

Universiteit Hasselt
Faculteit Verkeerskunde

**Modelling Private Road Transport of Flemish
Households.**

**The Mobility and Welfare Effects of Fuel Taxes
versus Tradable Fuel Rights.**

Proefschrift voorgelegd tot het behalen van de graad van

Doctor in de Verkeerskunde

aan de Universiteit Hasselt

te verdedigen door

Mark KEPPENS

Promotor:

Prof. dr. L. Vereeck

Co-promotor

Prof. dr. G. Wets

Juryleden

Prof. dr. Georges Heeren (voorzitter)

Prof. dr. Lode Vereeck (promotor)

Prof. dr. Geert Wets (co-promotor)

Prof. dr. Gerard de Jong

Prof. dr. Michel Bierlaire

Prof. dr. Cathy Macharis

Prof. dr. Willy Desaeyere

Dr. Evy Crals

2006

Cover photo: skyline Dubai 2008. ©Emaar Properties

Dubai is developing rapidly thanks to its oil revenues and now prepares its post-oil future. What do we do?

Acknowledgement

As a child, archaeological excavations always fascinated me. At home, I combed out trench-ploughed land, looking for relics of the "Battle at Neerwinden" in 1793,¹ where the Austrians defeated the French army. This defeat was the preambulatory event that would eventually lead to the melt-down of the French Revolution. Although these witnesses of historical events were made invisible for contemporary society, they are omnipresent somewhere under our feet.

The same is true for how our future transport system will look like. Just like an archaeologist unravels virgin territory looking for evidence of ancient civilisations, my doctoral dissertation explores the frontiers of knowledge in the virgin field of tradable transport permits. Like the archaeologist excavating a potential archaeological site, I started exploring the feasibility of transport permit schemes. Subsequently, both focus on the most promising spot. I thus developed a model to estimate car ownership-and-use in Flanders in order to find out the effectiveness of tradable fuel permits. However, my research does not aim to fully uncover an ancient civilisation, but rather to detect the first traces of the transport future.

Successful excavations are the work of an archaeologist who can count on a reliable support team. The same applies to scientific research.

Therefore, I owe many thanks to my supervisor, Prof. Lode Vereeck, and co-promoter, Prof Geert Wets, for the opportunity to pursue transport research in an academic setting. Back in 2001, granting a Ph.D. scholarship in transport research to an engineer at the Faculty of Economics was not a self-evident decision. Present developments at Hasselt University, such as the creation of the Bachelor/Master program in Traffic Sciences and the foundation of the

¹ A complete run-down of the Battle of Neerwinden was made by L'homme (2001)

Transport Research Institute, are clear demonstrations of their visionary ideas on transport research in Flanders.

I would like to thank the members of my advisory board for their advice during the last 4 years: Prof. Gerard De Jong (University of Leeds), Prof. Michel Bierlaire (Ecole Polytechnique Fédérale de Lausanne), Prof. Cathy Macharis (Free University of Brussels), dr. Evy Crals and Prof. Willy Desaeyere (Hasselt University). Moreover, I wish to express my gratitude to my colleagues at Hasselt University, specifically at the Transport Research Institute as well as my former colleagues at ITS (University of Leeds), DHV and KPMG.

My final thanks go to my friends and the family of my childhood and parenthood: my parents, my sisters, my partner Judith and my sons Lowie and Seppe, for who they are and what they mean to me.

Table of Content

| | |
|---|-------------|
| <i>Acknowledgement</i> | <i>i</i> |
| <i>Table of Content</i> | <i>iii</i> |
| <i>List of Figures</i> | <i>viii</i> |
| <i>List of Tables</i> | <i>xi</i> |
| <i>Nederlandse samenvatting</i> | <i>xv</i> |
| CHAPTER 1 Introduction | 1 |
| 1.1 Challenges in private road transport | 1 |
| 1.2 Research objectives | 5 |
| 1.3 Outline of this dissertation | 6 |
| 1.4 Contributions to the state of the art | 8 |
| CHAPTER 2 Theory of tradable permits | 9 |
| 2.1 Introduction | 9 |
| 2.1.1 Market-based instruments | 10 |
| 2.1.2 History of tradable permits | 10 |
| 2.1.3 Prejudices against rationing | 11 |
| 2.2 Structure of a permit scheme | 13 |
| 2.2.1 Threshold issues | 14 |
| 2.2.2 Design issues | 15 |
| 2.2.3 Implementation issues | 17 |
| 2.3 Permits versus taxes | 19 |
| 2.3.1 Combination of taxes and permits | 28 |
| 2.3.2 Discussion | 29 |
| CHAPTER 3 Tradable permits in road transport | 31 |
| 3.1 Outline of possible permit schemes | 31 |
| 3.2 Design of a tradable permit system | 33 |
| 3.2.1 Tradable Car Ownership Permits (TCOP) | 35 |

| | | |
|---|--|-----------|
| 3.2.2 | Tradable Fuel Permits (TFP) | 36 |
| 3.2.3 | Tradable Vehicle Kilometre Permits (TVK) | 40 |
| 3.2.4 | Tradable Differentiated Vehicle Kilometre Permits (TDVK) | 42 |
| 3.2.5 | Tradable Corridor Permits (TCP) | 43 |
| 3.2.6 | Tradable Cordon Entrance Permits (TCEP) | 44 |
| 3.2.7 | Tradable Parking Permits (TPP) | 46 |
| 3.3 | Qualitative evaluation of permit schemes | 48 |
| CHAPTER 4 Tradable fuel permits | | 51 |
| 4.1 | Fuel combustion and CO₂ production | 51 |
| 4.2 | Measures to reduce CO₂ emissions | 53 |
| 4.2.1 | General aspects | 54 |
| 4.2.2 | Private road transport | 55 |
| 4.3 | Standby Gasoline Rationing Plan | 58 |
| 4.3.1 | Threshold issues | 59 |
| 4.3.2 | Design issues | 59 |
| 4.3.3 | Implementation issues | 60 |
| 4.3.4 | Evaluation | 62 |
| 4.4 | Effects of tradable fuel permits | 63 |
| 4.4.1 | Reducing fuel use as a policy goal | 64 |
| 4.4.2 | Tradable permits as a policy instrument | 70 |
| 4.5 | Alternative schemes of tradable fuel permits | 79 |
| 4.5.1 | Threshold issues | 79 |
| 4.5.2 | Design issues | 80 |
| 4.5.3 | Implementation issues | 81 |
| CHAPTER 5 Literature review of car ownership-and-use modelling | | 83 |
| 5.1 | Discrete choice modelling | 83 |
| 5.1.1 | Model formulation | 83 |
| 5.1.2 | Random utility models | 85 |
| 5.1.3 | Logit distribution | 88 |

