basic formulation of the model the marginal resource cost of supplying public transport mode l with technology j , rc_{lj} was taken constant, as was the quality of public transport (measured by the value of time). MOHRING (1972) and VITON (1983) have shown that this assumption is not realistic. When demand for public transport in a given hour increases, one can increase the load factor of busses and/or increase the frequency of the bus service. Keeping the load factor constant, an increase in demand for public transport allows to increase frequency without any increase in marginal costs. The increase in frequency reduces average waiting times at bus stops, implying a decrease of the generalised trip cost. Keeping the service frequency constant, an increase in public transport demand allows to increase the load factor and to decrease marginal cost per passenger.

We extend the model framework, including service frequency of public transport as a policy variable. The simplest way to do this is to focus on only public transport mode l that is supplied using a unique technology. The total resource cost of public transport mode l is given by $RC(z_l, \phi)$ where ϕ represents the frequency of bus service (defined as headway, the inverse of the busses per hour). This is to be considered as a reduced function that includes elements like the number of passengers per bus (ϕz_l if not constrained by technology). We

also make travel time per passenger kilometre a function of the headway: $t_i=T(\phi)$. One could also make the value of time for public transport users a function of other quality variables but this does not add more insights.

Maximising objective function (3) with respect to the quality variable ϕ , we obtain first order conditions close to equation (7), because an improvement of public transport frequency acts like a change in the waiting time and therefore of the generalised price of public transport.

If the taxes on all other modes can be determined optimally, only two terms remain in the first order condition for ϕ :

$$-N x_l r_l \frac{d t_l}{d f} = \frac{d RC_l}{d f} \quad (16)$$

This means that the frequency of service should be increased up to the point where the marginal savings in waiting time for all users equal the marginal resource cost of improving the frequency of service. This is in line with a result by VITON (1983) who states that the public transport authority should select the quality of service so as to minimise the sum of waiting times and resource costs for the transit authority. In our case this result holds independently of the marginal cost of public funds λ because the money price of public transport is fully controlled by another policy variable. If the prices of the different modes can not be all controlled, all terms of equation (7) become relevant again and have to be added to equation (16). Choosing the quality of service of public transport then becomes an indirect instrument to lower the generalised cost of public transport and to make car users switch away from their undertaxed mode.

6. The marginal Cost of Public Funds

In the welfare function, changes in tax revenue (including public transport deficits) are valued at the marginal cost of public funds minus 1 (λ) and tax revenue is returned in a lump sum way to the individual. This is a reduced form formulation for a partial equilibrium framework that needs some more explanation¹.

One can consider the utility derived from the transport goods and the consumption good in the utility function in (3) as a composite consumption good CC. Assume further that the individual has no other sources of income than labour. Taxes are on labour and on consumption.

¹ The interested reader will find more explanation in Chapter 4 of this report or can consult the relevant TRENEN deliverable.

In the partial equilibrium model, we derive the optimal change in taxes on transport goods. A change in taxes on transport will change the aggregate tax on the composite consumption good and it is this revenue effect we want to value. It will depend on the way the extra tax revenue is used. If the supply of public goods and the transfer programs remain unchanged the extra tax revenue can be used to decrease labour taxes. If all individuals are identical, the decrease in labour tax will not generate any efficiency gain: real wages will remain unchanged because of the increase in the aggregate consumption tax. In this case, no welfare gain can be attributed to the increase of tax revenue raised on consumption activities and λ equals 0. Because the wage rate is absent in the model formulated in (3), the revenue effect is approximated by adding tax revenue to income.

The value of λ will be different if another use is made of the changes in the tax revenue from CC. Assume that there are other sources of income than labour, more specifically that a share κ of total income is non labour income. If all extra tax revenue is used to decrease labour taxes, the net tax wedge on wages will decrease and the welfare gain of this decrease will be equal to:

$$(MCPF_{labour} - 1) \text{ } dREV \quad (17)$$

where the marginal cost of public funds raised by a labour tax can be computed on the basis of a labour supply equation and where the $dREV$ stands for the tax revenue collected from consumption and transport goods. The fundamental reason to have $\lambda > 0$ is a shift of the tax burden from labour to non labour income.

One can imagine less efficient uses of the extra tax revenue and this will have an impact on the model formulation. Imagine that the tax revenue is returned as a head subsidy. In this case expression (17) becomes $(1 - MCPF_{labour})(1 - \kappa)dREV$, because the net tax wedge on labour has been increased. As the value attributed to extra tax revenue is now negative there is an incentive not to increase transport taxes too much.

7. Non Identical Individuals

The model can be reformulated with multiple types of individuals. Individuals can differ in the transport opportunities they have, in the income and prices they face and also in their preferences. The welfare function can be adapted using social welfare weights that are taken as constant in the optimisation of the transport prices. These welfare weights are defined as the relative social marginal utility of real income. All the elements of objective function (3) have to be allocated to individuals for this system to work: the distribution of

the extra tax revenue, the distribution of the change in real profits, the distribution of the efficiency gains on the labour market and the distribution of the damage of external effects.

8. Constraints on Policy Instruments

Constraints on the use of policy instruments exist. In fact, only certain inputs to the use of transport means can be taxed (fuel, vehicle, tolls, etc.), rather than the actual use of the modes itself. This heavily restricts the pricing possibilities. The model can handle these constraints. When more constraints are introduced on the pricing instruments, the first order conditions become analytically more and more intractable so that only numerical simulations can bring definite answers.

9. Explicit Network Representation instead of One Link Representation

In the model formulation we have assumed that most modes use only one link (congestion function (2)). In most TRENEN-applications we will use a one-link representation because of computational restrictions. We can rewrite the model and define transport commodities in function of their origin and destination and define congestion functions for the different routes¹.

10. The Use of the Model for Comparative Statics

The model is calibrated by plugging in observed or expected taxes and prices, quantities and regulations. This generates a reference market equilibrium.

Alternative market equilibria can be generated by changing the taxes or regulations. This is done by solving again the maximum problem (3) to (6) to which constraints on the values of tax parameters and the type of technologies are added. An infinity of market equilibria can be generated by the model in this simulation mode. Of particular interest are the best equilibria obtainable with a given set of tax and regulation instruments. These can be found by using the model in an optimisation mode, where the choice of the tax parameters is the solution to the maximum problem (3) to (6) with restrictions on the type (not the value) of policy instruments.

¹

A first attempt to this can be found in the network application for Amsterdam (deliverable 8bis).

CHAPTER 3: TRENEN II INTERREGIONAL: THEORY AND IMPLEMENTATION

The TRENEN II INTERREGIONAL model has basically the same structure as TRENEN II URBAN. Specific to the interregional model is the representation of a policy interaction between two regions, through a detailed representation of transit freight transport. In this chapter we concentrate on these specificities.

1. Transport Policies in a Federal System: A Strategy for Analysis

The design of optimal transport policies in a federation is a complex problem for a variety of reasons. First, in relatively small and open economies, there exists a substantial degree of exporting of both the benefits and taxes associated with domestic transport policies. Moreover, the degree of tax exporting strongly depends on the specific tax instrument being used. For example, the tax exporting possibilities of imposing a road toll on trucks using the domestic network differ from those implied by higher domestic excises on fuel. While the latter can be avoided simply by fuelling abroad, near the border, the former can only be legally avoided by avoiding the domestic network. Moreover, note that in the former case domestic externalities are avoided while it is not the case in the latter situation. Second, a federal setting raises the potential for tax competition between countries. Third, from the viewpoint of a given member state of the federation, international transport by firms of other member states contributes to domestic externalities. For example, transit freight flows cause domestic congestion and pollution. Moreover, some transport externalities generate international spill-overs, (e.g. global warming, acid rain, etc.), which should be appropriately accounted for.

In this chapter we try to gain some insights concerning the above mentioned phenomenon's by studying optimal pricing and regulation of passenger and freight transport services in a federation, using both theoretical analysis and a detailed simulation model.

The theoretical model builds upon three strands of literature: optimal taxation in the presence of externalities (Sandmo (1975), and Bovenberg and Van der Ploeg (1994)), the literature on tax exporting and tax competition in a federal system (Arnott and Grieson (1981), Gordon (1983), Mintz and Tulkens (1986), Kanbur and Keen (1993), and Wildasin (1987, 1988 and 1991)¹ and the literature on externalities with international spill-overs (Krutilla (1991), Markusen (1975) and Merrifield (1988)). The theoretical model is used to

¹ Dahlby (1995) gives an overview of the fiscal externalities that may arise in a federation, and how matching grants can be designed to internalise them.

study the characteristics of optimal domestic (i.e. regional) and federal pricing and regulatory policies. We consider a simple two-region model in which each region can tax all the transport flows occurring in its jurisdiction. This includes passenger transport which is assumed to be entirely domestic, and all freight transport by domestic and foreign firms within the jurisdiction. The model allows for general equilibrium effects of transport prices on other goods in the economy. The model is static in the sense that the localisation of households and firms is assumed exogenously given, and that car ownership is not explicitly treated.

The simulation model is designed to implement the theoretical results in a realistic setting with a number of concrete pricing (fuel taxes, road pricing, public transport prices, etc.) and regulatory instruments (emission norms, subsidies to cleaner technologies).

A sufficient degree of heterogeneity of transport services is allowed for by using nested utility and cost functions. In the empirical application particular attention is paid to the role of international coordination of transportation (and environmental) policies. The model considers optimal policies in a federation consisting of two asymmetric countries. The two countries analysed in the simulations differ with respect to their size, to the market shares of the various transport modes, to the magnitude of the external costs, and to their budgetary needs. The model is formulated as a standard welfare optimisation problem subject to relevant constraints on the policy instruments. It incorporates passenger and commodity transport (both domestic and international), it takes account of all (local and global) major external costs of the various transport modes and it captures the budgetary implications of government policies.

2. Structure of the Numerical Optimisation Model

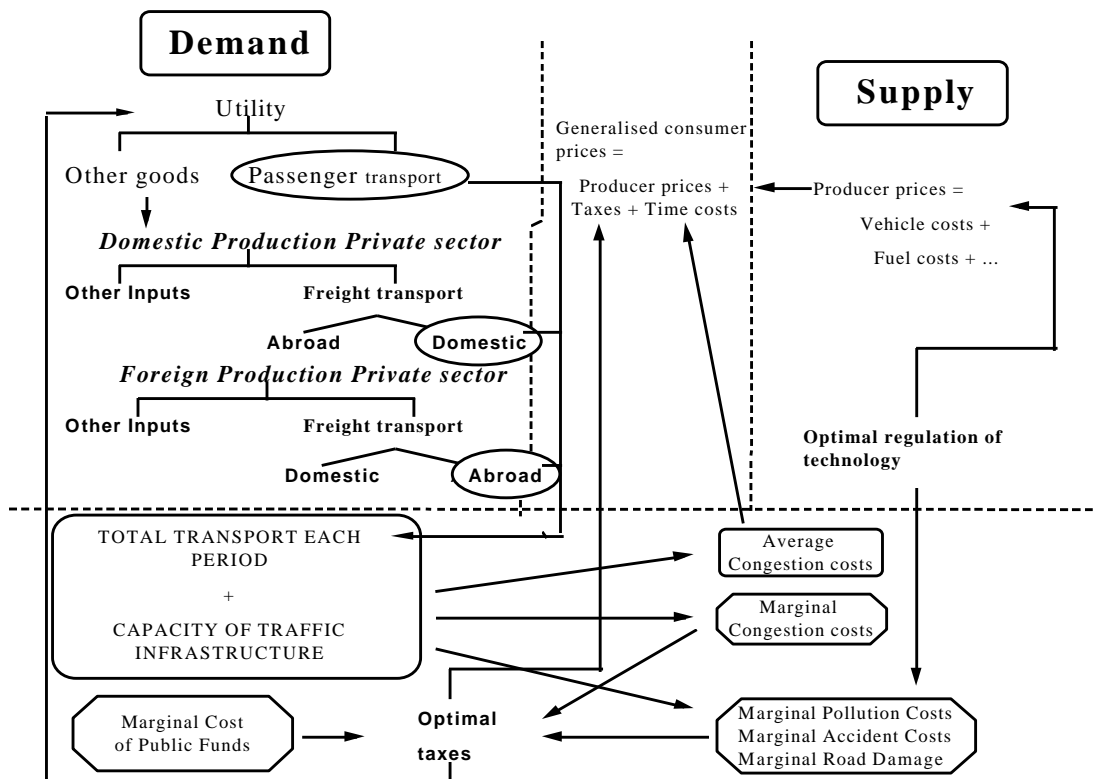
In this section we describe the construction of a simulation model used to determine optimal pricing policies for a large number of transport alternatives in a two-region setting¹.

In each region, the same number of different alternative transport flows are considered. The model distinguishes the demand for transport between the peak and the off-peak period of the day and includes all relevant modes (for passenger transport: the private car, bus and rail; for freight transport: truck, rail, inland waterways). Different types of cars (big and small) and fuel types (gasoline and diesel) are considered. The private car flow is desegregated into traffic on highways and traffic on other major roads. Furthermore, the

¹ The simulation model developed in this paper is a two-country extension of the model presented in De Borger and Swysen (1997).

model captures all relevant externalities associated with transport services, including congestion, road surface depreciation, noise, accident costs and emissions of various pollutants. The latter include transport's contribution to the greenhouse effect (CO_2 -equivalent), to the ozone problem (VOC , NO_x), to acid rain (SO_2 , NO_x) and to local air quality (CO). Domestic and international freight transport flows are distinguished. Finally, fuel tax competition between regions is allowed in the model.

Figure 3.1: Overall model structure of the TRENEN-II interregional model



The overall structure of the TRENEN-II model is represented in Figure 3.1.

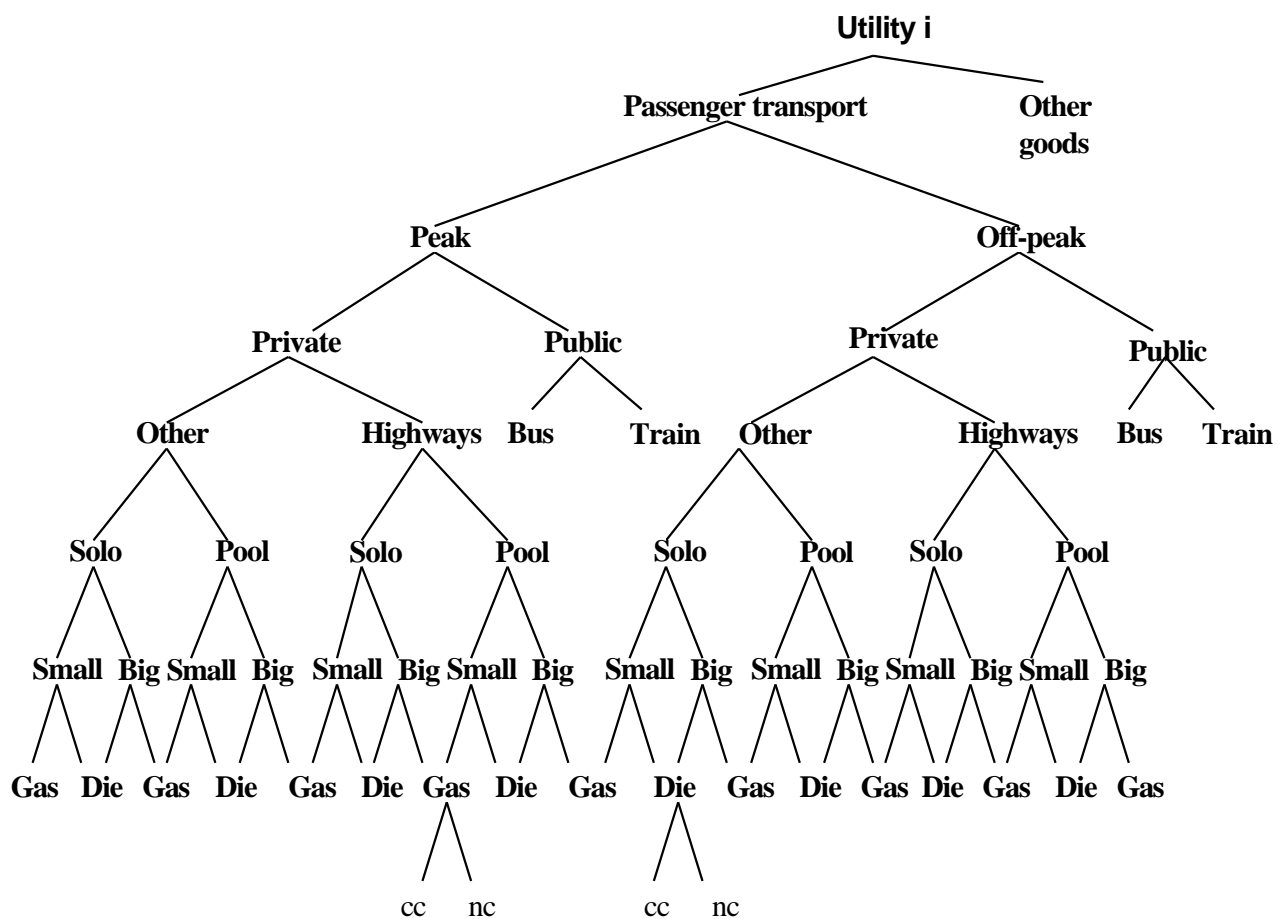
The *demand side* of the transport market is the result of consumers and private firms' behaviour: the utility of the representative consumers is determined by a trade-off between the level of demand for passenger transport and for a composite good, the production of which generates a demand for freight transport by private firms. Freight transport can either be purely domestic or international. The *supply side* of the transport market represents the activities and choices made by the producers of vehicles and the suppliers of the other inputs like fuels, vehicle maintenance etc. In the equilibrium price module, generalised prices (see below) are computed for the different types of transport modes and services.