| | | |
|---|---|------------|
| 5.2 | Conventional approach of car ownership-and-use modelling | 90 |
| 5.3 | Limitations of conventional models | 90 |
| 5.3.1 | Endogeneity bias | 90 |
| 5.3.2 | Sample selection bias | 91 |
| 5.4 | Dubin-McFadden approach | 93 |
| 5.4.1 | Introduction | 93 |
| 5.4.2 | Model specification | 94 |
| 5.4.3 | Applications of the Dubin-McFadden model | 99 |
| 5.5 | Limitations of MNL modelling | 100 |
| <i>CHAPTER 6 A discrete-continuous model of car ownership-and-use for Flanders</i> | | 103 |
| 6.1 | Introduction of car ownership-and use modelling | 103 |
| 6.2 | Data sources | 105 |
| 6.2.1 | Household Travel Survey of Flanders | 105 |
| 6.2.2 | Other sources | 105 |
| 6.3 | Data manipulation | 106 |
| 6.3.1 | Item non-response | 106 |
| 6.4 | Cost calculation | 110 |
| 6.4.1 | Fixed costs | 110 |
| 6.4.2 | Variable costs | 117 |
| 6.4.3 | Company car | 121 |
| 6.5 | Summary statistics | 122 |
| 6.5.1 | Car costs | 122 |
| 6.5.2 | Car ownership | 128 |
| 6.5.3 | Car use and costs | 130 |
| 6.6 | Model specification | 133 |
| 6.6.1 | General structure | 133 |
| 6.6.2 | Model formulation | 133 |

| | | |
|--|--|------------|
| 6.7 | Estimation results | 140 |
| 6.7.1 | Sub-model 1: Number of cars owned | 140 |
| 6.7.2 | Sub-model 2.a: Type of a single car owned | 145 |
| 6.7.3 | Sub-model 2.b: Type of pair of cars owned | 148 |
| 6.7.4 | Sub-model 3.a: Use of a single car | 151 |
| 6.7.5 | Sub-model 3.b: Use of first car | 153 |
| 6.7.6 | Sub-model 3.c: Use of second car | 155 |
| CHAPTER 7 Simulation for Flanders | | 159 |
| 7.1 | Working method | 159 |
| 7.2 | Aggregation to Flemish population | 160 |
| 7.2.1 | Problem statement | 160 |
| 7.2.2 | Problem solution | 161 |
| 7.2.3 | Robustness | 164 |
| 7.3 | Simulation base case scenario | 166 |
| 7.3.1 | General simulation results of base case scenario | 166 |
| 7.3.2 | Simulation results of base case scenario by income category | 169 |
| 7.3.3 | Simulation results of base case scenario by age category | 171 |
| 7.3.4 | Simulation results of base case scenario by household's size | 174 |
| 7.4 | Simulation results of scenario 1 | 176 |
| 7.4.1 | Policy goal: Reduction to level of 1990 | 176 |
| 7.4.2 | Use of taxes (scenario 1) | 177 |
| 7.4.3 | Use of tradable fuel permits (scenario 1) | 185 |
| 7.4.4 | Discussion of taxes versus permits in scenario 1 | 187 |
| 7.5 | Simulation Scenario 2 | 200 |
| 7.5.1 | Policy goal: Reduction to meet Kyoto target | 200 |
| 7.5.2 | Use of taxes (scenario 2) | 200 |
| 7.5.3 | Use of tradable fuel permits (scenario 2) | 201 |
| 7.5.4 | Discussion of scenario 2 | 209 |

| | |
|--|------------|
| <i>CHAPTER 8 Conclusions, limitations and topics for further research</i> | |
| | 223 |
| 8.1 Conclusions | 223 |
| 8.1.1 Prioritisation of policy goals | 223 |
| 8.1.2 Policy instruments | 224 |
| 8.1.3 Model to evaluate policy instruments | 224 |
| 8.1.4 Evaluation of fuel taxes and permits | 225 |
| 8.1.5 Relevance for policy makers | 228 |
| 8.2 Limitations | 230 |
| 8.2.1 Related to the model | 230 |
| 8.2.2 Related to permit scheme | 231 |
| 8.3 Further research | 232 |
| 8.3.1 Modelling activities | 232 |
| 8.3.2 Economic analysis of permit system | 234 |
| <i>Bibliography</i> | 235 |