2.1. Structure of the demand side of the transport market

2.1.1. Demand for passenger transport: Consumer's behaviour

The preference of the consumer has been modelled by using nested CES-type utility functions (see Keller (1976)). The homothetic nature of the CES implies that, at each level, quantity and price indices can be constructed as a weighted sum of lower-level quantities and prices, respectively. Moreover, each quantity index has a subutility interpretation. The CES-approach assumes that at each level subutility is separable in the different goods.

Figure 3.2: The Nested-CES utility function for passenger transport



The nested utility structure used for the simulation exercises is represented on Figure 3.2. At the highest level (level zero) total utility depends on two aggregate goods, viz. passenger transport and other goods, the production of which generate freight transport and on a third one viz. the "rest" which captures all goods that are not related neither with passenger

transport nor with freight transport. At the first level of the utility tree, the transport subutility component contains transport demands in two periods of the day (peak and off-peak) as arguments. At the second level, peak transport demand includes “private” and “public” peak demand. At the third level, public transport can be desegregated into bus and train. At even lower levels in the tree structure, private transport (i.e. car) can occur either on highways or on other major roads. At level four, both private transport on highways and on other major roads can occur either with “carpooling” or “driving solo”¹. Furthermore, two car sizes are being considered, viz., big and small. Finally, there are two possible fuels, gasoline and diesel and two possible types of technology, clean and non-clean technology.

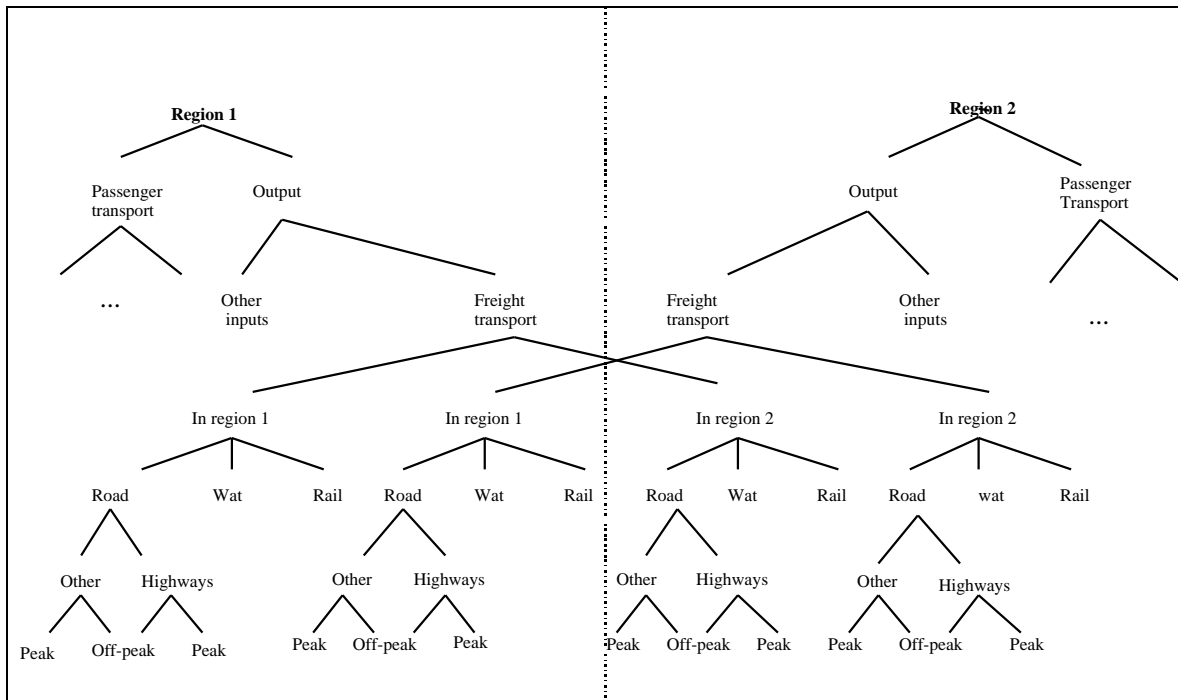
2.1.2. Demand for freight transport: Producer's behaviour

The freight transport demands are treated like derived demands for inputs by a private sector producing an aggregate private consumption good. This good enters the utility function of the representative consumer at the highest level (see previous section). Consumer demand for this good generates production by the private sector, in which freight transport is one among several inputs. The demand for freight transportation is then assumed to be the result of cost minimising behaviour by producers, conditional on the output level of the final good to be produced.

Again, a tree structure is used to represent producers' decisions with a large number of transport alternatives. The tree considered in the simulation model is shown on Figure 3.3. At level one of the tree structure, among all inputs required by the 'domestic' production, freight transport is isolated from the other inputs. At level two, two regions are explicitly distinguished, say "region one" and "region two". The flow of freight transport is fractionated according to the share transported in each region. Three relevant modes (road, rail, inland waterways) are distinguished at level three. At level four, freight transport by road can occur either on "highways" or on "other major roads". The lowest level (level five) differentiates road freight transport according to the period of the day. This distinction seems only relevant for road freight transport. No distinction has been made according to the type of fuel which is used by road freight transport since almost all trucks use diesel.

¹ Carpooling is considered as a particular mode in order to allow different prices (per car km) according to the car's occupancy rate.

Figure 3.3: The Nested-CES production function for freight transport



2.1.3. Price components for passenger and freight transport

The prices for cars and trucks are the sum of price components. For cars, we distinguish between the non fuel components (the acquisition costs, the periodically (yearly or monthly) recurring costs, ...), the price of fuel and the toll paid for road usage. For trucks, similarly, we distinguish between the non fuel components, the fuel price and the toll for road usage. Fuel tax competition across regions is taken into account in the model by giving the possibility to car and truck users to buy fuel domestically and abroad. To model this phenomenon, we use exponential and logistic functions that give the proportion of fuel bought in each region i as function of the relative fuel prices. For public transport and freight transport by waterways and railways, no price components are distinguished.

2.2. Structure of the supply side of the transport market

The supply of the various transport modes is introduced in the model via cost functions for the different modes and alternatives. For freight transport and public passenger transport, resource costs include expenditures on labour, energy, materials, rolling stock etc. For private passenger transport (i.e., car) resource costs consist of depreciation expenditures,

insurance, energy, parking costs, maintenance, etc. The choice of emission technology is also captured as part of the supply component. The emission technology to be provided by suppliers will result from the overall optimisation and will be such as to minimise social costs. The decision variables here are the quantities supplied of vehicles equipped with a certain type of emission technology.

2.3. Externalities taken into account

The following external costs caused by transport are considered in our model: congestion, air pollution, accident costs, and road depreciation. We refer to the next chapter for a description of the methodology.

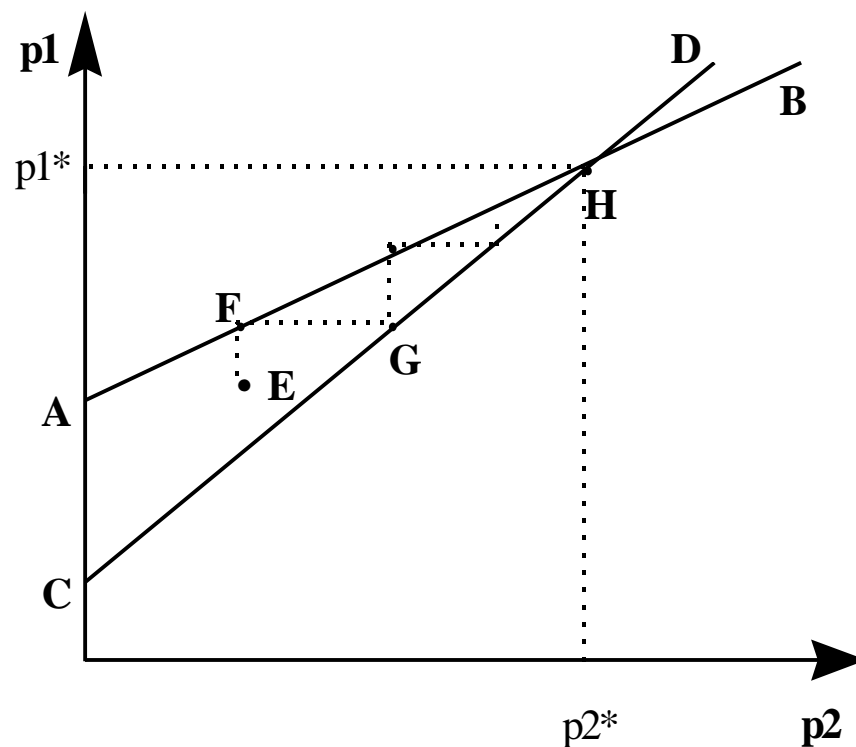
3. Scenarios in the Interregional Model

The objective function can take two alternative forms. It can be the welfare of a region or the welfare of the federation, i.e. the sum of welfare of both regions. On the basis of the objective function used, different exercises can be considered.

1. Maximise the welfare of region i only (we assume that all instruments in the region $j (\neq i)$ are kept at the reference level). We obtain then what we call a "local optimum" for region i . The output of this exercise consists of all prices and choices of technology as well as the related demand levels for the various modes which maximise the welfare of region i .
2. In the first exercise considered, we implicitly assume that the other region (region j) does not retaliate the unilateral decision made by region i . However, we can naturally assume that region j will try to maximise its own welfare in response to the optimal welfare obtained unilaterally by region i . This leads the two regions towards competition using as instruments ("strategies") their local prices and their choices of technology. Their payoffs are the regional welfare functions. This non-cooperative "game" yields a Nash-equilibrium in which the instruments chosen by each region are locally optimal given the optimal choice of instruments made by the other region. This can be easily illustrated graphically (see Figure 3.4) in a case where each region has only one instrument. Suppose for example that "p1" is the price of a transport service in region 1 and "p2" is the price of the same transport service in region 2. The curve between A and B gives the optimal price for region 1 for each choice of price by region 2 (reaction curve of region 1). Similarly, the curve between C and D designates the optimal price for region 2 for each choice of price by region 1. Suppose that the pair of prices in the reference situation is given by point E on Figure 3.4. The first region, by maximising its

own welfare, will attain point F on its reaction curve. The region 2 will retaliate and maximise its welfare to attain point G on its reaction curve. This iterative process yields the two regions to an equilibrium point (point H on Figure 3.4 where the two reaction curves intersect). The pair of prices which corresponds to this point ($p1^*, p2^*$) is the Nash-equilibrium.

Figure 3.4: Illustration of a Nash-equilibrium



3. In the previous exercise, each region chooses the instruments which are optimal for its own welfare, without taking into account the effects of its choice on the welfare of the other region. In reaction to this situation, we can perform a third kind of exercise where the welfare of the federation is maximised. We obtain then a cooperative equilibrium, a "federal optimum".

Each of these three exercises can be implemented with various constraints imposed on the instruments. Table 3.1 gives an overview of different exercises that can be done by using alternative instruments and objective functions.

By fixing prices and regulation instruments at their reference levels, the initial market equilibrium always results from the exercises (whatever the behaviour of the two regions) since the program solves a system of simultaneous equations and no variables are left for

optimisation. From the point of view of optimal transport pricing in the presence of externalities, the reference situation can of course not be considered as a Nash-equilibrium. The reason is that current strategic behaviour is not aimed at the internalisation of external costs.

A local full or second best optimum results when the utility of one region is maximised unilaterally using perfect or constrained instruments. The Nash-equilibrium is obtained in our framework by an iterative process in which both regions maximise their welfare using perfect or constrained instruments. First, starting from the reference situation, we compute a local optimum for one region. Second, relative to the optimal choice of instruments made by the first region, we run the model to obtain a local optimum for the other region. We repeat for each region the second stage of the process until we reach convergence. The maximisation of the federal welfare with the use of perfect or constrained instruments leads to a full or a second best federal optimum, respectively.

Table 3.1: Overview of possible exercises

Objective function	Instruments used			
	Perfect instruments	Constrained instruments	Instruments at their reference levels	
Welfare of region <i>i</i>	- Unilateral	Local full optimum	Local second best optimum	Reference situation for both regions
	- Competition	Nash Equilibrium	Constrained Nash Equilibrium	Reference situation for both regions
Welfare of federation		Full federal optimum	Federal second best optimum	Reference situation for both regions

CHAPTER 4: OPERATIONALISATION OF THE MODEL CONCEPTS

We discuss the representation of demand supply, the congestion function, external costs and the marginal costs of public funds.

1. Demand representation

Passenger transport demand is represented using a nested CES function (Keller (1976)). The CES function has been chosen because it is easy to calibrate and requires a minimum of behavioural information: prices and quantities in a reference equilibrium together with substitution elasticities at each level. Its main limitations are the unitary income elasticities, which makes it unsuited for long term forecasting, and the separability structures which are imposed. Nested logit functions are in theory a superior way to represent transport demand but are more data intensive and can not easily be used for the computation of optimal taxes.

The nested CES utility function that has been used for TRENEN-URBAN contains seven nests. The elasticity of substitution for Brussels¹ is given between brackets, they are chosen assuming that the lower we go down the tree, the easier one can substitute between the alternatives.

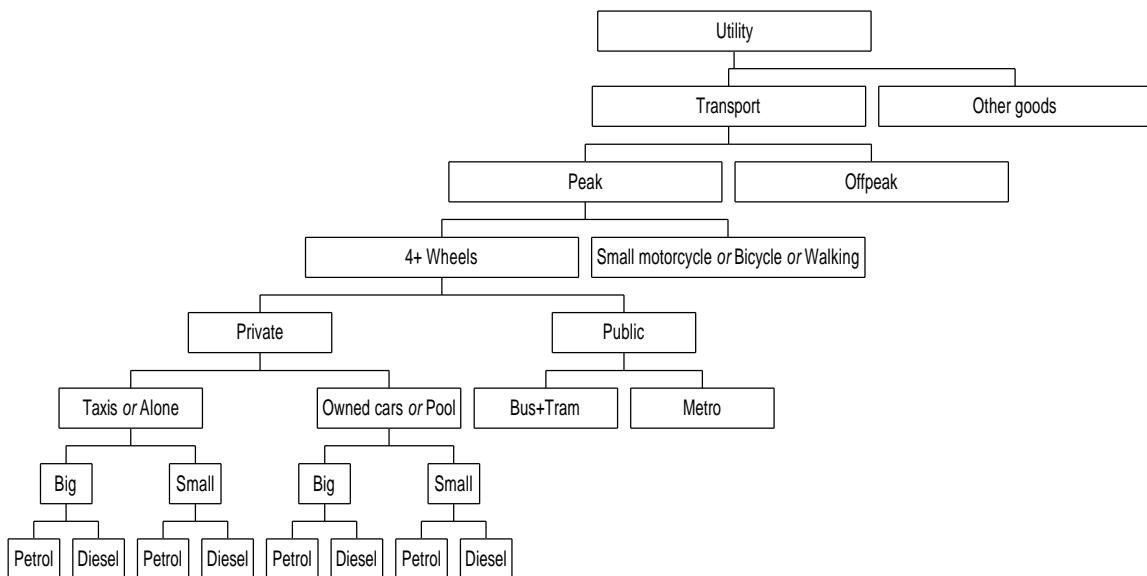
1. transport and non transport goods (0.7);
2. peak and off peak transport (0.8);
3. motorised and non motorised (walking, bicycle or motorcycles) (0.4);
4. public and private transport (0.95 in peak and 1.85 in off peak);
- 5a. solo or carpool for car (0.7 in peak and 1.7 in off peak); this level may also be used to represent private versus taxi transport;
- 5b. metro or bus & tram for public transport (1.1 in peak and 1.65 in off peak);
6. small and large cars (1.5);
7. petrol and diesel cars (1.6).

The full structure is shown in Figure 4.1.

In determining the order of the nests one should bear in mind the assumption of separability underlying the nested structure. All goods that are located on the same branch of a tree will react identically to a price change of a good that is situated on another branch of the tree.

¹ Elasticities of substitution and the structure of the tree differ slightly among case studies.

Figure 4.1: Utility tree urban model



The nested CES-function that has been used for passenger transportation in the interregional model contains 7 nests too (elasticities of substitution for country 1):

1. transport and non transport goods (0.5);
2. peak and off peak transport (0.8);
3. private and public transport (0.8);
- 4a. other roads and highways (0,4);
- 4b. bus and train (1.8);
- 5a. solo and pooled driving (1.2);
6. big and small cars (1.5);
7. petrol and diesel cars (1.6).

The structure of the nested CES-function for interregional freight transport is represented in chapter 3, Figure 3.3.

2. Supply representation

The supply part is kept very simple in this model. The main function of the supply part is to represent the resource costs of alternative transport modes. In the present version there will be no real choice possibility included in the model for most parts of the supply process, except for the emission technology of cars. The producer can be forced by regulation to offer a particular car technology.

The assumption of perfect competition for the private transport modes ensures that producers will minimise total costs and sell at marginal cost the quantity demanded. This marginal cost will be equal to the marginal resource cost.

Two types of modes are distinguished: public and private transport modes.

A. Private transport modes

For the private passenger transport modes, a distinction is made between large and small cars, between diesel and petrol cars and between pooled and non-pooled cars. Resource costs are taken as constant per vehicle kilometre for each of these categories. This implies that the costs of ownership and of use of cars are not explicitly distinguished. This is less of a problem in a static implementation of the model that represents a long run adjustment.

For petrol cars two technological options are distinguished: standard technology that includes a normal 3 way catalytic converter and improved technology that contains a pre-heated 3 way catalytic converter. The latter is more efficient in reducing harmful emissions in urban areas. For diesel cars there are also two possibilities available. The improved technology adds a particulates filter to the standard technology.

Only one road freight transport supply mode is distinguished, namely diesel trucks.

For the private transport modes we distinguish six different inputs, which combined produce a carkm. There is no substitution possible between these inputs, their proportions are thus fixed. To obtain one km in period X by individual of type Y with cartype Z, there is a fixed amount of fuel and parking time needed, the other costs are vehicle depreciation costs, insurance costs, maintenance costs and (possibly) road toll costs.

The relevant costs are the marginal costs per vehicle km.

- (1) fuel cost

This cost equals the product of:

1. the resource cost per litre of fuel
2. the fuel consumption in litre needed per km

The first part is simply the cost (thus exclusive of taxes) of a litre of petrol or a litre of diesel, which is a constant.

The second part is not only different per fuel type, but will also depend on the size of the car and the occupancy rate (car pool is slightly more fuel consuming than car solo). Fuel consumption depends on traffic speed.

- (2) vehicle cost

Because we are not able to treat differently fixed and variable cost components, we have to express the cost of the vehicle as a cost per vehicle km (assuming a certain amount of km driven during the lifetime of an average vehicle and using an annuity concept). We use a constant cost for each vehicle type (size and fuel type)

- (3) parking cost

Two components:

1. the resource cost per hour of parking
2. the average parking time per vehicle km driven

The cost of an hour of parking can be different according to the period of the day and the size of the vehicle. Parking time may also depend on period of day, and it can differ between residents and non residents of the city.

- (4) other resource costs

The costs of oil, tyres, maintenance and insurance are grouped in this cost component. Their level depends on vehicle and fuel type.

B. Public transport modes

The cost of public transport is represented via a linear cost function. The total cost of operating public transport on an annual basis equals the sum of

$$TC = FC + v_p \cdot VOL_p + v_{op} \cdot VOL_{op}$$

fixed cost (FC), a constant variable cost that is different in the peak (p) and in the off-peak (op) period. The fixed cost component covers these cost components that do not vary strongly with output. The extent of the fixed cost element determines the degree of increasing returns to scale in producing public transport. The variable cost component for the peak contains the capacity costs of the carriages (peak load pricing principle) as well as wages of drivers, fuel and maintenance. The off-peak variable cost does not contain capacity costs. Fixed occupancy rates that differ between the peak and off-peak period have been used.

Estimation of the marginal resource costs of public transport proved to be more difficult than the resource costs of cars and trucks.

We have introduced walking times to the public transport stops and waiting times at stops as part of the generalised cost of public transport. We allow waiting times to vary in function of public transport volumes. The relation between waiting times, bus frequencies

and public transport volumes is based on the optimality rule derived by Mohring (1972). We assume that frequency can be changed (increased or decreased) at constant marginal costs.

3. The Congestion Function

The model represents the city as a hypothetical one link system with homogenous congestion conditions for the whole city. The congestion function used is exponential. This form is based on extensive tests with detailed urban network models in cities with different structures (Kirwan, O'Mahony, O'Sullivan (1994)).

4. The Marginal Costs of Public Funds

At present, there exist already high taxes and subsidies in the transport sector. The introduction of optimal prices can affect strongly the net total tax revenue of the transport sector. The way this tax revenue is handled as welfare cost or benefit is important for the optimal tax outcome. Traditionally one counts the net tax revenue as an additional benefit with a weighting identical to the consumer surplus benefit. Sometimes one imposes a tax revenue constraint on the transport sector as a whole. In TRENEN-II we depart from this practice in two ways. First, the change in net tax revenue is treated as an income supplement for the consumers. Secondly, we attribute an extra weight (called MCPF, marginal cost of public funds) to net increases in tax revenue if the tax revenue from the transport sector is used to decrease other more distortionary taxes.

We will first embed the TRENEN approach in a general equilibrium context and show how the tax revenue effects considered in TRENEN can affect the rest of the economy (section 1). In section 2 we discuss the inclusion of the MCPF in TRENEN, and section 3 deals with the empirical determination of the MCPF.

4.1. The TRENEN approach in a general equilibrium context

TRENEN exclusively focusses on optimal taxation and pricing on transport markets. It considers production prices and tax rates on other consumer goods and on labour as fixed. This can not hold if there are substantial increases or decreases in the tax revenue raised in transport markets. A general equilibrium model is presented which shows how account can be taken of the effects of changes in tax revenues.

Consider an economy in which N identical consumers consume two goods: an aggregate consumption good C and leisure, where leisure is the total time budget minus labour

supply L . The aggregate consumption good C will later be seen to correspond to the utility function in the TRENEN partial equilibrium framework. Assuming linear technologies, all producer prices P_C and P_L are fixed, with $P_L=1$. The consumer prices are equal to producer prices plus taxes, T_C and T_L . These tax rates and a head tax A are the only tax instruments available. Government supplies a quantity of public goods PG of which the marginal production cost equals 1. Equations (1) and (2) describe this economy.

Welfare function

$$NU(C, L, PG) = NV\left(P_C + T_C, 1 - T_L, PG, A\right) \quad (1)$$

Government budget constraint

$$T_C N C + T_L N L + N A = PG \quad (2)$$

Because of Walras' law, the production feasibility constraint is satisfied when equations (1) and (2) are satisfied.

We now investigate how welfare changes if we increase the tax on the consumption good and lower the tax on labour, keeping the supply of PG constant. Differentiating the welfare function w.r.t T_C and T_L gives:

$$N \frac{\partial V}{\partial T_C} dT_C + N \frac{\partial V}{\partial T_L} dT_L \quad (3)$$

After division by α , the marginal utility of income, we obtain:

$$-N C dT_C + N \frac{1}{\alpha} \frac{\partial V}{\partial T_L} dT_L \quad (4)$$

The first term in this expression will correspond to the change in consumer surplus measured in the objective function of the TRENEN model when the average tax on the consumption bundle is increased. The second term measures the welfare effects of the change in labour taxation which is made possible by an increase in the average consumption tax. This is the term we want to add to the 'partial equilibrium' objective function. It can also be written as follows:

$$N \frac{1}{a} \frac{\partial V}{\partial T_L} = \left[N \frac{1}{a} \frac{\partial V}{\partial T_L} \right] \left[\frac{\partial R}{\partial T_L} dT_L \right] \quad (5)$$

The term on the right hand side equals the product of the marginal cost of raising revenue by labour taxes ($MCPF_L$) and the amount of revenue that needs no longer to be raised by the labour tax. For the $MCPF_L$, empirical estimates are available in the literature and a method of computation is also presented in section 4.3. What is still missing to make (5) operational is the additional revenue which is raised on the consumption bundle (T_C) and which must no longer be raised via labour taxes. It can be computed by totally differentiating the budget equation for the government, keeping A and PG constant.

$$dREV + N T_L \frac{\partial L}{\partial T_C} dT_C + \frac{\partial R}{\partial T_L} dT_L = 0 \quad (6)$$

where $dREV$ is the tax revenue computed in the TRENEN model:

$$dREV = \left(N C + N T_C \frac{\partial C}{\partial T_C} \right) dT_C \quad (7)$$

We have now arrived at an expression for the second term of equation (4), the term we want to include in the objective function of TRENEN:

$$N \frac{1}{a} \frac{\partial V}{\partial T_L} = MCPF_L \left[dREV + N T_L \frac{\partial L}{\partial T_C} dT_C \right] \quad (8)$$

where $dREV$ is defined in (7).

If it is assumed that labour income is the only type of income and that all individuals are identical, then an increase in T_C and a decrease of T_L will not be a net decrease in the effective tax rate on labour income (equation (6) equals zero). The reason is that any increase of the tax on consumption comes down to a decrease of the real net wage. This decrease of the real wage offsets completely the decrease in the labour tax which is made possible by the increased tax revenue from consumption taxes: only relative prices matter.

In order to have a real decrease in labour taxes we need non-labour incomes (transfers, pensions, child allowances, etc.). Increasing the tax on consumer goods acts then as a net

tax on non-labour income, and the proceeds of this tax can be used to decrease the labour taxes. The net decrease in labour taxes that is possible equals $m dREV$ (where m is the share of non-labour income in total income) and the term to be added to TRENEN is then:

$$MPCF_L m dREV \quad (8b)$$

4.2. Including the MCPF in the TRENEN approach

In TRENEN the utility from the composite commodity C is optimised by modifying taxes and subsidies on transport, taking into account the different types of externalities. In order to make expression (8b) operational we need $dREV$, the tax revenue raised on the composite commodity C.

Assume there is only one ‘other consumption’ good G and one transport good X, with production prices P_G , P_X and tax rates T_G , T_X . The change in tax revenue generated by a change in dT_X is given by:

$$N \left[T_G \frac{\partial G}{\partial T_X} + T_X \frac{\partial X}{\partial T_X} + X \right] dT_X + N \left[T_G \frac{\partial G}{\partial T_L} + T_X \frac{\partial X}{\partial T_L} \right] dT_L \quad (9)$$

The first term is the direct change in tax revenue, which can easily be computed in TRENEN, as both G and X are explicitly represented. It has also to be noted that the first derivatives in the first term implicitly take account of the feedback of congestion externalities on the consumption of G and X. The second term of (9) represents the general equilibrium effect of using the tax revenue collection from consumption of G and X to reduce labour taxes. Assuming that the substitution effects are negligible, we approximate this second term by income effects. (9) becomes then, using (6):

$$dREV = N \left[T_G \frac{\partial G}{\partial T_X} + T_X \frac{\partial X}{\partial T_X} + X \right] dT_X + \left[T_G \frac{\partial G}{\partial Y} + T_X \frac{\partial X}{\partial Y} \right] \left[dREV + N T_L \frac{\partial L}{\partial T_C} dT_C \right] \quad (10)$$

Expression (10) can be used to compute the ‘equilibrium’ change in tax revenue $dREV_E$, and multiplying by the share μ gives the labour tax reduction term:

$$(MPCF_L - 1) m dREV_E \quad (11)$$

We use $MCPF_L-1$ because the utility gain of redistributing the tax revenue is already included in the first part of the TRENEN objective function $V(Q_G, Q_X, Z, Y+dREV_E)^1$.

4.3. Empirical implementation of MCPF

For the empirical implementation of the MCPF parameter in the TRENEN models, we start from Snow and Warren's (1996) general expression for the MCPF of a labour tax. Their approach encompasses previous studies and can be used to compare empirical estimates. The expression for $MCPF_L$ used in TRENEN is a simplified form of the general case :

$$MCPF_L = \{ \eta_w^c(dm/da) - (\eta_w^c - \eta_w^u) \} / D$$

where $D = (1-m)/m + \eta_w^c(\gamma(1-m)/m - (1-\gamma)(a/m)(dm/da)) + \eta_w^c - \eta_w^u$

η_w^c is the compensated wage elasticity of labour supply,

η_w^u is the uncompensated wage elasticity of labour supply,

m is the marginal wage tax rate,

a is the average wage tax rate,

γ is (minus) the elasticity of marginal labour productivity to labour supply.

Estimates were constructed for the first four of these parameters, mainly on the basis of fiscal statistics. Marginal and average income tax rates are relatively easy to calculate per country. Elasticities are more difficult to obtain. We use the survey-based interval of estimates constructed by Hansson and Stuart (1985). As in most studies (Snow and Warren (1996)) we will assume $\gamma=0$. We obtain the following central estimates for $MCPF_L$.

Table 4.1: Estimates of $MCPF_L$

	Central estimate
Belgium	1.20
Greece	1.07
Ireland	1.13
Italy	1.11
Netherlands	1.22
United Kingdom	1.08

¹ For the model applications, empirical estimates of MCPF and share of labour income are required. The procedure for these estimates is described in Deliverable 8 of the project.

The central estimate for Belgium is 1.2, a value in line with findings in the literature. For the other countries, the reported values are rough first approximations. The estimates show that the $MCPF_L$ increases as average and marginal tax rates increase. Sensitivity analysis points out that the elasticity values are very important in determining the final value.

5. Software Implementation

TRENEN II is programmed in GAMS v2.25. The core of the model is formed by two files, T2CAL.GMS and T2OPT.GMS, the calibration and optimisation programmes. Once a calibration has been constructed and an idea of the initial values for counterfactual equilibria has been formed, a complete model run takes approximately 3 minutes (on a Pentium 133 Mhz for TRENEN II URBAN). Since the solver performs a nonlinear optimisation, the construction of the calibration and of the first counterfactual equilibria can be quite time intensive, because not much is known about initial values. We advise to implement changes from a known equilibrium one by one, instead of changing several parameters or constraints simultaneously.

The global programme structure is as follows:

- CALIBRATION
 - Declaration of sets, variables, equations
 - Specification of data for calibration (incl. declaration of scalars and parameters)
 - Elasticities of substitution
 - Prices and quantities in reference situation
 - non-transport data
 - transport data
 - Specification of equations
 - Specification of starting values and bounds
 - Solve statement
 - Fixing of reference values
 - Link to elast.inc for computation of price elasticities
- OPTIMISATION
 - Declaration of additional sets, variables, equations
 - Specification of equations
 - Specification of starting values and bounds
 - Solve statement
 - Output management.

The calibration determines the demand functions and welfare function, starting from data on elasticities of substitution, the income level, duration of periods, values of time, and on the prices and quantities for the reference equilibrium. Intermediate calculations are for traffic flows and speeds, generalised prices at all levels and expenditures.

The optimisation starts from the calibrated equilibrium and optimises a welfare function (including external costs and the valuation of public funds). The welfare function is optimised by selecting optimal values for a given set of policy instrument (including different types of taxes and regulations).

TRENEN II simulates and/or optimises the impact of pricing and technology instruments on external effects in transport markets and on social welfare. In a simulation, the effect of a predefined value of an instrument is calculated. In an optimisation the optimal value of an instrument is computed. Simulation and optimisation elements can be combined in one scenario (e.g. optimal private transport prices with fixed values of public transport prices). Constraints on instruments can be defined in an optimisation exercise (e.g. private transport taxes can not be different for petrol and diesel cars).

A scenario is defined by specifying the values for policy variables in the case of simulation, and by defining the constraints on optimal values in the case of optimisation. This is done in three blocks of equations, one for the use of technology, one for all pricing instruments not related to parking, and one for parking related instruments.

CHAPTER 5: EXTERNAL COSTS OF TRANSPORT

This chapter provides more details for the computation of the marginal external costs used in the TRENEN applications. The internalisation of external cost is one of the major determinants of optimal taxes and merits therefore particular attention. The following categories of external costs are considered: congestion, environmental externalities (air pollution and noise), accidents and road damage externalities. The methodology is based on Mayeres, Ochelen and Proost (1996). The following adaptations are introduced:

- (1) new figures are proposed for the marginal external air pollution costs. They are based on the ExterneE-Transport project of the European Communities;
- (2) for the accident externalities we use new empirical information obtained by by CERTE in the framework of the TRENEN-project (Dickerson, Peirson, Vickerman (1998);
- (3) the report considers the road damage externalities of trucks which were not taken into account in Mayeres, Ochelen and Proost (1996).