List of Figures

| | |
|--|-----|
| Figure 1.1: General overview of the topics discussed in this dissertation | 6 |
| Figure 2.1: Implementation stages of a cap-and-trade program | 19 |
| Figure 2.2: Efficiency losses when marginal abatement costs are uncertain... | 22 |
| Figure 2.3: Measures of welfare changes | 26 |
| Figure 3.1: General outline of TFP scheme | 39 |
| Figure 3.2: Basic model of TVK permit scheme | 41 |
| Figure 3.3: General model of the TCE permit system | 46 |
| Figure 4.1: Market players of TFP system | 64 |
| Figure 4.2: Fuel consumption as a function of vehicle speed: US tests in three different years | 67 |
| Figure 4.3: Effect of a TFP | 72 |
| Figure 4.4: Change in consumer surplus of TFP | 74 |
| Figure 4.5: The endowment effect | 77 |
| Figure 5.1: Self-selection bias | 92 |
| Figure 5.2: Discrete-continuous choice modelling | 94 |
| Figure 6.1: Evolution of depreciation rates of cars by age..... | 111 |
| Figure 6.2: Distribution of insured car owners according to Bonus/Malus score in 2000 in Belgium | 114 |
| Figure 6.3: Road tax level in 2000 in Belgium..... | 115 |
| Figure 6.4 Level of registration tax in 2000 in Belgium | 116 |
| Figure 6.5: Relative distribution of cars according to fuel type in 2000 in Belgium | 117 |
| Figure 6.6: Comparison of fuel consumption by make observed in HTS(2000) and Verbruikersunie (1997) | 118 |
| Figure 6.7: Evolution of leased company cars in Belgium..... | 121 |
| Figure 6.8: Calculation method of company car's allowance..... | 122 |
| Figure 6.9: Fixed cost distribution according to main car characteristics..... | 123 |
| Figure 6.10: Variable kilometre cost distribution according to main car characteristics..... | 124 |

| | |
|--|-----|
| Figure 6.11: Total cost distribution according to main car characteristics | 126 |
| Figure 6.12: Outline of car ownership-and-use model | 133 |
| Figure 6.13: Structure of choice set of sub-model 2.a | 134 |
| Figure 6.14: Structure of choice set of sub-model 2.b | 135 |
| Figure 7.1: Relative share of car ownership (base case) | 167 |
| Figure 7.2: Car ownership by income category (base case) | 169 |
| Figure 7.3: Annual fuel consumption of households by income category (base case) | 171 |
| Figure 7.4: Car ownership by age of household's head (base case) | 172 |
| Figure 7.5: Annual fuel consumption of households by age of household's head (base case) | 173 |
| Figure 7.6: Car ownership by household's size (base case) | 174 |
| Figure 7.7: Annual fuel consumption of households by household's size (base case) | 175 |
| Figure 7.8: Relative change of car ownership by income category (tax = 0.598 euro) | 179 |
| Figure 7.9: Absolute change (in l) of household's annual fuel consumption by income category (tax=0.598 euro) | 181 |
| Figure 7.10: Relative change (in %) of car ownership by age of household's head (tax=0.598 euro) | 182 |
| Figure 7.11: Absolute change (in l) of household's annual fuel consumption by age of household's head (tax=0.598 euro) | 183 |
| Figure 7.12: Relative change (in %) of car ownership by household's size (tax=0.598 euro) | 184 |
| Figure 7.13: Absolute change of household's annual fuel consumption (in l) by household's size (tax=0.598 euro) | 185 |
| Figure 7.14: Relative reduction levels (in %) of scenario 1 | 188 |
| Figure 7.15: Consumer losses by income category (scenario 1) | 190 |
| Figure 7.16: Relative consumer losses (in %) of scenario 1 by income category | 191 |

| | |
|--|-----|
| Figure 7.17: Consumer losses (in euro) of scenario 1 by age of household's head..... | 193 |
| Figure 7.18: Consumer losses (in euro) of scenario 1 by household's size. | 194 |
| Figure 7.19: Financial losses by income category (scenario 1)..... | 196 |
| Figure 7.20: Relative financial losses (in %) of scenario 1 by income category | 197 |
| Figure 7.21: Financial losses (in euro) of scenario 1 by age of household's head | 198 |
| Figure 7.22: Financial losses (in euro) of scenario 1 by household's size. | 199 |
| Figure 7.23: Relative change (in %) of car ownership by income category (permit level= 404)..... | 203 |
| Figure 7.24: Change in annual fuel consumption of household by income category (permit level = 404) | 204 |
| Figure 7.25: Relative change (in %) of car ownership by age of household's head (permit level = 404)..... | 205 |
| Figure 7.26: Change in annual fuel consumption of household by age of household's head (permit level = 404)..... | 206 |
| Figure 7.27: Relative change (in %) car ownership by household's size (permit level=404) | 207 |
| Figure 7.28:Change in annual fuel consumption of household by household's size (permit level = 404) | 208 |
| Figure 7.29: Relative reduction levels of scenario 2..... | 209 |
| Figure 7.30: Consumer loss by income category (scenario 2)..... | 210 |
| Figure 7.31: Relative consumer loss (in percent) by income category (scenario 2) | 211 |
| Figure 7.32: Consumer loss by age of household's head (scenario 2). | 212 |
| Figure 7.33: Consumer loss by household's size (scenario 2) | 213 |
| Figure 7.34: Financial loss by income category (scenario 2)..... | 214 |
| Figure 7.35: Relative financial loss (in %) by income category (scenario 2).. | 215 |
| Figure 7.36: Financial loss by age of household's head (scenario 2). | 216 |
| Figure 7.37: Financial loss by household's size (scenario 2) | 217 |

List of Tables

| | |
|--|-----|
| Table 1.1: Level of human needs and fulfillment by car | 2 |
| Table 1.2: Projections of the peaking of world oil production | 4 |
| Table 2.1: Comparison of efficiency losses under taxes and tradable permits | 21 |
| Table 3.1: Economic instruments to regulate road use | 32 |
| Table 3.2: Average CO ₂ emissions factors from fuel for passenger cars | 38 |
| Table 4.1: Average emissions factors from fuel combustion of cars | 52 |
| Table 4.2: Spatial effects of emission | 52 |
| Table 4.3: Policy measures to improve fuel efficiency and expected reduction rates | 57 |
| Table 4.4: Possible actions of the car user | 65 |
| Table 4.5: Relative increase in fuel consumption at speed ramps and roundabouts. | 68 |
| Table 6.1: Employed methods to handle item non-response | 109 |
| Table 6.2: Tyre set price values according to car type | 120 |
| Table 6.3: Summary statistics of cost structure of car sample | 125 |
| Table 6.4: Percentile ranking of car sample | 127 |
| Table 6.5: Summary statistics of households and number and car | 128 |
| Table 6.6: Summary statistics of number of cars, their use and costs | 129 |
| Table 6.7: Summary statistics of car use and costs by household's income | 130 |
| Table 6.8: Summary statistics of car use and costs by age of household's head | 131 |
| Table 6.9: Summary statistics of car use and costs by sex of household's head | 131 |
| Table 6.10: Summary statistics of car use and costs by household's size | 132 |
| Table 6.11: Value of socio-economic categorical data in HTS | 136 |
| Table 6.12: Definition of socio-economic dummy variables | 137 |
| Table 6.13: Definition of car-related dummy variables | 137 |
| Table 6.14: General estimation results (sub-model 1) | 141 |