1. The Marginal External Congestion Costs

The marginal external congestion costs are calculated endogenously in the TRENEN-models. This paragraph provides the background information for the incorporation of the marginal external congestion costs in the TRENEN-models. The speed-flow relationship is of crucial importance in the calculation. It describes how average speed is influenced by traffic flow. Traffic flow is measured in millions of passenger car units (PCU) per hour. PCU are used instead of the number of vehicles in order to reflect the difference in congestive effect of the vehicle types considered. Generally, a bus or a truck is assumed to correspond to 2 PCU. The aggregate speed-flow relationship has to be derived from simulations with a network model. Such a model is necessary to compute the impact on average speed of a proportional increase in all trips. Kirwan et al. (1995) conclude that an exponential type of aggregate congestion function is the most satisfying. They propose the following general form for the exponential congestion function:

$$t_{i,j} = \frac{60}{s_{i,j}} = d_j [a + b \exp(c \cdot q_i)] \quad (1)$$

It gives the minutes needed to drive one km by mode j (j =car, bus, tram, truck) in period i (i = peak, off-peak period) as a function of number of PCU vkm per hour in that period (q_i). s_{ij} is the speed of vehicle type j in km per hour. a , b and c are parameters of the congestion function. The speed of the bus and tram mode is assumed to be proportional to that of cars

and trucks. This is expressed by the parameter d_i . The average speed of metro and non-motorized transport is assumed to be independent of the volume of other traffic. The congestion function can be calibrated on the basis of three observation points¹.

The congestion function allows us to compute the time loss suffered by the other road users if an additional PCU joins the traffic flow. This has to be combined with information on the value of a marginal time saving in order to calculate the marginal external congestion cost of an additional PCU km. This is given by:

$$MECC_{q_i} = \sum_{j=car,bus,tram,truck} \frac{\partial t_{i,j}}{\partial q_i} X_{i,j} VOT_{i,j} \quad (2)$$

X_{ij} is the number of passenger km traveled in period i by mode j . VOT_{ij} is the value of a marginal time saving for that mode. In order to arrive at the marginal external congestion cost of a truck, tram or bus vkm of an additional PCU km one needs to multiply by 2.

We use VOT studies for the Netherlands to express the time loss in monetary terms. For passenger transport, a willingness-to-pay study carried out for the Netherlands by Hague Consulting Group (HCG, 1990) provides empirical evidence about monetary valuations of travel time savings or losses by travelers using private cars and public transport for different trip purposes. The methodology and results are discussed extensively by HCG (1990), Bradley (1990) and Bradley & Gunn (1991). Combining their findings with the relative importance of different trip purposes in Brussels in 1990 (Stratec (1992)), we obtain the results presented in Table 5.1. This table gives the VOT for the year 2005. They are derived from the values for 1990 using the relationship between the VOT and income. MVA Consultancy et al. (1987) and HCG(1990) have found that the value of time increases with income, but less than proportionally. From the results of the stated preference analysis by HCG (1990), we estimate a linear relationship, the elasticity of the VOT with respect to income equals 0.368.

The VOT in freight transport is based on De Jong et al. (1993) in which the short and medium term VOT in freight transport are estimated by means of a contextual stated preference method. The average VOT over the different goods categories equals 25.8 ECU/h in 1990. The value for 2005 is obtained by assuming that the labor cost, which is

¹ For Brussels, e.g., the first observation point is the peak period situation in 1991 which is characterized by a traffic flow of 0.5337 million PCU per h and an average car speed of 38.2 km/h. In the second observation point, which represents the peak period situation in 2005 with unchanged infrastructure, the traffic flow is 20% higher than in 1991 and the average speed has fallen to 23.7 km/h. Finally, there is the free-flow situation with a traffic flow equal to zero and an average speed of 50 km/h. This results in the following values for a , b and c : $a=1.13461337$, $b=0.005386$, $c=7.95287524$.

one of the main components of freight transport, increases by 2% annually between 1990 and 2005.

Table 5.1: The value of a marginal time saving in passenger and freight transport in 2005

	Peak	Off-peak
Passenger transport: private (ECU/passenger/hour)		
Urban		
Amsterdam, Brussels, London	7.7	7.3
Athens	4.6	4.4
Dublin	4.2	5.1
Interregional		
Belgium	7.5	7.5
Ireland	4.2	5.1
Passenger transport: public (ECU/passenger/hour)		
Urban		
Amsterdam, Brussels, London	5.4	5.7
Athens	3.2	3.4
Dublin	1.6	5.1
Interregional		
Belgium	5.5	5.5
Ireland	1.6	5.1
Freight transport: truck (ECU/tonne/hour)	2.2	2.2

Source: Own calculations based on HCG (1990), De Jong et al. (1993), Stratec (1992), MVA Consultancy et al. (1987) and Steer Davis Gleave (1995)

2. The Marginal External Air Pollution Costs

This section determines the costs to society of a marginal increase in the emission of air pollutants by road and rail transport and by inland navigation. This generally requires four steps. The first step consists of the calculation of the emissions caused by an additional vehicle km. The second step establishes the relationship between the change in emissions and the resulting ambient concentrations of the primary and secondary air pollutants. This requires atmospheric dispersion models which predict the spread of the pollutants from their origin, and chemical transformation models which describe how different air pollutants react together to form so-called secondary air pollutants. The third step consists of relating the change in the ambient concentration to its effects on health, vegetation,

materials, visibility, ecosystems and so on. This requires the use of so-called exposure-response relationships. The final step assigns a monetary value to the different effects of air pollution.

First, we describe the approach which is used in the TRENEN case studies to calculate the marginal external air pollution costs. This approach is used for all transport modes except for public transport in the urban case studies. Next, we turn to the marginal external air pollution costs of urban public transport.

2.1. The marginal external air pollution costs of all transport modes except urban public transport

For all transport modes except urban public transport the TRENEN case studies use the findings of the ExternE-Transport project for the last three steps in the calculation of the air pollution costs. The ExternE-Transport project provides data on the damage cost per g of pollutant emitted, which are combined with the emission factors of the different vehicle types. An overview of the main ExternE-Transport results and a brief discussion of the methodology is presented in Bickel *et al.* (1997). Table 5.2 summarizes the impacts of air pollution considered by ExternE-Transport. The impacts marked by 'XX' are valued in monetary terms by the project, while the ones marked by 'X' are not. In the TRENEN case studies the health effects of carcinogens and lead are not taken into account, nor is the contribution of the N₂O and CH₄ emissions to global warming.

The results of ExternE-Transport for the damage cost per g of each pollutant are used. From Bickel *et al.* (1997) we can derive the following damage costs per g of pollutant¹:

Table 5.3: Damage cost per g of pollutant (10^{-3} ECU/g)[Bickel *et al.* (1997)]

	PM	NO _x	SO ₂	CO	HC	CO ₂
Urban						
Paris	2619.6	21.4	37.9	0.02	0.78	0.0008-0.0252
Athens	-	4.9	18	0.01	0.78	0.0008-0.0252
Stuttgart	347.6	10.4	9.8	0.003	0.78	0.0008-0.0252
Amsterdam	304.4	5.3	8.0	0.002	0.78	0.0008-0.0252
Barnsley	388.6	6.3	16.2	0.004	0.78	0.0008-0.0252
Average Amsterdam, Stuttgart and Barnsley	346.9	7.3	11.3	0.003	0.78	0.0008-0.0252
Stuttgart-Mannheim	184.5	13.6	8.4	0.002	0.78	0.0008-0.0252
Tiel drive	155.1	5.1	10.4	0.002	0.78	0.0008-0.0252
Average Stuttgart-Mannheim and Tiel drive	169.8	9.4	9.4	0.002	0.78	0.0008-0.0252

Table 5.4 summarizes the way in which the findings of ExternE-Transport are used in the TRENEN case studies. For CO₂, the maximum of the ExternE-Transport range is used (i.e., 25.2 ECU/t CO₂).

In order to calculate the marginal external air pollution costs these findings are combined with constant emission factors (per vkm, pkm or tkm) for different vehicle types (vehicle size, fuel type, emission technology, fuel efficiency) in the different transport markets (time of day, occupation rate). An overview of the emission factors is given in Appendix 4. The appendix also describes the main assumptions underlying these emission factors. For cars the emissions are given for standard and for improved emission technology, and for standard and increased fuel efficiency. In the reference situation all cars are assumed to use standard technology with a standard fuel efficiency. Improved technology or increased fuel efficiency can be imposed by regulation or by emission taxes.

¹ The data underlying these results are presented in Appendix 3.

Table 5.4: The use of the ExternE-Transport results in the TRENEN case studies

TRENEN case study	Values of ExternE-Transport used in the TRENEN case study
Urban	
London	Paris
Athens	- all pollutants except PM: Athens - PM: Paris
Amsterdam	Amsterdam
Brussels, Dublin	Average of Stuttgart, Amsterdam and Barnsley
Interregional	
Belgium, Ireland	Average of the route Stuttgart-Mannheim and the Tiel drive

Table 5.5 presents the marginal external air pollution costs of standard passenger cars and public transport in Brussels in 2005. Even among private cars the variation in air pollution costs between the different car types and uses is quite important (e.g., compare the marginal external air pollution costs of a large diesel car in the peak period and those of a small gasoline car in the same period). For gasoline vehicles CO₂ is the dominant cause of air pollution costs, followed by PM. For diesel cars PM have the dominant share. Table 5.6 presents the results for interregional transport in Belgium.

Table 5.5: The marginal external air pollution costs of passenger cars in Brussels in the reference equilibrium (10⁻³ ECU/vkm)

	Brussels						
	NO _x	CO ₂	VOC	CO	PM	SO ₂	Total
Gasoline car^a							
Peak small	0.788	5.015	0.133	0.005	2.706	0.305	8.952
Peak large	1.110	6.754	0.187	0.008	2.706	0.305	11.069
Off-peak small	0.702	4.259	0.108	0.003	2.706	0.305	8.083
Off-peak large	0.972	5.242	0.152	0.005	2.706	0.305	9.382
Diesel car^a							
Peak small	2.270	4.511	0.091	0.001	28.064	1.572	36.509
Peak large	3.638	5.569	0.194	0.002	45.930	1.958	57.291
Off-peak small	1.774	3.301	0.055	0.001	17.449	1.148	23.728
Off-peak large	2.575	4.183	0.097	0.002	26.781	1.462	35.100

^a The values are for a car with an occupancy rate of 1.

Table 5.6: The marginal external air pollution costs of interregional transport in Belgium in the reference equilibrium

	Belgium interregional						Total
	NO _x	CO ₂	VOC	CO	PM	SO ₂	
Gasoline car ^a (10 ⁻³ ECU/vkm)	Not available						
Peak small							
Peak large							0.0066
Off-peak small							
Off-peak large							0.0064
Diesel car ^a (10 ⁻³ ECU/vkm)							
Peak small							0.0181
Peak large							
Off-peak small							0.018
Off-peak large							
Public px transport ^b (10 ⁻³ ECU/pkm)							
Peak bus	8.937	0.535	0.135	0.000	1.393	0.213	11.212
Off-peak bus	14.910	0.823	0.219	0.000	1.667	0.328	17.948
Peak rail	0.290	0.305	0.001	0	0.527	0.450	1.572
Off-peak rail	0.573	0.603	0.000	0	1.037	0.890	3.103
Truck ^c (10 ⁻³ ECU/tkm)	5.056	1.715	0.022	0.000	1.799	0.292	8.884
Freight rail (10 ⁻³ ECU/tkm)	1.094	0.855	0.005	0.000	1.768	0.304	4.025
Inland navigation (10 ⁻³ ECU/tkm)	1.422	1.111	0.006	0.000	2.258	0.394	5.192

^a The values are for a car with an occupancy rate of 1.

^b The following occupancy rates are assumed for public transport: peak bus: 36.95 passengers/vehicle; off-peak bus: 22.66 passengers/vehicle; peak rail: 119.47 passengers/vehicle; off-peak rail: 73.27 passengers/vehicle.

^c A truck is assumed to have an average load factor of 11.30 tonnes/vehicle

2.2. The marginal external air pollution costs of urban public transport

The marginal external air pollution costs of urban public transport are taken from the ExternE-Transport project. Table 1.9 presents the findings of this project. The values are best estimates for a typical medium sized urban area. They are used in the TRENEN case studies for Brussels. For diesel buses in London and Athens a marginal external air pollution cost of $224 \cdot 10^{-3}$ ECU/pkm¹ is assumed. Note that no differentiation is made between peak and off-peak transport. The values are for average occupancy rates and average emission factors. In the peak period the emission factors and the occupancy rates can be expected to be higher than the average, in the off-peak period, the reverse is true.

Table 5.7: The marginal external air pollution costs of urban public transport

Vehicle type	marginal external air pollution costs (10^{-3} ECU/pkm)
Diesel bus	31
Electric bus	3.8
Tram	3.2
Light rail	4.2
Train (urban)	5

Source: Bickel *et al.* (1997)

3. The Marginal External Accident Costs

From the economic literature we know that the accident cost relevant for pricing is the difference between the marginal social and the average private accident cost. This difference is the marginal external accident cost. Following the notation of Jansson (1994), the total accident cost (TAC) can be written as follows:

$$TAC = \sum_{i=1}^6 \sum_{n=1}^4 \left(a^n + b^n + c^n \right) \sum_{j=1}^7 X_i \quad (3)$$

The indices i and j represent the transport modes: car, bus, tram, metro, truck and nonmotorized transport. In addition, index j includes external objects (such as a wall or a

¹ This value is obtained by multiplying the value for medium sized areas by the ratio between the marginal external air pollution costs of diesel cars in London and those in medium sized urban areas.

tree) as a category. Index n indicates the severity of the accident. A distinction is made between fatal accidents, accidents with serious injuries, accidents with light injuries and accidents with only material damage. X_i is the number of vehicle km travelled by transport mode i . r_{ij}^n is the probability that an accident of severity n occurs between transport modes i and j and in which i is the victim. It is defined as

$$\begin{aligned} r_{ij}^n &= A_{ij}^n / X_i \\ A_{ij}^n &= A_{ij}^n(X_i, X_j) \forall i, j \end{aligned} \quad (4)$$

A_{ij}^n gives the number of accidents between modes i and j in which i is the victim. It is assumed not to depend on the number of vehicle kilometers driven by transport modes other than i and j . a^n stands for the willingness-to-pay (WTP) to avoid an accident of type n . b^n is the WTP of the relatives and friends of the victim to avoid an accident of type n . a^n and b^n are the so-called 'warm-blooded' costs as opposed to the 'cold-blooded' cost category c^n which consists of the pure economic costs (net output losses, ambulance costs, medical costs, etc.) which are borne by the rest of society.

The marginal social accident cost (MSAC) of a car is the derivative of the TAC with respect to the number of car km:

$$\begin{aligned} MSAC_{car} &= \sum_{n=1}^4 (a^n + b^n + c^n) \sum_{j=1}^7 r_{carj}^n \\ &+ \sum_{n=1}^4 (a^n + b^n + c^n) \sum_{j=1}^7 \frac{\partial r_{car,j}^n}{\partial X_{car}} X_{car} \\ &+ \sum_{i \neq car} \sum_{n=1}^4 (a^n + b^n + c^n) \frac{\partial r_{i,car}^n}{\partial X_{car}} X_i \\ &= MSAC_{car}^1 + MSAC_{car}^2 + MSAC_{car}^3 \end{aligned} \quad (5)$$

It consists of three terms. The first term gives the social costs of the risk that the car occupants themselves are involved in an accident. The second and the third term give the social cost of the increased accident risk for cars and other road users due to the additional car km. A similar formula can be obtained for the marginal social accident cost of buses, trucks, etc. However, to keep the explanation as simple as possible, we limit ourselves to

cars. In the determination of the marginal external accident costs there are two main problems. First of all, one needs to determine the relationship between the number of road users and the number of accidents. Secondly, it must be determined which part of the accident costs is internalized in each road user's decision process.

Part of the marginal social cost is already internalized. From the literature on accident costs we know that road users take into account the average private accident costs. These include the insurance premium and two cost categories associated with their own accident risk, namely their own utility loss due to the accident risk (a) and possibly also the utility loss of their relatives and friends¹ (b). Thus in the first term of equation (5), only the c cost category would be external. However, this depends on the type of insurance that is in place. If insurance covering costs of type c is compulsory, then the cold-blooded costs associated with the own accident risk are internalized through the insurance premium. In Belgium this is the case for car passengers but not for car drivers. Therefore, the cold-blooded costs are assumed to be external for car drivers only. For public transport these costs are assumed to be external for both the driver and the passengers².

The second term of equation (5) can be written as:

$$MSAC_{car}^2 = \sum_{n=1}^4 \left(a^n + b^n + c^n \right) \sum_{j=1}^7 \epsilon_{(car,j)car}^n r_{car,j}^n \quad (6)$$

in which $\epsilon_{(car,j)car}^n$ is the elasticity w.r.t. the number of car km driven of the probability of an accident of type n between the car mode and mode j ($r_{car,j}^n$) in which car users are the victims. If an additional car km does not increase the risk of accidents of cars with other road users, the elasticities $\epsilon_{(car,j)car}^n$ equal zero so that expression (6) reduces to zero. However, if for some transport modes j $\epsilon_{(car,j)car}^n$ is positive, the marginal external costs associated with increased accident risks for cars are nonzero. The value of $\epsilon_{(car,j)car}^n$ depends on the relationship between the number of accidents and the traffic flow. In the literature different views are taken on this relationship. For the accidents between two motorized road users an accepted convention³ is to assume that the number of accidents is proportional to the traffic volume, such that the elasticities $\epsilon_{(car,j)car}^n$ are zero.

The third term in expression (5) can be rewritten as:

¹ See the articles of Newbery (1988), Jones-Lee (1990) and Jansson (1994).

² This point needs investigation about the insurance systems used by the public transport firms.

³ We refer to Vitaliano & Held (1991), Jones-Lee (1990), Great Britain, Department of Transport (1987) and US Federal Highway Administration (1982).

$$MSAC_{car}^3 = \sum_{I \neq CAR} \sum_{n=1}^4 \left(a^n + b^n + c^n \right) \epsilon_{(i,car)car}^n r_{i,car}^n \frac{X_i}{X_{car}} \quad (7)$$

$\epsilon_{(i,car)car}^n$ is the elasticity w.r.t. the number of car km of the risk of accidents between mode i and the car mode in which the users of mode i are the victim (with $i \neq car$). If the number of these accidents is proportional to the number of car km, these elasticities are equal to one. We have assumed this to be the case for all modes. This assumption is corroborated by a recent empirical study by CERTE (Dickerson, Peirson, Vickerman (1998)). In contrast with Mayeres, Ochelen & Proost (1996) the assumption also holds for accidents with non-motorized transport modes. In addition, we have assumed that the car driver is confronted with the average accident costs he causes to these transport modes, through the insurance premia he pays¹. The combination of these two assumptions entails that there are no marginal external accident costs w.r.t. to non-car transport modes.

As an illustration we apply this methodology to the city of Brussels and interregional transport in Belgium. The results are presented in Table 5.8.

Table 5.8: The marginal external accident costs for Brussels and Belgium 2005 (in mECU(1990) per vkm)

	Brussels 2005	Belgium interregional 2005
Car	32.65	45.70
Bus	23.47	62.64
Tram	25.53	
Metro	2.61	
Truck	96.42	47.63

It should be mentioned that the monetary value of the different accident cost categories is different from Mayeres, Ochelen & Proost (1996). In contrast to that paper, we choose not to include the willingness to pay of relatives and friends of the victim to avoid the accident. In this we follow ExternE, which points to the high uncertainty associated with the findings of the economic literature on this part of the valuation.

¹

This is a strong assumption. First of all, it can be argued that insurance mainly covers the so-called "cold-blooded" accident costs and only to a minor extent the other cost categories. If this is the case, the costs associated with the WTP of the victims and their relatives and friends are partially external. Secondly, it can be argued that the insurance premia are perceived as fixed rather than as variable costs by the car users, so that they are not taken into account into their decision whether or not to travel. This implies that the marginal social accident costs associated with the risk to non-car and nonmotorized road users are completely external. Both aspects need further analysis.

4. The Marginal External Noise Costs

The marginal external noise costs are calculated only for the urban TRENEN case studies. All of these use the results for Belgium.

4.1. Noise function

In order to calculate the marginal external noise costs, one needs to determine the effect on the noise level of an additional vehicle-km. The index for noise used is the energy mean sound level, $L_{eq}(dB(A))$. It gives the average sound level over a given period. The Institut Bruxellois pour la Gestion de l'Environnement (1995) presents a number of functions that relate the noise level in a street to, *inter alia*, the traffic flow. We assume that the average street in Brussels has a U-shape, i.e., that it has houses on both sides of the street. In that case the function is:

$$L_{eq}(A) = 53.9 + 10 \log(V_{light} + E V_{heavy}) - 10 \log l + K \quad (8)$$

where $L_{eq}(A)$ is the equivalent noise level at 2 metres of the façade. V_{light} stands for the flow of light vehicles (<3.5 t) in vehicles per hour. V_{heavy} is the flow of heavy vehicles (>3.5 t) in veh/h. E is an equivalence factor. For slopes smaller than 2% one heavy vehicle is assumed to be equivalent to 10 light vehicles. The width between the façades (in m) is given by l . K is a correction factor for speed which makes that one decibel is added for each 10 km/h above a speed of 60 km/h.

The practical problem that we face is that this function is established to compute the noise in a particular street, and not the average city-wide noise level. We have to make several assumptions to deduct an average noise function from this information. More specifically, we have to convert the PCU city-wide to the PCU of an average street. We know that the road network is approximately 2000 km long, taking all types of roads into account. However, the study of the Institut Bruxellois (1995) takes into account only the roads with relatively heavy traffic. This amounts to 500 km. We will assume that 75 per cent of all traffic is concentrated on this 500 km network, and that this is the only area where noise externalities occur¹. This means that expression (9) becomes:

¹ In the 2005 reference peak period we have a volume of 0.922 million car units per hour (in which bus, tram and truck are equivalent to 10 cars). Assuming that the noise externality is generated by 75% of this total volume on the busiest 500 km of the road network, we have 1383 car units per hour per road km. Assuming an average width between façades of 12 m, we obtain a noise level of 74.5 dB using the noise formula for U-shaped roads. Using the same assumptions in the off peak period, we have an average flow of 337.5 car units per our per km, generating a noise level of 68.3 dB.

$$L_{eq}(A) = 53.9 + 10 \log \left[\frac{0.75(V_{car} + 10(V_{bus} + V_{tram} + V_{truck}))}{500} \right] - 10 \log l + K \quad (9)$$

4.2. Monetary valuation

For the monetary valuation we use the hedonic housing market method, which is the most widely used method for the valuation of the social costs of noise. The basic idea underlying this technique is that the value of a house depends not only on its intrinsic characteristics, but is also a function of a number of environmental attributes, such as accessibility, proximity to schools, shops and parks and pollution. If the value of a house is, amongst other factors, a function of noise, this means that when individuals buy or rent a house, within their price range they have the possibility of buying a property in a quiet location rather than a similar property in a noisy location. It is reasonable to expect that *ceteris paribus* - houses located in noisy areas are of less value than those located in quiet areas. Therefore the housing market constitutes a surrogate market for noise (Pearce and Markandya, 1989). For a detailed description of the method and its strengths and weaknesses we refer to Pearce and Markandya (1989).

Nelson (1982) and Pearce and Markandya (1989) summarize the results of North American hedonic price studies on traffic noise. The majority of the findings correspond with a house value depreciation in the range of 0.4% to 0.5% per dB(A), giving a mean of 0.4%. The results refer to a standardized house value. This way one tries to eliminate the possibility that higher priced properties may have a greater depreciation than lower priced ones. Traffic noise is expressed in L_{eq} units. According to Alexandre and Barde (1987), as a rule of thumb a 0.5% house value depreciation per dB(A) constitutes a reasonable guide and is based upon a substantial number of studies. However, they point to the fact that it is probable that this depreciation rate is valid only above a certain noise threshold, say 50 dB(A) L_{eq} , since most surveys show a very low level of annoyance below this level. Furthermore, they mention the possibility that the unit percentage of depreciation increases both with the noise level and with the value of the house.

From the literature we use the average house depreciation rule of 0.5%. We assume a standardized value of 70 600 ECU per house. Thus for an increase of 1 dB which would continue during 50 years, the value of one exposed house decreases with 355 ECU. However, we need to know the value of a brief increase of the noise level. We assume an expected house life time of 50 years and a discount factor of 5% . This gives a value of

0.003 ECU(90) per dB(A) during one hour for one house. Assuming an average of 200 exposed houses per km, we obtain 0.6 ECU per dB per street of 1 km.

We assume that real housing prices remain constant between 1991 and 2005 and the valuation of 1 dB is also supposed to remain the same in the future reference situation.

4.3. Results

The total external noise cost for Brussels is the monetary value per dB, multiplied by the noise level above the threshold of 50 dB(A), multiplied by the number of road km where a noise externality is generated (we assumed 500 km *supra*)¹.

To compute the resulting marginal external noise cost (*MENC*) in the reference equilibrium, we derive the total external noise cost function with respect to the number of vehicle km. Using the noise formula (9) given above we find that the *MENC* of a car km is given by²:

$$MENC_{car} = 0.6 \left[\frac{10}{\ln 10} \frac{1}{V_{car} + 10(V_{bus} + V_{tram} + V_{truck})} \right] 500 \quad (10)$$

The resulting marginal external noise cost for the 2005 reference situation is given in Table 5.9. As expected, the marginal external noise cost generated by a vehicle is much higher in the off peak period than in the peak period hours of the day. Indeed an extra vehicle on a quiet moment causes more disturbing noise than an extra vehicle on top of a lot of congestion. By definition, the *MENC* of heavy vehicles is ten times higher than that of passenger cars.

Table 5.9: Marginal external noise cost in Brussels in 2005 [10^{-3} ECU/vkm]

	car	bus, tram
Peak	1.9	19
Off-peak	7.3	73

¹ For the reference peak period 2005 this gives (74.5dB-50dB) * 0.6 ECU * 500 km, or a total external noise cost of 7350 ECU per peak period hour in Brussels.

² In the reference peak period 2005 the marginal external noise cost of a car amounts to 0.6 ECU * 0.0000047 * 500 = 0.00141 ECU per car km. For a truck or bus this is 10 times higher. The marginal external cost in the off peak period is 0.0058 ECU per car km.

5. The Marginal External Road Damage Costs

The external road damage costs are discussed extensively in Newbery (1988). They arise when the passage of trucks causes damage to the road surface. Two types can be distinguished: the increased repair cost of the road, borne by the government and the increased vehicle operating costs for the other road users. Under a number of conditions, Newbery shows that the second type of road damage costs are negligible in all reasonable cases and that, if road damage is not only caused by vehicle passage but also by weather conditions, the cost to be charged is a fraction of the average repair cost allocated over the total number of equivalent standard axles (ESA)¹. In his 1990 study for the UK he estimates them to be 3.5 pence per ESAkm, which corresponds with appr. 0.0489 ECU per ESAkm. For an 5-axles-truck with an average load capacity of 25.3 tons and an average load factor of 44.66% (see De Borger, Swysen (1995), the average road damage externality then amounts to 1.411 mECU per vkm².

¹ One ESA is defined as $(W/8.2)^4$, where W is the load on a dual tyre single axle in tonnes.

² $1.411=5*0.0489*1000*((25.3*0.4466/5)/8.2)^4$

CHAPTER 6: CASE-STUDIES

1. Introduction

In this chapter, we summarise the main findings of the case studies. Each case study consists of two parts. First there is an analysis of a reference equilibrium that corresponds to the expected situation for 2005 with unchanged pricing policies. This analysis is the result of calibrating a TRENEN model to the observed transport price and volume data in a given zone. Next, the calibrated model is used to test several common scenarios of pricing reform. These common scenarios include cordon pricing in urban areas and tolls on motorways, resource cost pricing of parking and regulation of emission characteristics of vehicles. For the analysis of the pricing reform scenarios, two benchmarks are used. There is the reference scenario with unchanged policies and there is the optimal pricing scenario where perfect pricing instruments are assumed.

6 urban case studies and 3 interregional case studies have been made:

Table 6.1: TRENEN-II common case studies

Urban		Interregional	
Amsterdam	(VU Amsterdam)	Belgium	(SESO, UFSIA Antwerp)
Athens	(NTU Athens)	Ireland	(TC Dublin)
Bologna	(TREC-Venice)	Italy	(TREC-Venice)
Brussels	(CES-KULeuven)		
Dublin	(TC Dublin)		
London	(CERTe, Kent)		

In this chapter we represent results of common case studies where harmonised models and comparable policy alternatives have been tested. Therefore we do not present results for the Bologna and Italian case studies. In both case studies the level of aggregation over space (province or country) and over time (peak and off-peak period have more or less identical flows per hour) is different from the other 7 case studies. In fact the aggregation in these two case-studies has made the congestion problem disappear.

In section 2 we discuss the results of the urban case studies. We examine consecutively the expected reference equilibrium for 2005, the optimal pricing scenario and some more realistic policy scenarios. In section 3 we analyse the results of the interregional case

studies. In section 4 we summarise our findings on the performance and optimal use of different policy instruments. Section 5 discusses some implementation issues of new pricing policies.

2. Urban Case-studies

Table 2 supplies some key characteristics of the case studies for *Amsterdam*, *Athens*, *Brussels*, *Dublin* and *London* for the year 2005. Figures 6.1 and 6.2 give generalised prices and generalised marginal social costs for the peak and off peak period of a small petrol car driven alone by an inhabitant who does not pay for his parking at destination. The generalised price (left block for every city) includes the resource costs (except parking), taxes and own time costs. The generalised marginal social cost (right block) includes resource costs, parking resource costs, own time costs and marginal external costs. Figures 6.3 and 6.4 show the same type of information for transit per bus in the peak and the off peak. Subsidised consumer prices (variable costs not covered) appear as negative elements in the consumer price block diagrams. All price and cost information is expressed in ECU per passenger kilometer¹.

Comparison across case studies shows that per kilometre resource costs (vehicle costs, maintenance costs and fuel costs) are quite similar in all cities considered. Parking costs and time costs differ strongly. Parking costs are highest in the most densely populated cities (Athens, London) and in Amsterdam (due to strict parking supply policies). The share of drivers with access to free parking was estimated at 70% for all cities except Amsterdam (30%), where a strict parking policy is implemented in the reference situation (30% non payers). Parking costs are a substantial part of total trip costs in all cities considered. Time costs are the result of transport demand and supply conditions in the reference situation. The road networks (capacity and utilisation) in the different cities differ strongly leading to different average speeds.

When transport prices are efficient, the consumer price should equal the marginal social cost². Figure 6.1 shows that peak car use covers only one third to half of its full marginal costs. There are two main sources of discrepancies: unpaid parking and important external congestion costs. Unpaid parking³ distorts prices in the peak and off peak. Its importance

¹ 1 ECU = 1 EURO = 1,15 US dollar on Jan 4,1999.

² This is the partial equilibrium result when no account is taken of the way in which tax revenues are used. Results from the interregional model follow this approach. In the urban model, it was assumed that tax revenues are used very efficiently, such that optimal transport taxes exceed marginal external costs.

³ Unpaid parking is called an unpaid resource cost rather than an external cost. In the case of free parking for shopping and employer provided parking, households do not take this cost into account in their trip

varies across cities: parking costs are much higher in London and Amsterdam than in Brussels and Dublin. The external costs shown in the figures cover congestion, air pollution, accidents and noise.

Table 6.2: Characteristics of Case Studies

	Potential Transport users	% inhabitants	% free parking	Peak speed Km/h	Offpeak speed Km/h
Amsterdam	492 192*	70	30	13	35
Athens	4 500 000	89	70	11	25
Brussels	1 585 474	59	70	23	49
Dublin	1 260 000	21	70	19	35
London	7 498 576	89	70	27	33

*actual users

External congestion costs are high in the peak period and small (except in London) in the offpeak. The estimation of marginal external congestion costs depend crucially on the slope of the aggregate speed-flow relationship. The figures show important differences in marginal congestion costs between urban areas. These can not be explained easily (smaller in London than in other areas)¹. Figure 6.2 shows that pricing of off peak car use is much more efficient except for the parking resource costs.

Taxes are more or less equal in peak and off peak periods at present. This shows that structure and level of prevailing transport taxes in European cities are not adequate for an efficient internalisation of marginal external costs.

decision and mode choice. Ultimately the resource cost of free parking is paid by all households through higher product prices or lower wages.

¹ Part of the differences is correlated with the size of the area studied. The London network (Greater London Region) is (a) on a larger scale *and* (b) includes a much higher share of high capacity roads than the Brussels network (Brussels Region *without* principal ringroad). Factor (a) explains the relatively low time cost in London for the peak period. Factors (a) and (b) lead to low marginal external costs in London and high marginal external costs in Brussels and Amsterdam (high marginal external costs may be caused by a large number of transport users, and/or a large sensitivity of travel speed for changes in traffic volume).