| | |
|---|-----|
| Table 6.15: Values of estimated parameters (sub-model 1) | 143 |
| Table 6.16: t-values of estimated parameters (sub-model 1) | 144 |
| Table 6.17: General estimation results (sub-model 2.a) | 145 |
| Table 6.18: Detailed estimation results (sub-model 2.a) | 147 |
| Table 6.19: General estimation results (sub-model 2.b) | 148 |
| Table 6.20: Detailed estimation results (sub-model 2.b) | 150 |
| Table 6.21: General estimation results (sub-model 3.a) | 151 |
| Table 6.22: Detailed estimation results (sub-model 3.a) | 153 |
| Table 6.23: General estimation results (sub-model 3.b) | 153 |
| Table 6.24: Detailed estimation results (sub-model 3.b) | 154 |
| Table 6.25: General estimation results (sub-model 3.b) | 155 |
| Table 6.26: Detailed estimation results (sub-model 3.c) | 155 |
| Table 6.27: Estimated parameters of car use model (summary) | 157 |
| Table 7.1: Sample and population proportion by age of household's head | 161 |
| Table 7.2: Sample and population proportion by household's size and sex of household's head | 161 |
| Table 7.3: Probability weighting factors | 163 |
| Table 7.4: Cell values of our total sample | 164 |
| Table 7.5: Cell values of samples of households owning one car and two cars | 165 |
| Table 7.6: Total numbers of car by household type (base case) | 167 |
| Table 7.7: Annual kilometres travelled by household type (base case) | 168 |
| Table 7.8: Total fuel consumption by household type (base case) | 168 |
| Table 7.9: Household's fuel efficiency (in l/100km) by income category (base case) | 170 |
| Table 7.10: Household's annual kilometres travelled by income category (base case) | 170 |
| Table 7.11: Total kilometres travelled and fuel consumption by income category (base case) | 170 |
| Table 7.12: Household's fuel efficiency (in l/100 km) by age category (base case) | 172 |

| | |
|--|-----|
| Table 7.13: Household's annual kilometres travelled by age category (base case) | 173 |
| Table 7.14: Average annual kilometres travelled and fuel consumption by age category (base case) | 174 |
| Table 7.15: Fuel efficiency (in l/100 km) by household's size (base case) | 175 |
| Table 7.16: Household's annual kilometres travelled by household's size (base case) | 176 |
| Table 7.17: Average annual kilometres travelled and fuel consumption by household's size (base case) | 176 |
| Table 7.18: Total fuel consumption in Belgium | 176 |
| Table 7.19: Relative change (in percent) of car ownership-and-use (tax = 0.598) | 177 |
| Table 7.20: Relative change (in %) of fuel efficiency by income category (tax=0.598 euro) | 180 |
| Table 7.21: Relative change (in %) of fuel efficiency by age of household's head (tax=0.598 euro) | 183 |
| Table 7.22: Relative change (in %) of fuel efficiency by household's size (tax=0.598 euro) | 184 |
| Table 7.23: Relative changes (in %) of car ownership-and-use (permit level = 439) | 186 |
| Table 7.24: Relative changes (in %) of car ownership-and-use (tax= 1.206 euro) | 200 |
| Table 7.25: Relative changes (in %) of car ownership-and-use (permit level=404) | 202 |
| Table 7.26: Relative change of fuel efficiency by income category (permit level=404) | 203 |
| Table 7.27: Relative changes of fuel efficiency by age of household's head (permit level = 404) | 205 |
| Table 7.28: Relative changes of fuel efficiency by household's size (permit level=404) | 207 |
| Table 7.29: Estimation of the transaction costs of the TFP scheme | 221 |

Nederlandse samenvatting

Een model voor privaat wegverkeer in Vlaanderen. De mobiliteits- en welvaartseffecten van brandstofaccijnzen versus verhandelbare brandstofrechten voor Vlaamse gezinnen.

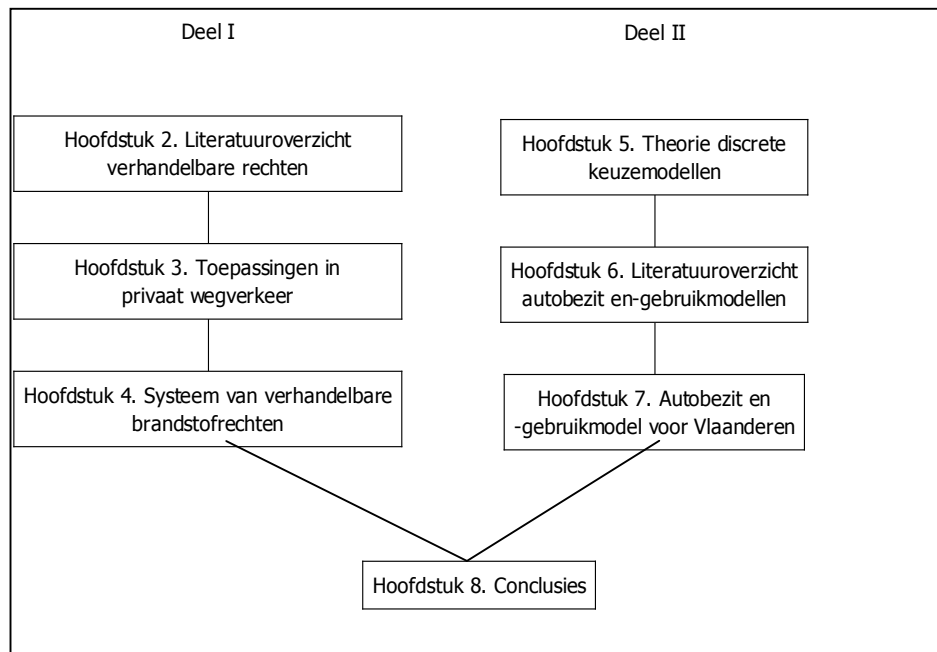
De succesvolle introductie van de personenwagen als vervoermiddel in het privé-transport heeft enkele belangrijke neveneffecten. De auto levert niet enkel en alleen voordelen op voor de gebruiker, doch creëert ook belangrijke negatieve (externe) effecten voor de maatschappij zoals congestie, ongevallen, vervuiling, ruimtegebruik en aantasting van de menselijke gezondheid. Deze milieu- en gezondheidseffecten worden voornamelijk veroorzaakt door de keuze van fossiele brandstoffen, met name olieproducten als energiebron. Tot op heden werden er nog maar weinig vragen gesteld over de blijvende beschikbaarheid van deze fossiele brandstoffen. In de academische wereld zijn er twee stromingen. Enerzijds, de School van Adelman, die argumenteert dat oliereserves bepaald worden door productieprocessen eerder dan geologische beperkingen. Anderzijds, de School van Hubbert, die oliereserves beschouwt als een beperkte voorraad, die afneemt naarmate de productie stijgt. Bijgevolg zal de olieproductie tot een maximum stijgen om nadien te dalen.

De toekomstverwachtingen over dergelijke piek in de olieproductie lopen sterk uiteen. Sommige onderzoekers voorspellen dat deze piek zich het komende decennium zal manifesteren, anderen zijn van mening dat dit later zal gebeuren of zelfs helemaal niet.

Naast de externe effecten veroorzaakt door het gebruik van fossiele brandstoffen, is er dus ook de onzekerheid of de steeds toenemende mondiale vraag naar deze brandstoffen kan verzekerd blijven. De reductie van het brandstofgebruik is dan ook een relevante beleids- en onderzoeksvraag. Dit onderzoek ambiëert een uitbreiding van het beleidsinstrumentarium om brandstofgebruik te verminderen. De doelstellingen van dit onderzoek zijn tweeledig. Vooreerst wenst dit onderzoek de haalbaarheid van verhandelbare

rechten in de private transportsector na te gaan. De tweede doelstelling omvat de welvaartseffecten op verschillende huishoudcategorieën van brandstofaccijnzen en verhandelbare rechten te vergelijken. Dergelijke analyse vereist specifieke modellen die het gedrag van huishoudens voorspellen. Hiertoe zullen we op basis van de resultaten van het "Onderzoek Verplaatsingsgedrag Vlaanderen 2001" een (econometrisch) autobezit en – gebruik model ontwikkelen.

Het onderstaand schema geeft een overzicht van de thesisopbouw



We onderscheiden twee onderzoeklijnen. In de eerste onderzoeklijn (hoofdstuk 2 tot en met hoofdstuk 4) wordt onderzocht hoe verhandelbare rechten in het private wegvervoer kunnen toegepast worden. In de tweede onderzoeklijn (hoofdstuk 6 tot en met hoofdstuk 7) wordt een nieuw instrument ontwikkeld om beleidsinstrumenten in de Vlaamse transportsector te evalueren.

Hoofdstuk 2 omvat de theorie van verhandelbare rechten. Door het uitgeven van een beperkt aantal rechten kan de overheid het gebruik van een bepaald

goed vastleggen op een specifiek niveau. Gebruikers kunnen hun consumptiepatroon aanpassen aan de hoeveelheid rechten die in hun bezit zijn, of hun hoeveelheid rechten in overeenstemming brengen met hun consumptieniveau. Dit is mogelijk omdat rechten verkocht en aangekocht kunnen worden. Bijgevolg vertegenwoordigen deze rechten een bepaalde prijs. In tegenstelling tot "command-and-control" – maatregelen, kan een systeem van verhandelbare rechten, net zoals taksen, worden beschouwd als een marktgeoriënteerd beleidsinstrument. Dit betekent dat ze het (consumptie)gedrag beïnvloeden door marktveranderingen waardoor de consumenten zelf kunnen bepalen hoe men de vooropgestelde beleidsdoelstelling wenst te bereiken. Beleidsdomeinen waarbij verhandelbare rechten werden toegepast omvatten water- en luchtvervuiling, beheer van drinkwater.

Er bestaan heel wat vooroordelen over het gebruik van hoeveelheidbeperkingen als beleidsinstrumenten. Deze zijn vaak gebaseerd op vroegere ervaringen met systemen van rantsoeneringen, waarbij de rechten niet verhandelbaar zijn:

1. De overgang van rantsoenering naar een vrije markt in de Oost-Europese landen en de voormalige Sovjetunie tonen aan dat dit systeem van rantsoeneringen niet werkt;
2. Rantsoeneringen creëren een systeem van een parallelle munt, met name de rechten;
3. Rechten zijn een stug beleidsinstrument met hoge transactiekosten;
4. Rechten zijn te vergelijken met aflaten, waarbij de overheid iets verkoopt dat ze eigenlijk niet bezit.

In dit proefschrift worden door middel van een literatuuronderzoek deze vooroordelen weerlegd.