Figure 6.1: Peak car reference prices and costs

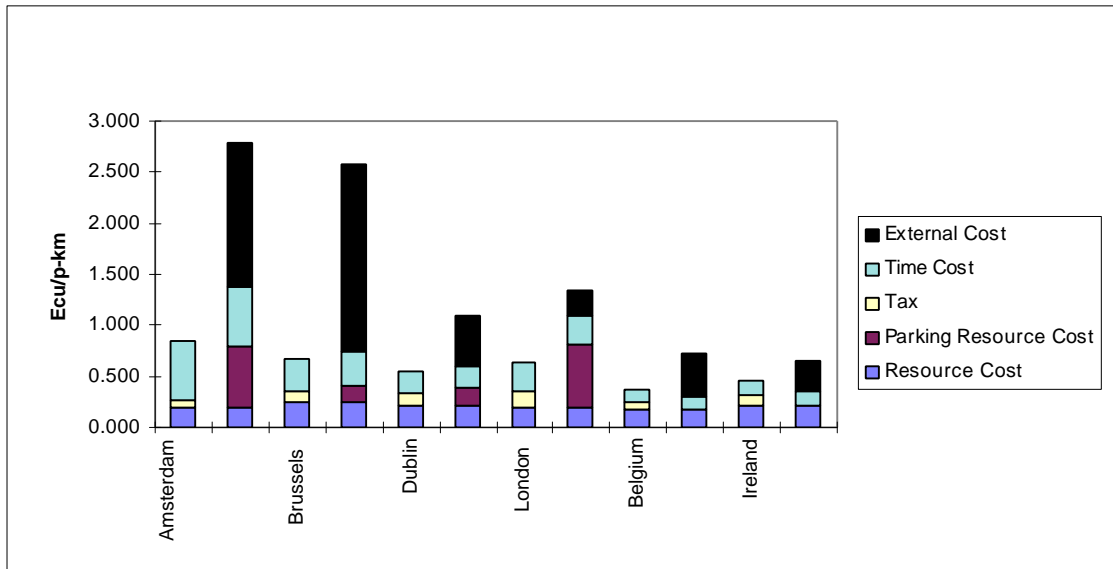
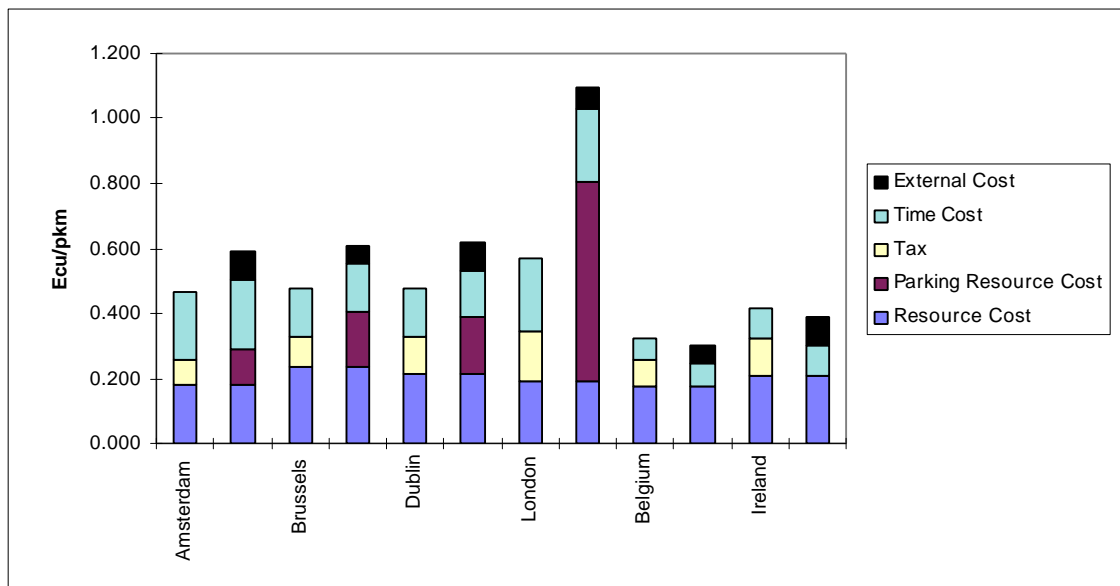


Figure 6.2: Off-peak car reference prices and costs



Figures 6.3 and 6.4 show that urban transit (here we confine ourselves to busses) also generates external costs but that prices are for these modes much better in line with social costs. In London, where subsidies for public transport are much lower, prices tend to exceed marginal social costs.

Figure 6.3: Peak bus reference prices and costs

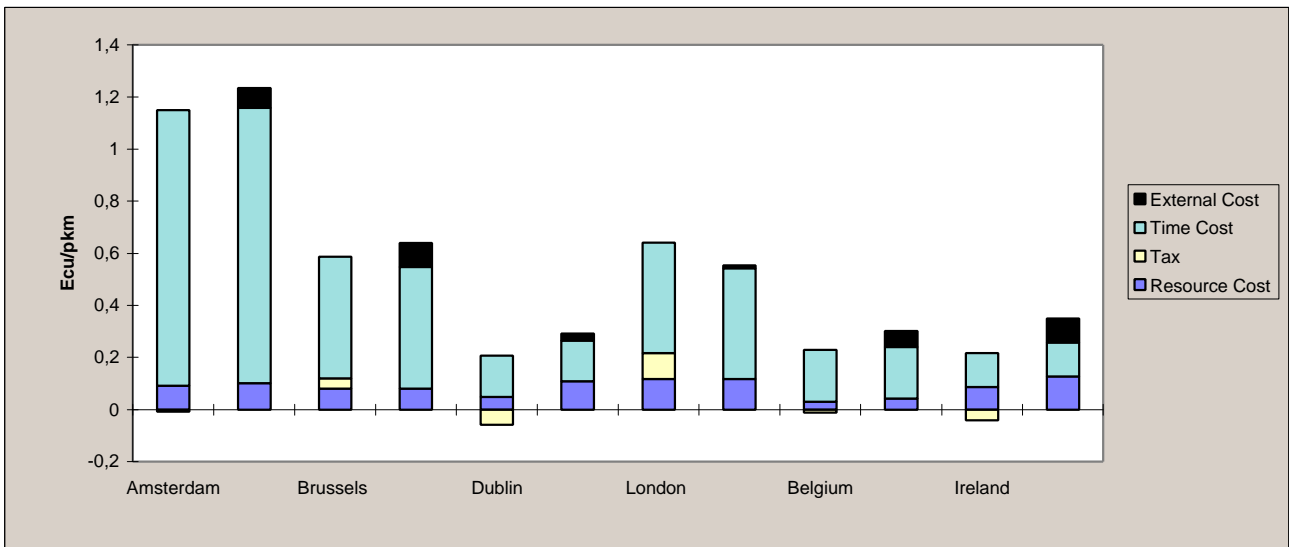
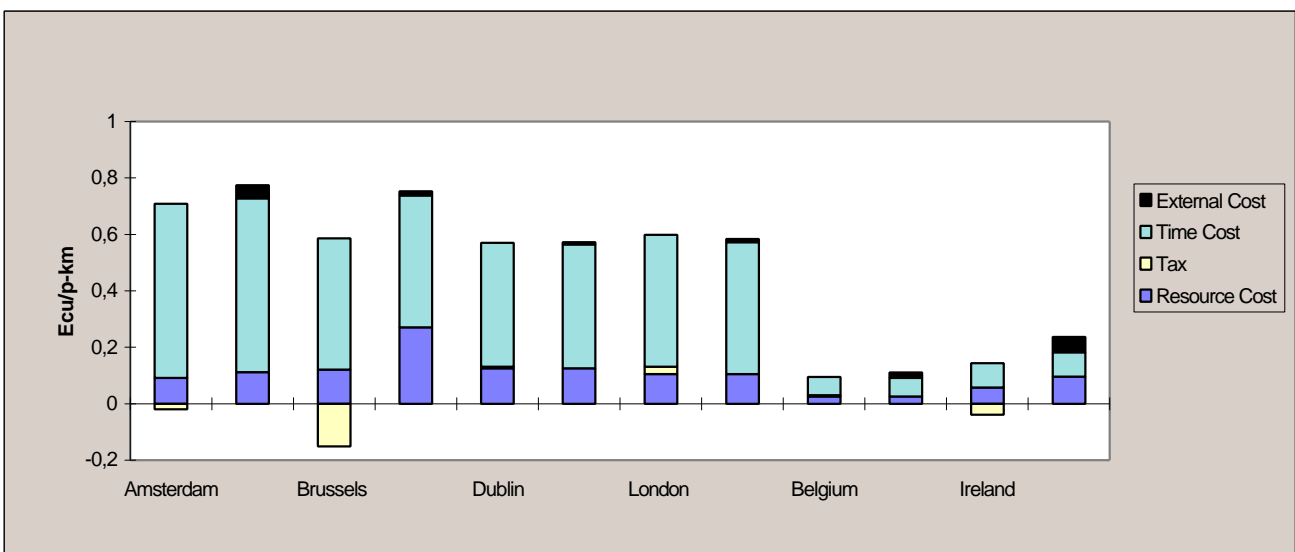


Figure 6.4: Off peak bus reference prices and costs



Urban transport pricing policies

Table 6.4 presents welfare impacts of different types of transport pricing policies. Welfare summarises the impacts on consumer and producer surplus, on government revenue and on external costs. Welfare is measured in terms of generalised income: money budget plus value of leisure time. Policy options analysed in all case studies are given in table 6.3.

Table 6.3: Description of common scenarios

scenario	existing taxes and subsidies that are abolished	policy instruments used
Optimal pricing (benchmark)	all abolished	taxes and subsidies can be differentiated by veh km or pass km according to mode, type of vehicle, time of the day
Cordon pricing	all subsidies to public transport except for fixed cost	1 cordon that is optimally differentiated between peak and off peak public transport prices are equal to marginal resource cost
Uniform pricing	fuel taxes	fuel taxes are increased to a common EU level (0.5 ECU/l per gasoline and 0,393 ECU/l of diesel) this implies small increases in most countries except for a larger increase in Greece)
Cordon pricing + parking charges	all subsidies to public transport except for fixed cost subsidies to parking	1 cordon that is optimally differentiated between peak and off peak public transport prices are equal to marginal resource cost
Uniform pricing + parking charges	fuel taxes subsidies to parking	fuel taxes are increased to a common EU level (0.5 ECU/l for diesel), this implies small increases in most countries except for a larger increase in Greece parking charges equal to resource costs
Emission technology regulation for cars (results not shown in table 4)	existing technology regulation for cars	more expensive but cleaner emission technologies reduction of emissions (except CO ₂) of some 50%
Optimised public transport prices (results not shown in table 4)	existing subsidies and taxes on public transport	public transport prices can be fixed optimally in peak and off peak

Table 6.4: Welfare Impact of Alternative Policy Measures: maximal potential gain (%) and share of maximal gain

	welfare gain as % of generalised income	expressed as % of maximal gain			
	Optimal pricing	Optimal pricing	Cordon pricing	Cordon + parking charges	Uniform pricing
Amsterdam	1.29	100%	18%	76%	3%
Athens	1.70	100%	15%	67%	16%
Brussels	0.89	100%	44%	59%	8%
Dublin	0.48	100%	53%	65%	6%
London	1.04	100%	13%	87%	0%

As can be seen from table 6.4, large potential welfare gains can be achieved in most cities if theoretically optimal prices can be implemented. This is a benefit estimate before implementation costs. Moreover the estimates assume that the increases in net tax revenue from the transport sector generate a net benefit of 7% by using it to reduce existing distortionary labour taxes.

In the optimal pricing scenario peak car money prices increase strongly (+100% to +250%) to cover resource costs of parking and to cover marginal external costs. The change in prices in the optimal pricing scenario is summarised in table 6.5. Optimal prices are typically somewhat larger than marginal resource costs plus external external costs because we assume that revenues can be used to reduce distortionary labour taxes. The marginal external congestion cost that is charged in the optimum is only one third to one half of the external congestion cost measured in the reference equilibrium. The pricing inefficiencies measured in the reference equilibrium (figures 1 to 4) are therefore an insufficient guide to optimal prices. Note also that there is no need to discriminate between pooled and non pooled cars. Off peak money car prices increase also (+60% to + 180%) to cover resource costs of parking and the different external costs. Moreover optimal vehicle use prices are higher for diesel cars because of their higher external health damage costs. Finally it is optimal to impose the use of cleaner vehicles (less conventional emissions) in urban zones, certainly for diesel cars.

Table 6.5: Prices (% change wrt reference), taxes and costs (Ecu per passenger-km) for the urban case studies in the optimal pricing scenario

	<i>URBAN MODEL*,**</i>														
	Amsterdam			Athens			Brussels			Dublin			London		
	Money Price	Tax	MEC	Money Price	Tax	MEC	Money Price	Tax	MEC	Money Price	Tax	MEC	Money Price	Tax	MEC
Peak car sml pet															
Inhabitants	147%	0.912	0.800	361%	0.777	0.211	155%	0.600	0.459	116%	0.454	0.239	152%	0.544	0.112
Commuters	233%	0.842	0.800	281%	0.7654	0.211	138%	0.563	0.459	91%	0.392	0.239	128%	0.445	0.112
Offpk car sml pet															
Inhabitants	179%	0.133	0.084	230%	0.315	0.073	61%	0.204	0.051	67%	0.251	0.076	135%	0.443	0.056
Peak car sml die															
Inhabitants	146%	0.935	0.829	292%	0.992	0.404	134%	0.614	0.486	143%	0.472	0.267	176%	0.553	0.131
Peak bus															
Inhabitants	63%	0.047	0.047	-66%	0.092	0.004	38%	0.085	0.023	424%	0.149	0.012	23%	0.150	0.005
Offpeak bus															
Inhabitants	-1%	-0.021	0.046	20%	0.071	0.004	210%	0.101	0.015	124%	0.169	0.006	71%	0.119	0.009

* Improved system of parking charges

** Improved technologies

The strong increase of car user prices goes together with an important adjustment of the public transport prices. For use of busses in the peak period, optimal prices increase by 23 to 424% as subsidies are now replaced by taxes to cover the different costs. For urban rail services price increases are smaller as their external costs are smaller. Off peak prices for busses increase strongly when there were high subsidies in the reference situation.

The drastic price changes generate only relatively small reductions in the total volume of transport. There are two reasons for this. First, passenger transport is price inelastic. Secondly higher money prices are compensated partly by reduced time costs. The total volume across all modes and measured in passenger kilometre, declines by 7 to 14%. Peak car use declines by 20 to 33% and off peak car use by 8 to 41%. Off peak car use decreases will be particularly high where there is unpriced congestion and unpaid parking.

The change in volumes in the optimal pricing scenario are summarised in table 6.6.

The optimal volume of peak public bus transport is higher in most cities (up to 34%) except in one city (Dublin) where there are excessive subsidies in the reference. Off peak public transport use increases in the reference. Off peak public transport use increases strongly in some cities (53 to 84%) and decreases in those where subsidies were too high. Volumes of urban rail transport increase everywhere.

Table 6.6: Total volume and composition of traffic (% change wrt reference) in urban case studies in the optimal pricing scenarios

	<i>URBAN MODEL*,**</i>				
	Amsterdam	Athens	Brussel	Dublin	London
Peak private	-28%	-49%	-22%	-19%	-33%
Peak public	34%	98%	28%	-30%	32%
Offpeak private	-19%	0	-8%	-14%	-41%
Offpeak public	53%	36%	-22%	0%	84%
Total volume	-6.66%		-8.25%	-14.32%	-13.73%

* Improved system of parking charges

** Improved technologies

For urban areas, the optimal pricing scenario generates an important net increase in tax revenues (all taxes minus all subsidies to public transport). Households will therefore only experience a net welfare increase when the returned tax revenue is also taken into account. A mix of instruments will be needed to approach this optimal pricing scenario.

One of the obvious policy mixes is to keep all taxes at their present level and add a cordon toll (differentiated between peak and off peak) together with resource pricing for public transport. This is the *cordon pricing scenario* described in table 3 and reported in table 4. The placement of the cordon will determine its effectiveness. The higher the proportion of commuters that are affected by the tolls, the more effective will be the cordon pricing. This is the reason why cordon pricing is rather effective in Brussels and Dublin. The optimal cordon tolls are high: money price increases for commuters in the peak between 90 and 248%. The overall effectiveness of the scenario is limited because the congestion externality can only be corrected for part of the car users. In fact the inhabitants even increase their peak car use because they are attracted by the higher speed. Moreover the free parking problem and the misuse of diesel cars in urban areas is not corrected in this scenario.

Adding to the *cordon pricing scenario* the *pricing of parking at resource cost* improves strongly the overall efficiency. Particularly in those cities where the parking costs are high. This mix of instruments is not yet perfect because the external congestion cost of the inhabitants is not directly addressed. Moreover the external air pollution costs are not minimised.

The *uniform pricing scenario* shows that a small increase of fuel taxes is not effective at all to cope with the different pricing inefficiencies. Of course one could try higher increases, this could reduce peak traffic levels and off peak traffic levels and reduce the use of diesel cars. This instrument has some effectiveness in urban areas but will at the same time discourage off peak non urban peak car use too much. Moreover it will spur excessive efforts to increase the fuel efficiency of cars. These efforts will be cost-effective for consumers but not for society because the consumer price of fuel exceeds the resource cost plus the marginal air pollution cost of fuel.

Adding parking *resource pricing to the fuel price instrument* improves the efficiency greatly in these cities where unpriced parking is the biggest problem.

With respect to the *regulation of emission technology of cars*, it can be shown that this measure on its own can *maximally* achieve 4.5% of the maximum welfare gain. Detailed analysis of this policy option shows zero or slightly negative welfare effects for Brussels. While it can be interesting to impose stricter emission regulations for cars in large urban areas (certainly for diesel cars), this policy addresses only one of the minor pricing inefficiencies found in urban transport markets.

3. Interregional Case-studies

The interregional model focuses on passenger and freight transport simultaneously. In terms of volume, freight transport can be as important as passenger transport. We discuss first the inefficiencies in passenger transport.