In de organisatie van een systeem van verhandelbare rechten kan men drie aspecten onderscheiden

- Startpuntaspecten omvatten de definiëring van doelstelling, geografisch gebied en de aard van de rechten;
- Ontwerpaspecten zijn een verdere detaillering van de startpuntaspecten en omvatten geografische beperkingen en tijdsbeperkingen, het oprichten van instellingen en de initiële verdeling van de rechten;
- Uitvoeringsaspecten omvatten de gebruikte technologie, de controle en handhaving.

Zoals eerder aangegeven zijn taksen en rechten beide marktgeoriënteerde beleidsinstrumenten. In ideale omstandigheden (first-best) hebben ze dezelfde effecten. Dergelijke ideale wereld vereist wel dat een aantal veronderstellingen moeten gemaakt worden. Indien een of meerdere van die veronderstellingen verzacht worden, spreken we over de "second best" omstandigheden.

We gebruiken de volgende criteria om taksen en verhandelbare rechten in een "second-best" wereld te vergelijken:

- Efficiëntie;
- Nood aan informatie;
- Controle en handhaving;
- Flexibiliteit;
- Stimulans tot innovatie;
- Verdelingseffecten.

In de literatuur worden de verschillen tussen beide systemen uitgebreid beschreven. Praktische redenen (organisatorisch, ideologisch, politieke, wettelijke, historische of andere) kunnen de reden zijn om een van beide systemen te verkiezen.

Echter, de aangegane veronderstellingen zijn essentieel om rechten en taksen te vergelijken. In dit proefschrift beschouwen we verhandelbare rechten die gratis toegekend worden en een lineaire taks. Op basis van deze

veronderstellingen worden twee belangrijke verschillen tussen beide systemen in aanmerking genomen:

- De efficiëntie is afhankelijk van de relatieve hellingsgraden van de marginale nuts- en kostfunctie;
- Beide systemen hebben een verschillend herverdelingseffect. Terwijl er bij taksen een transfer is van private huishoudens naar de overheid, geschiedt de herverdeling bij rechten tussen de private huishoudens.

In hoofdstuk 3 wordt de theorie van verhandelbare rechten toegepast op het privaat wegverkeer. Dit resulteert in 7 verschillende systemen van verhandelbare rechten met verschillende beleidsdoelstellingen:

- Verhandelbare Autobezit Rechten;
- Verhandelbare Brandstof Rechten;
- Verhandelbare Voertuigkilometer Rechten;
- Verhandelbare Gedifferentieerde Voertuigkilometer Rechten;
- Verhandelbare Corridor Rechten;
- Verhandelbare Toegang Rechten;
- Verhandelbare Parkeer Rechten.

Een kwalitatieve evaluatie van verhandelbare rechten in de transportsector geeft aan dat verhandelbare rechten uitermate effectief zijn om een vooropgestelde kwantitatieve doelstelling te bereiken. Bovendien bepaalt de marktwerking de prijs van een recht, hetgeen een weerspiegeling is van de betaalbaarheid van de consument: zij kunnen kiezen om hun consumptie te verminderen of bijkomende rechten te verwerven. Tenslotte worden de consumenten met gewenst duurzaam mobiliteitsgedrag beloond en hoeft de overheid geen rechtvaardige herverdelingsmechanismen op te zetten. De Verhandelbare Voertuigkilometer en Corridor Rechten laten omwille van de tijds- en plaatsdifferentiatie, de internalisering van alle externe kosten toe. Onderzoek naar de implementatie en efficiëntie van dergelijke systemen is echter uitermate complex en tot op heden nog niet beschreven in de literatuur. Daar dit systeem eenvoudig te implementeren is zonder al te veel in te boeten

op efficiëntie van het systeem, gaan we in dit proefschrift dieper in op Verhandelbare Brandstofrechten (Hoofdstuk 4). Aan elk individu worden een aantal verhandelbare rechten toegekend waardoor men brandstof kan aankopen. Deze rechten worden bijgehouden op een rechtenrekening bij een financiële instelling. Deze treedt ook op als makelaar bij de aan- en verkoop van rechten. De ontwaarding van de rechten gebeurt bij het tanken door middel van een chipkaart. De controle gebeurt bij de brandstofhandelaars.

Daar de hoeveelheid brandstof een goede maatstaf is voor de hoeveelheid geproduceerde CO₂, zijn verhandelbare brandstofrechten een waardevolle uitbreiding van het bestaande beleidsinstrumentarium om CO₂-emissies te reduceren. Dat het concept van verhandelbare brandstofrechten niet nieuw is, bewijst het "Standby Gasoline Rationing Plan". Dit plan werd in de nasleep van de oliecrisis van de jaren 70 ontwikkeld door de Verenigde Staten. Het voorzag een hoeveelheidsbeperking van benzine van zodra er grote schaarste optrad. Verhandelbare rechten werden toegekend aan de eigenaars van benzineauto's. De rechten werden onder de vorm van papieren coupons verdeeld, waarbij de uitwisseling en ontwaarding van de rechten gebeurde via financiële instellingen en benzinstations. Hoewel het plan in 1980 werd goedgekeurd door het Amerikaans congres, werd het nooit uitgevoerd.

Het invoeren van verhandelbare brandstofrechten heeft 2 soorten effecten.

Eenzijds, zijn er de effecten die gegenereerd worden door een reductie van het brandstofgebruik voorop te stellen. De verschillende marktpelers (industrie, overheid en consumenten) kunnen op verschillende manieren reageren om de CO₂-emissie te wijzigen:

- Acties gerelateerd met de hoeveelheid emissie per liter brandstof;
- De brandstofefficiëntie (aantal l/km);
- Totaal afgelegde kilometers.

Terwijl de industrie en de overheid enkel indirecte maatregelen kunnen nemen (i.c. wijziging consumptiegedrag van de huishoudens), moeten de consumenten kiezen welke maatregelen ze wensen te nemen om in overeenstemming te zijn met de vooropgestelde beleidsdoelstelling.

De volgende effecten worden in dit proefschrift beschouwd:

- Keuze brandstoftype;
- Voertuigkeuze;
- Bezettingsgraad;
- Rijgedrag;
- Gemiddelde snelheid;
- Routekeuze in tijd en ruimte;
- Vervoerswijzekeuze;
- Reisafstand;
- Aantal verplaatsingen.

Anderzijds zijn er ook effecten die specifiek ontstaan door de keuze van verhandelbare rechten als beleidsinstrument:

- Effectiviteit, met name de beleidsdoelstelling wordt volledig bereikt doordat er niet meer geconsumeerd kan worden als de vooropgestelde hoeveelheid;
- Verdelingseffecten tussen consumenten;
- "Endowment"-effecten die ontstaan doordat rechten (gratis) toegekend worden;
- Transactiekosten.

De keuze van een huishouden om zich te verplaatsen, bestaat uit twee gerelateerde beslissingen: de discrete keuze van het aantal en van het type wagen(s) waarover het huishouden wenst te beschikken en de continue keuze van het aantal afgelegde kilometers: hoeveel en welk type auto's zijn er nodig en hoeveel kilometers moeten er afgelegd (te geschrap) worden. Deze tweeledige keuze kan gemodelleerd worden door gebruik te maken van discrete-continue keuzemodellen. Om deze modellen beter te begrijpen worden in Hoofdstuk 4 de basisprincipes van discrete keuzemodellen beschreven. Zo moeten er bij de formulering van discrete keuzemodellen welbepaalde veronderstellingen gemaakt worden over de beslissingsnemer, de alternatieven, de attributen en de beslissingsregels. Verschillen in veronderstellingen leiden tot

verschillende soorten modellen. In dit proefschrift worden nutsmodellen gebruikt, waarbij huishoudens hun nut trachten te maximaliseren, met name modellen waarbij de afwijking een "logit"-verdeling heeft. Dit veronderstelt dat de verdeling van de afwijking van de verschillende alternatieven onafhankelijk en identiek verdeeld zijn met de Gumbel-verdeling. Deze veronderstelling heeft een aantal belangrijke implicaties. Allereerst betekent de onafhankelijkheid dat er geen gemeenschappelijke niet-waarneembare factoren zijn die het nut van de verschillende alternatieven beïnvloeden. Ten tweede betekent de identieke verdeling dat de variantie in de niet-waarneembare factoren dezelfde is voor alle alternatieven. Tenslotte laat deze veronderstelling ook toe dat de "logit"-modellen een gesloten mathematische vorm hebben. Daar de discrete keuzeset in dit proefschrift uit meer dan twee alternatieven bestaat, worden MultiNominale Logit (MNL)-modellen gebruikt om de discrete keuze van het aantal en van het type wagen(s) te schatten.

Deze discrete keuzemodellen kunnen niet zomaar verbonden worden met een continu keuzemodel. In het schatten van de discrete keuze ontstaat er een afwijking omwille van endogeniteit, terwijl bij het schatten van de continue keuze er een afwijking ontstaat ten gevolge van de steekproefselectie.

Om aan beide problemen tegemoet te komen, wordt er gebruik gemaakt van het Dubin en McFadden-model waarbij de verbinding wordt gemaakt door het invoeren van een correctieterm.

Hoofdstuk 5 past deze theorie toe op een gedisaggregeerd model voor autobezit en -gebruik in Vlaanderen. Dit model is gebaseerd op de resultaten van het "Onderzoek Verplaatsingsgedrag Vlaanderen 2000". In dat onderzoek werden er meer dan 3,000 huishoudens bevroegd naar o.a. hun autobezit en -gebruik.

Allereerst worden de resultaten van deze bevraging, samen met onderzoeksresultaten van de Verbruikersunie, gebruikt om te berekenen wat de jaarlijkse (anno 2001) kostprijs is voor een gezin om hun wagen(s) te bezitten en te gebruiken. In dit proefschrift wordt er een onderscheid gemaakt tussen vaste en variabele kosten. De (jaarlijkse) vaste kosten omvatten alle kosten die

gerelateerd zijn met het bezitten van een (rijklare) wagen: ontwaarding, verzekering, taksen, automobelinspectie en een éénmalig jaarlijks onderhoud.

De variabele kosten omvatten alle kostenrubrieken die gepaard gaan met het autogebruik: brandstof, onderhoud, herstelling en bandenslijtage. In onze steekproef merken we dat zowel de vaste als de variabele kosten verschillen naargelang de voertuigkarakteristieken zoals grootte, merk, brandstoftype en aankoopwijze (nieuw, tweedehands wagen of bedrijfswagen).

Naast de vaste en variabele kosten worden ook andere voertuigkenmerken en socio-economische gezinskenmerken opgenomen als onafhankelijke variabelen in het model. Door dergelijke gegevens op huishoudniveau te gebruiken, kunnen gedragsveranderingen tussen verschillende types van huishoudens zeer nauwkeurig geschat worden. Het ontwikkelde model schat:

- Het aantal wagens dat het gezin bezit;
- Het type wagen dat het gezin bezit indien het 1 wagen bezit;
- Het type wagen dat het gezin bezit indien het 2 wagens bezit;
- Het aantal gereden kilometers indien het gezin 1 wagen bezit;
- Het aantal gereden kilometers van de eerste wagen indien het gezin 2 wagens bezit;
- Het aantal gereden kilometers van de tweede wagen indien het gezin 2 wagens bezit.

Om de parameters van de variabelen van de discrete keuzes te schatten, wordt een MNL-model gebruikt, waarbij de keuzewaarschijnslijkheden worden geschat door de "maximum likelihood" methode. Hiervoor wordt het statistische softwarepakket "Biogeme" gebruikt.

De modevaluatie gebeurt op basis van de volgende criteria:

- De aangepaste F^2 -waarde meet de relatie tussen de waargenomen en de verwachte waarde van de afhankelijke variabele;
- Het teken en de grootte van de geschatte parameters;
- De t-statistiek bepaalt de statistische significantie van de geschatte parameters.