Passenger transport

Interregional passenger transport pricing inefficiencies are in general less important than in the case of urban transport. This becomes clear from inspecting the right hand part of figures 6.1 to 6.4 where results for non-urban transport in Belgium and in Ireland are presented. As in the case of urban transport, we focus on the differences between the generalised price and the generalised marginal social cost for two typical modes (small gasoline car and bus) in the peak and off peak period.

Prices of peak period car use do not cover marginal external congestion costs. The congestion cost itself is however smaller than in urban areas. In the off peak period, cars pay slightly more than their marginal social cost. Public transport pricing inefficiencies exist but are less important per kilometre than in urban markets. Non-urban bus transport is heavily subsidised and underpriced in both cases.

Three policy scenarios have been examined for the interregional passenger and freight transport.

Table 6.7: Definition of common policy scenarios for non-urban zones

scenario	existing taxes subsidies abolished	policy instruments used
Optimal pricing (benchmark)	all abolished	taxes and subsidies can be differentiated by vehkm, passkm or tonkm according to mode, vehicle and time of the day
Congestion pricing	public transport subsidies on variable costs are abolished public transport priced at resource cost	toll differentiated between peak and off peak period on highways (Belgium) and all roads (Ireland)
Uniform pricing	fuel taxes	fuel taxes are increased to a common EU-level (0.5 ECU/l for gasoline and 0.393 ECU/l for diesel), this comes down to small increases in most countries. Additional fee of 1000 ECU/year for trucks and 100 ECU for cars for the use of highways.

Table 6.8: Welfare Impact of Alternative Policy Measures: maximal potential gain (%) and share of maximal gain

	Potential welfare gain (% of total generalised income)	Optimal Pricing	Congestion Pricing	Uniform Pricing
Belgium	0.80%	100%	83%	8.5%
Ireland	0.29%	100%	59%	-1.2%

The required changes in prices and volumes in the optimal pricing scenario are summarised in the two following tables. In the optimal pricing scenario, the correction of the pricing inefficiencies requires increases in the money-prices for peak car transport of 35 to 45% that lead to volume reductions in the peak of about 10%. Off peak prices have to decrease by 5 to 10%. The maximal welfare gains that can be achieved by better pricing policies are substantial. In the optimal pricing scenario, the overall volume of transport (passkm) does almost not decrease (- 2%). There are however important shifts away from peak car use to off peak car public transport. The volume of off peak transit decreases because the very high subsidies to cover variable costs are abolished in the optimal pricing scenario.

Table 6.9: Prices (% change wrt reference), taxes and costs (Ecu per passenger-km) for the interregional model in the optimal pricing scenario

	<i>INTERREGIONAL MODEL*</i>					
	Belgium			Ireland		
	Money Price	Tax	MEC	Money Price	Tax	MEC
Peak car small petrol Inhabitants	45%	0.195	0.195	38%	0.234	0.233
Offpeak car small petrol Inhabitants	-10%	0.056	0.056	-6%	0.097	0.096
Peak car small diesel Inhabitants	79%	0.202	0.202	57%	0.240	0.239
Peak bus Inhabitants	127%	0.027	0.028	143%	0.082	0.082
Offpeak bus Inhabitants	47%	0.018	0.020	110%	0.056	0.056

* improved technologies

Table 6.10: Total volume and composition of passengers traffic in interregional case studies in the optimal pricing scenario

	<i>INTERREGIONAL MODEL*</i>	
	Belgium	Ireland
Peak private	-12%	-9%
Peak public	11%	-33%
Offpeak private	7%	6%
Offpeak public	-20%	-19%
Total volume	-28.6%	-2.35%

* improved technologies

For the non urban zones considered, optimal pricing yields substantial increases in net revenues (taxes-subsidies). The increase is smaller for passenger transport (+25% to +29%) than for freight transport (+233% and more).

In the congestion pricing scenario, the money price of peak car transport is raised by 35 to 40% and this allows to obtain an important part of the welfare gain. In this scenario, public transport is priced at resource cost so that also the inefficient part of the subsidies is corrected.

In the uniform pricing scenario, the price increase is not differentiated between peak and off peak car use so that the welfare effects are at best poor.

Freight transport

The existing pricing inefficiencies in domestic freight transport are shown in figures 5,6 and 7. For trucks, the prices are smaller than the marginal social costs in the peak period . The major external cost is again congestion. When subsidies are not excessive, as they are in Ireland, the prices of rail are closer to the marginal social cost. Because external costs of inland waterways are small, prices and marginal social costs are roughly in line with each other.

Figure 6.5: Peak truck reference prices and costs

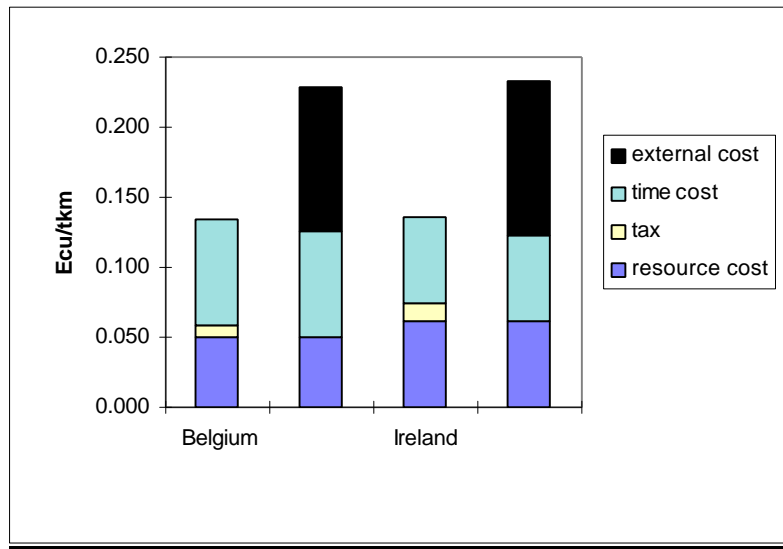
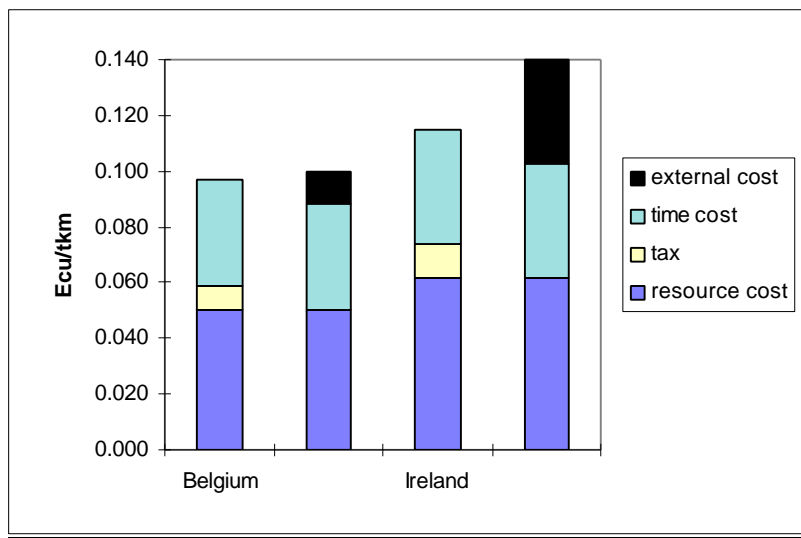
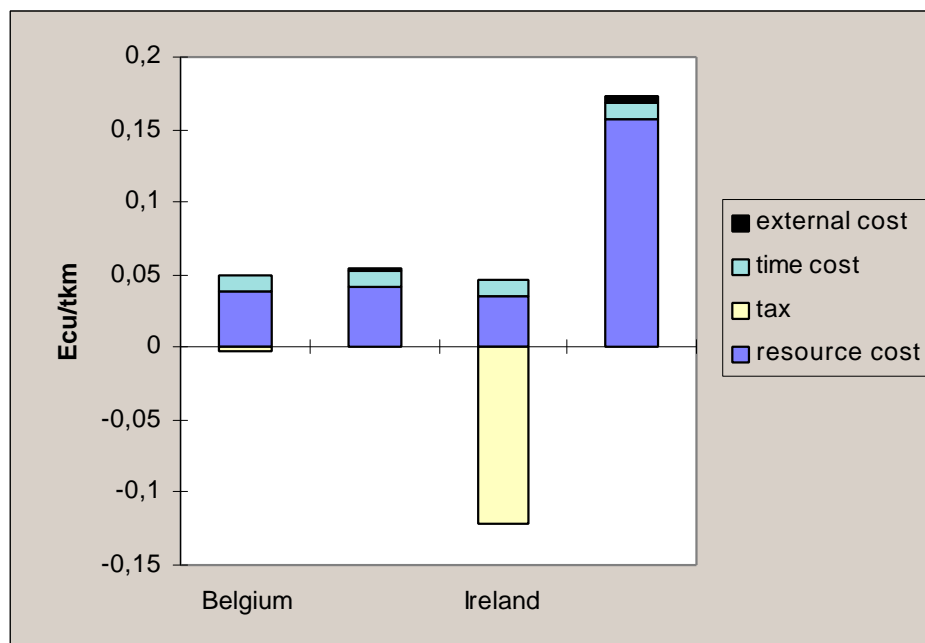


Figure 6.6: Off-peak truck reference prices and costs



Optimal pricing of trucks requires money price increases of 63 (Belgium) to 100% (Ireland). Off peak prices are raised by 7 to 36%. Prices of rail services increase too by 15% (Belgium) to 350% (Ireland). No major price change is required for inland waterways in Belgium. These price changes cause an overall decrease of freight transport volume of 4 (Belgium) to 7% (Ireland). The share of rail decreases and the market share of inland waterways increases in Belgium.

Figure 6.7: Rail reference prices and costs



Price changes and volume changes for freight are summarised in the next two tables.

Table 6.11: Prices (% change wrt reference), taxes and costs (Ecu per tonne-km) in the optimal pricing scenario

	Belgium			Ireland		
	Money	Marginal		Money	Marginal	
	Price	exter. cost		Price	Tax	exter. cost
FREIGHT (domestic)						
Peak road	63%	0.046	0.046	100%	0.085	0.085
Offpeak road	7%	0.013	0.013	36%	0.039	0.038
railways	15%	0.003	0.003	353%	0.004	0.004
waterways	0%	0.004	0.004	-	-	-

Table 6.2.2 Volumes, composition of traffic and speeds (% change wrt reference)

	Belgium		Ireland	
	Volume	Speed	Volume	Speed
Domestic freight				
Road	-3%	peak: 5% (87%) Offpk: 0% (0%)	1.50%	peak:12.11% Offpk:-1.30%
Railways	-12%	0%	-87.85%	0%
Waterways	3%	0%	n-m~	n-m~
Transit freight				
Road	4%	same as domestic	n-m	n-m
Railways	-26%	same as domestic	n-m	n-m
Waterways	9%	same as domestic	n-m	n-m
Total volume	-3.73%		-7.44%	

~ not modeled

Congesting pricing on motorways can be an effective way to control external congestion costs in interregional transport. Raising fuel prices, even in a harmonised way over Europe is not very efficient because off peak passenger and off peak truck consumer prices are not systematically lower than the marginal social cost.

The need for international coordination

The previous case studies have all considered countries or urban zones in isolation. This is not very realistic as in some countries international traffic flows are important.

In a separate case-study with the Belgian model the benefits of policy coordination were examined numerically. In the model, two countries (Belgium and an aggregate of the neighbouring countries) can set their policy variables (taxes, regulations) either independently (Nash equilibrium, see table 3.1) or in coordination. It was shown that both equilibria will generate different outcomes. Differences can be expected to be especially large for freight transport and for small open economies where international transport flows are an important share of the total.

4. Performance and Optimal Use of Different Policy Instruments

The case studies reported do not cover the whole of the EU and their results depend on the very simple model structure and the many assumptions on resource costs, external costs and transport behaviour. Nevertheless the case studies have allowed to advance some working conclusions on the relative performance of different policy instruments. We start with the effects of the simplest policy instruments, ending with the more sophisticated ones.

- parking policies

Making all road users pay for the resource cost of their parking place plus an extra charge can be a very effective instrument. It corrects the parking inefficiency and reduces at the same time the congestion externality. This achieves between 30% and 65% of all potential welfare gains in urban areas.

- improved car emission technologies

Using taxes or standards to favour the introduction of cleaner cars is an important instrument for urban areas, in particular for limiting the emissions of diesel cars. The investment in cleaner cars is not necessarily justified in non-urban areas. This instrument can be responsible for between 1 and 4% of maximal potential welfare gains.

- fuel tax policies

Higher fuel excises could reduce car traffic in urban areas and in non urban areas in the peak. For this reason, fuel tax instruments can be effective. They also reduce non-urban passenger and freight road transport in the off peak period and this is not necessarily justified. Increased fuel excises are therefore not a good instrument to improve pricing on transport markets. The fuel price instrument is flawed because of two additional problems. First, fuel prices cannot be differentiated strongly between countries without stimulating important tax evasion efforts by international transport. Second, too high fuel excises stimulate the use of excessively fuel efficient cars and trucks, which is another form of inefficient tax evasion. This tax evasion is inefficient because, given present levels of fuel excises, the marginal cost of avoiding fuel consumption has become much higher than the marginal social cost of fuel use.

- reduced subsidies to public transport

Once one can correct the pricing of car transport, it is no longer justified to set tariffs much below the marginal social cost for public transit. Optimal transit prices differ between peak and off peak periods and should cover also the marginal external costs.

- simple congestion pricing

The simplest congestion pricing is cordon pricing in urban areas and congestion pricing on interregional highways. If this can be combined with an elimination of subsidies for variable costs of public transport, important welfare gains are possible. For urban areas these gains vary from 16% to 60% (depending on the location of the cordon) and for interregional transport between 60% and 83% of the potential maximal welfare gains.

5. Implementation of New Pricing Policies

The case studies have shown that we need new pricing policies for transport. The two major elements of the new policies are the overall higher price levels and their degree of differentiation over time and over space. A general increase of the price levels of transport and appropriate differentiation brings them in line with the corresponding marginal social costs. Of course, the translation of simulation results of highly simplified models to policy making raises many new issues. We discuss five of them: the reliability of the results, the costs of implementation, the use of tax revenues, the division of authority and the relation with environment and safety policies.

5.1. Reliability of results

The main contribution of using highly simplified models is to advance a direction of reform that is logical and internally consistent. Of course, using simple models to simulate important changes comes at a cost and is always somewhat risky. Therefore, the results need confirmation in several ways. More sensitivity tests and use of the models on a larger part of the European Community are needed as well as verifications on the basis of more detailed models and experiments. Network models can provide the necessary spatial disaggregation; dynamic models are well suited to study in more detail the optimal transition to better pricing instruments.

5.2. Implementation costs of road pricing

In the simulation results no account has been taken of the transaction costs of new pricing technologies like road pricing. The implementation costs consist of the costs of extra equipment in the vehicles, sensor equipment along the roads and operating costs. The latter may include important enforcement and monitoring costs. We have not studied the practical implementation and it is therefore difficult to advance cost estimates for the different cities and countries. Previous studies have shown that the cost of the simpler

pricing systems (e.g., one or two city cordons) cost about 30 to 50 ECU per car per year. This amounts to some 20 to 30% of the gross benefits of congestion pricing. Moreover the cost of these systems decreases every year due to learning effects and technological evolution. A reliable and cheap road pricing technology with technical specifications that are harmonised all over Europe is a prerequisite for the pricing reforms studied in this paper.

5.3. Use of congestion tax revenues

The pricing reforms studied can be an important source of net tax revenue. The internalisation of marginal external costs of cars and trucks is a source of additional tax revenue. For public transport the case is different from country to country. In some cities and countries, the marginal resource costs of public transport are not covered by the fares and this subsidy is no longer justified for efficiency reasons when the other modes can be priced correctly. In other countries an important extension of public transport is justified and this could, given the decreasing marginal social cost of public transport, require higher subsidies.

In the analysis it has been assumed that the net revenue from the transport sector is used in an efficient way in the rest of the economy. The implicit assumption has more specifically been that these revenues are used to decrease other existing distortionary taxes (e.g., taxes on labour). When this efficient use of tax revenue is guaranteed, optimal taxes in the transport sector should in general be higher than the marginal social costs. Of course if the increased tax revenue is used inefficiently by spending it on non-justified projects in the transport sector or in other sectors, the optimal level of taxes in the transport sector could very well be much smaller than proposed here.

In general one advocates two ways of using the extra revenue. The first is an investment in road infrastructure and in public transport. Investments in road infrastructure (beyond adaptation of network to road pricing) are not necessarily justified just because there are funds available. Road pricing will decrease the use of existing roads to the most efficient level and can be seen as a short term substitute for road extension projects. It is the new, lower level of road use that should be considered as the basis for investment appraisal. Investments in public transport infrastructure are probably needed in most cities and regions. There is however no relation between the net revenue from optimal pricing in the transport sector and the needs for subsidies to public transport. Every project has to be judged on its own merits given the transport demand levels that can be expected with new pricing. An important second type of claim on the increased tax revenues on the transport sector is based on an income distribution argument. One can try to compensate all victims

of higher transport taxes, and in particular low income groups. To compensate all victims is technically infeasible and not efficient. On average all households will be compensated by lowering existing taxes and by improved transport quality (higher speeds in peak periods). The poor households may need a specific compensation because of equity concerns. The best way to do this is via specific income supplements rather than via reduced transport prices (see Mayeres & Proost, 1997). As a consequence distributional arguments do not provide a compelling reason not to account for external costs in pricing structures.

5.4. Who decides best on new prices ?

The most important feature of more efficient pricing systems is their adaptation to local transport conditions. This requires that the levels of taxes on road use are not fully harmonised at a European level. On the contrary they need to be varied, both between urban and non-urban areas and between different cities. One implication of optimal pricing is that the role of fuel taxes and registration taxes decreases, because road pricing systems take over their revenue and regulating function. This requires that the authority on pricing decisions will have to move at least partly from the European level to the national and local levels. This raises two issues. First, what is the appropriate reallocation of transport tax revenues over levels of government. There will be a shift of tax resources to the more local levels and this requires compensations for the other governmental levels if there is no parallel shift in public expenditure responsibilities. The second problem has to do with the incentive of local governments to implement correct pricing levels. Local governments have superior information on local transport conditions but may abuse the new instrument to engage in tax practices where non-residents pay more than the marginal external costs. This can only be avoided partly by requiring non-discriminatory road pricing as the local governments may systematically charge more on routes or modes that are used more frequently by non residents.

5.5. Safety and pollution policies

This study addresses several types of externalities simultaneously. The case studies have mainly been focused on the congestion externality. The major policy instrument studied has been the price of different transport modes at different times of the day. As the congestion problem is directly linked to the flow of transport this is the most performant instrument. Accident externalities and air pollution externalities have been reduced simultaneously but other complementary instruments should be used to reduce them. In the case studies the forced introduction of cleaner vehicles has been studied briefly. This

needs to be complemented by instruments that address the present variance in car emissions as a function of make, age, fuel quality and maintenance. The same holds for the noise and road damage externalities. Also the accident externalities need to be addressed with specific instruments that pay attention to the driver's behaviour (insurance and liability incentives) and to the potential of infrastructure and road safety policies.

REFERENCES

- An. (1997), ExternE Transport, *ExternE, The Newsletter of the EC Study on the Externalities of Energy*, July, Issue 5, 1-6.
- Arnott and Grieson (1981), Optimal Fiscal Policy for a State or Local Government, *Journal of Urban Economics*, 9, 23-48.
- Arnott R., De Palma A., Lindsey R. (1993), A Structural Model of Peak-Period Congestion: A Traffic Bottleneck Model with Elastic Demand, *American Economic Review*, 83, 1, 161-179
- Assessments Policy and Methods Division.
- Atkinson A., Stiglitz J. (1980), *Lectures on Public Economics*, McGraw Hill, London.
- Bickel P., Schmid S., Krewitt W., Friedrich R. (eds.) (1997), *External Costs of Transport in ExternE*, Final Report
- Bovenberg A.L., De Mooij R.A. (1994), Do Environmental Taxes Yield a Double Dividend, *American Economic Review*, 4, 1085-1089.
- Bovenberg A.L., Goulder L.H. (1996), Optimal Environmental Taxation in the Presence of Other Taxes: General-Equilibrium Analysis, *American Economic Review*, 86, 4, 985-1000.
- Bovenberg and Van der Ploeg (1994), Environmental Policy, Public Finance and the Labour Market in a Second Best World, *Journal of Public Economics*, 55, 349-390.
- Bradley, M. (1990), *Application of the VOT Models to Obtain Representative Average Values of Time*, Hague Consulting Group, The Hague.
- Bradley, M. and H. Gunn (1991), Further Application and Validation of the Netherlands Value of Time Study. paper presented at the 6th International Conference on Travel Behaviour, Quebec.
- Dahlby B. (1995), Fiscal Externalities and the Design of Intergovernmental Grants, paper presented at the 51st congress of the International Institute of Public Finance, August, Lisbon.
- De Borger B. (1997), Optimal Pricing of Public Final and Intermediate Goods in the Presence of Externalities, *European Journal of Political Economy*, Forthcoming.
- De Borger B. and Swysen D. (1997), Optimal Pricing and Regulation of Transport Externalities: A Welfare Comparison of Some Policy Alternatives, *Working Paper 13.97, Fondazione Eni Enrico Mattei, Milan*.
- De Borger B., Mayeres I., Proost S., Wouters S. (1996) Optimal Pricing of Urban Passenger Transport, A Simulation Exercise for Belgium, *Journal of Transport Economics and Policy*, January, 31-54.
- De Borger B., Ochelen S., Proost S., Swysen D. (1997), Alternative Transport and Regulation Policies: a welfare theoretic analysis for Belgium in 2005, *Transportation Research-D*, vol. 2, 1, 177-198.
- De Borger, B. and D. Swysen (1995), *TRENEN-Interregional, Model Documentation*, SESO.
- Diamond P.A., Mirrlees J.A. (1971), Optimal Taxation and Public Production I: Production Efficiency, *American Economic Review*, 8-27.
- Diamond P.A., Mirrlees J.A. (1971), Optimal Taxation and Public Production II: Tax Rules, *American Economic Review*, 261-278.
- Dickerson, A., J. Peirson, R. Vickerman (1998), The relationship between road accidents and traffic flow, *TRENEN-deliverable D7bis*.

- EC doc II/576/95-EN (1995), *A Welfare Cost Assessment of Various Measures to Reduce Pollutant Emissions from Passenger Road Vehicles for the year 2010*, Final Report, 12 October.
- Glaister S., Lewis D. (1978), An Integrated Fares Policy for Transport in London, *Journal of Public Economics*, 9, 341-355.
- Gordon (1983), An Optimal Taxation Approach to Fiscal Federalism, *Quarterly Journal of Economics*, 98, 567-586.
- Great Britain, Department of Transport (1987), *COBA 9*, Department of Transport,
- Gwilliam K.M. (1993), Transport Policy in an International Setting; in: Polak, Jacov and Arnold Heertje, *European Transport Economics*, Oxford and Cambridge, 244-265.
- Hague Consulting Group (1990), *The Netherlands' 'Value of Time' Study: Final Report*, Den Haag, Hague Consulting Group.
- Halcrow Fox (1996), Transport Research APAS - Urban Transport VII-28: Pricing and Financing of Urban Transport, ECSC-EC-EAEC, Brussels-Luxembourg.
- Hansson I., Stuart C. (1985), Tax Revenue and the Marginal Cost of Public Funds in Sweden, *Journal of Public Economics*, 27, 331-353
- Holland, M. (1997), *Transfer of ExternE Data to GEM-E3 and Primes*, Draft, ETSU.
- Jansson, J.O. (1994), Accident Externality Charges, *Journal of Transport Economics and Policy*, Vol. 28, 31-43.
- Jones-Lee, M.W. (1990), The Value of Transport Safety, *Oxford Review of Economic Policy*, Vol. 6, 39-60.
- Kaitala V., Mäler K.-G. and Tulkens H. (1995), The Acid Rain Game as a Resource Allocation Process with an Application to the International Cooperation among Finland, Russia and Estonia, *Scandinavian Journal of Economics* 97 (2), 325-343.
- Kanbur and Keen (1993), Jeux sans Frontières: Tax Competition and Tax Coordination When Countries Differ in Size, *Journal of Public Economics*, 52, 141-162.
- Keller W.J. (1976), A Nested CES-Type Utility Function and Its Demand and Price-Index Functions, *European Economic Review*, 7, 175-186.
- Kirwan K.J., O'Mahony M.M., and O'Sullivan D. (1995), Speed-Flow Relationships for Use in an Urban Transport Policy Assessment Model, *working paper*, Trinity College, Dublin.
- Krutilla (1991), Environmental Regulation in an Open Economy, *Journal of Environmental Economics and Management*, 20(2), 127-142.
- Laffont J.J., Tirole J. (1993), *A Theory of Incentives in Procurement and Regulation*, MIT Press, Cambridge.
- Markusen (1975), International Externalities and Optimal Tax Structures, *Journal of International Economics*, 15-30.
- Mayeres I. (1993), *The Private Car User Costs*, working paper, CES, Leuven.
- Mayeres I. (1993a), The Marginal External Costs of Car Use - with an application to Belgium, *Tijdschrift voor Economie en Management*, Vol. 38, 3.
- Mayeres I. (1993b), *The Private Car User Costs*, mimeo, Leuven, CES.
- Mayeres I. (1994), The Marginal External Costs of Trucks, *Working Paper*, CES, Leuven.
- Mayeres I., Ochelen S., Proost S. (1996), The Marginal External Cost of Urban Transport, *Transportation Research D*, 1, 2, 111-130.

- Mayeres I., Proost S. (1997), Optimal Tax and Investment Rules for Congestion Type of Externalities, *Scandinavian Journal of Economics*, 99, 2, 261-279.
- Merrifield (1988), The Impact of Selected Abatement Strategies on Transnational Pollution, the Terms of Trade and Factor Rewards: a General Equilibrium Approach, *Journal of Environmental Economics and Management*, 15(3), 259-284.
- Mintz and Tulkens (1986), Commodity Taxation Between Member States of a Federation: Equilibrium and Efficiency, *Journal of Public Economics*, 29, 173-197.
- Mohring H. (1972), Optimization and Scale Economies in Urban Bus Transportation, *American Economic Review*, 591-604
- Newbery, D.M. (1990), Pricing and Congestion: Economic Principles to Pricing Roads, *Oxford Review of Economic Policy*, vol. 6, pp. 22-38.
- Newbery, D.M.G. (1988), Road User Charges in Britain, *The Economic Journal*, vol. 98, pp. 161-176.
- OCDE (1991), *Annual Bulletin of Transport Statistics for Europe*.
- OECD (1996), The OECD Observer - OECD in Figures - Statistics on Member Countries, OECD-ADOBE.
- Oum T.H. and Tretheway M.W. (1988), Ramsey Pricing in the Presence of Externalitiy Costs, *Journal of Transport Economics and Policy*, vol.22, 307-317.
- Région de Bruxelles-Capitale (1993), Plan régional des déplacements , Plan IRIS, Constat et scenario tendanciel, Brussels.
- Sandmo (1975) Optimal Taxation in the Presence of Externalities, *Swedish Journal of Economics*, 77, 86-98.
- Simpson, D. and S. Malik (1996), Photochemical Oxidant Modelling, and Source Receptor Relationships for Ozone, in: K. Barrett and E. Berge (eds), *Transboundary Air Pollution in Europe*, Part 1 and Part 2, EMEP-MSC-W Report 1/96, pp. 123-144 and E:1-27.
- Small K.A. (1983), The Incidence of Congestion Tolls on Urban Highways, *Journal of Urban Economics*, 13, 90-111.
- Small K.A. (1992), *Urban Transport Economics*, Harwood Academic Publishers.
- Small K.A., Chu X. (1997) Hypercongestion, *Irvine Economics Paper*, 96-97-11, University of California, Dept. of Economics, Irvine.
- Snow A., Warren R.S. (1996), The Marginal Welfare Cost of Public Funds: Theory and Estimates, *Journal of Public Economics*, 61, 289-305.
- Stratec (1992) Plan régional des déplacements, Analyse de 'enquête 'Ménages'. Région Bruxelles Capitale, Bruxelles.
- US Federal Highway Administration (1982), *Final Report on the Federal Highway Cost Allocation Study*, USGPO, Washington.
- Vitaliano, D.F. and Held, J. (1991), Road Accident External Effects: An Empirical Assessment, *Applied Economics*, Vol. 23, pp. 373-378.
- Viton P.A. (1983), Pareto-Optimal Urban Transportation Equilibria, in: Keeler T.E., *Research in Transportation Economics*, JAI Press, Connecticut, 75-101.
- Wildasin (1987), The Demand for Public Goods in the Presence of Tax Exporting, *National Tax Journal*, 40, 591-601.
- Wildasin (1988), Nash Equilibria in Models of Fiscal Competition, *Journal of Public Economics*, 35, 229-240.
- Wildasin (1991), Income Redistribution in a Common Labor Market, *American Economic Review*, 81(4), 757-774.

ANNEX 1: LIST OF SYMBOLS

Chapter 1

a	average (marginal private) cost of a vehicle-kilometre
MECC	marginal external congestion cost
MEEC	marginal external environmental cost
MSC	marginal social cost
P_i	generalised price per vehicle-kilometre
r	marginal resource cost of a vehicle-kilometre
t	tax per vehicle-kilometre
X_i	volume of vehicle-kilometre

Chapter 2

λ	1 – marginal cost of public funds
ϕ	frequency of bus service
κ	share of non-labour income in total income
μ	marginal utility of income
μ_r	marginal utility of income in reference equilibrium
$\alpha_i, \alpha_f, \gamma_{ij}$	lagrangian multipliers
C	set of consumer goods
CC	composite consumption good
CES	constant elasticity of substitution
ec_{ij}	non-congestion marginal external costs of transport
$f = 1, \dots, F$	freight transport modes
$i = 1, \dots, I$	passenger transport modes
$j = 1, \dots, J$	transport supply technologies
$MCPE_{labour}$	marginal cost of public funds raised through labour taxes
m_i	contribution of mode i to congestion
N	identical individuals
p_i	producer price per vehicle kilometre of mode i
q_i	money price of transport mode i
q_i	generalised price of mode I
q_o	generalised price of non-transport commodities
$RC(z_l, \phi)$	total resource cost of public transport mode l
rc_{ij}	marginal resource cost per vehicle kilometre of mode i with technology j
REV	tax revenue
ρ_i	value of time for transport mode i
S_i	set of transport modes using common infrastructure
t_i	time spent in using transport mode i
T_i, T_f	operator for congestion function
T_{ii}, T_{ff}	derivative of transport time with respect to transport volume
$tmcong_k$	total marginal congestion cost of increasing use of mode k
$V(.,.)$	indirect utility function
x_f	freight transport demand for mode f

x_i	individual passenger transport demand for mode i
x_{kqi}	derivative of x_k with respect to q_i
Y	exogenous consumer income
z_{fj}	freight transport supply of mode f with supply technology j
z_{ij}	passenger transport supply of mode i with supply technology j

Chapter 3

cc	catalytic converter
CES	constant elasticity of substitution
i, j	regions
nc	non catalytic converter
p_1, p_2	price of transport services 1,2

Chapter 4

γ	elasticity of marginal labour productivity to labour supply
α	marginal utility of income
μ	share of non-labour income in total income
A	head tax
a	average wage tax rate
C	aggregate consumption good
CES	constant elasticity of substitution
FC	annual fixed cost of public transport
G	non-transport commodity
η_{cw}	compensated wage elasticity of labour supply
η_{uw}	uncompensated wage elasticity of labour supply
L	labour supply
m	marginal wage tax rate
MC _{PF}	marginal cost of public funds
MC _{PF₁}	marginal cost of public funds raised through labour taxes
N	identical consumers
P_c	fixed producer price of aggregate consumption commodity
P_g	producer price of non-transport commodity
PG	supply of public goods
P_1	fixed producer price of labour (=1)
P_x	producer price of transport commodity
TC	total annual operational cost of public transport
T_c	tax on consumption commodity
T_g	tax on non-transport commodity
T_l	tax on labour
T_x	tax on transport commodity
U(.)	utility function
V(.)	indirect utility function
VOL_p, VOL_{op}	volume of public transport inpeak (p) and offpeak (op)
$v_{p,op}$	constant variable cost of public transport in peak (p) and offpeak (op)
X	transport commodity

Chapter 5

a, b, c	parameters of congestion function
A_{ij}^n	number of accidents
a^n	willingness to pay to avoid accident
b^n	willingness to pay of relatives and friends to avoid accident
c^n	pure economic costs of accident
d_i	proportionality between bus+tram speed and car+truck speed
E	equivalence factor
$\epsilon_{car,j}^n$	elasticity of accident probability with respect to volume of vkm
ESA	equivalent standard axles
g	gramme
i	period (peak, offpeak)
j	transport mode (car, bus, tram, truck) (including external objects in case of marginal external accident costs)
K	correction factor for speed (in noise function)
Leq(A)	equivalent noise level at 2 metres from the façade
MECC _{qi}	marginal external congestion cost for mode i
MENC	marginal external noise cost
MSAC	marginal social accident costs
n	severity of accident
PCU	passenger car units
pkm	passenger kilometre
q_i	number of PCU kilometre per hour in period I
r_{ij}^n	probability of accident
s_{ij}	speed of mode j in period i in kilometre per hour
t	width in metre between façades
TAC	total accident cost
$t_{i,j}$	time in minutes to drive one kilometre by mode j in period i
tkm	tonne kilometre
Vheavy	flow of heavy vehicle per hour
vkm	vehicle kilometre
Vlight	flow of light vehicles per hour
VOT _{i,j}	value of marginal time saving for i and j
WTP	willingness to pay
X_i	volume of vehicle kilometre