Voor het schatten van de continue wordt er gebruik gemaakt van de instrumentele variabele methode. Hiervoor kan een standaard statistisch software pakket (i.e. SPSS) gebruikt worden.

Daar dit model de causale verbanden schat tussen de in aanmerking genomen variabelen en autobezit en –gebruik, kan dit model gebruikt worden om veranderingen in een van deze variabelen te schatten. Dergelijke scenario's worden opgebouwd in Hoofdstuk 6

Allereerst gebruiken we de waarde van de variabelen zoals in de steekproef waargenomen werd om de referentiesituatie te simuleren. De resultaten van deze simulatie tonen aan dat auto en brandstofconsumptie positief gecorreleerd zijn met de grootte van het gezinsinkomen. Bovendien zijn het autobezit en –gebruik gecorreleerd met de gezinsgrootte en de leeftijd van het gezinshoofd.

In een eerste scenario wordt een vergelijking gemaakt tussen verhandelbare brandstofrechten en accijnzen om een reductie van de brandstofconsumptie van 14.6 % (niveau 1990) te bekomen. Tenslotte wordt in het tweede scenario het reductieniveau verhoogd tot 21.3 % (Kyoto norm).

De hiervoor gehanteerde methodiek was enigszins verschillend van de in de literatuur gangbare aanpak. Terwijl autobezit en –gebruik-modellen veelal gehanteerd worden om het effect van een prijsverhoging op de brandstofconsumptie te schatten, werd in dit proefschrift in elk scenario een vast reductieniveau vooropgesteld, hetgeen resulteerde in een specifieke verandering van de brandstofprijs (i.c. accijns) en de prijs van een recht. Dit levert voor het eerste scenario een accijnsverhoging op van 0.598 euro per liter brandstof en een prijs van 0.798 euro per verhandelbaar brandstofrecht.

In het tweede scenario zijn deze waarden respectievelijk 1.206 en 1.809 euro. De hogere rechtenprijs kan verklaard worden door de toekenning van een aantal rechten. Hierdoor hebben gezinnen een hoger inkomen, waardoor ze (aanvankelijk) ook meer kunnen spenderen aan autobezit en –gebruik. De initiële toekenning van rechten is gebaseerd op het aantal gezinsleden en hun leeftijd: elk gezinslid krijgt eenzelfde hoeveelheid rechten behalve degenen die ouder zijn dan 65 jaar. Omwille van hun geringere verplaatsingsbehoefte

krijgen ze maar de helft van deze rechten. Zo krijgt elk gezinslid in het eerste scenario 439 rechten, waarvoor men 439 liter brandstof mag aankopen. In het tweede scenario is dit beperkt tot 404 rechten.

Beide instrumenten zijn effectief om beide beleidsdoelstellingen te bereiken. Echter, de resultaten van de simulaties tonen aan dat accijnzen en rechten deze reductie op verschillende manieren bereiken: de reductieniveaus van autobezit, brandstofefficiëntie en totaal afgelegde kilometers zijn verschillend. Waar accijnzen resulteren in een hogere reductie van de autovloot, geven rechten aanleiding tot zuinigere wagens, waardoor gezinnen meer kilometers rijden in vergelijking met een accijnsverhoging.

Tenslotte wordt er naast mobiliteitseffecten ook onderzocht of er welvaartsverschillen optreden tussen gezinnen indien accijnzen of rechten worden ingevoerd. Hiertoe wordt het consumentenverlies gemeten. Vermits viervijfde van de gezinnen gebruik maken van de wagen, betekent een reductie van de brandstofconsumptie ongetwijfeld een verlies aan welvaart voor deze gezinnen. Dit wordt gemeten door middel van de verandering in consumentensurplus voor en na het invoeren van de accijnzen of rechten. De simulatieresultaten tonen aan dat er een positieve relatie bestaat tussen het niveau van het gezinsinkomen en het consumentenverlies. Bovendien is dit verlies voor alle inkomenscategorieën hoger bij accijnzen dan bij rechten. Indien het consumentenverlies relatief tot het gezinsinkomen wordt beschouwd, blijkt dat accijnzen regressief zijn vanaf de tweede inkomenscategorie, terwijl rechten progressief zijn. Uiteraard moet hierbij vermeld worden dat we geen herverdelingsschema's voorzien in het geval van accijnsverhoging. Om dergelijke schema's uit te werken, zijn deze simulatieresultaten voor accijnzen noodzakelijk.

Hoewel we het ontwikkelde autobezit en –gebruik-model voor Vlaanderen enkel toegepast hebben voor twee scenario's -voor zowel een accijnsverhoging als het invoeren van verhandelbare brandstofrechten-, heeft dit model heel wat meer beleidstoepassingen:

- Doorrekenen van alle prijsmaatregelen (bijv. variabiliseren van vaste kosten, wegvignet al dan niet variabel, afschaffing wegentaks, vergroening van de fiscaliteit) en technische maatregelen (bijv. invoeren bepaalde technisch standaards, promoten bepaalde voertuigtype);
- Effect van dergelijke maatregelen voor verschillende gezinnen (gezinsgrootte, inkomen, woonplaats, aantal kinderen, leeftijd gezinshoofd, ...) op hun verplaatsingsgedrag en inkomen;
- Toekomstscenario's voor het autobezit en afgelegde kilometers in Vlaanderen op basis van socio-economische perspectieven;
- Verfijning van inputgegevens voor heel wat andere, reeds bestaande modellen (multimodaal model, emissiemodellen).

Er moet echter vermeld worden dat dit model ook een aantal beperkingen heeft:

- Dit model is een partieel-evenwicht model;
- Beperkte beschikbaarheid van data;
- Autobezit wordt door een discrete-keuzemodel geschat;
- Lange-termijn effecten zoals herlocalisatie en nieuwe ruimtelijke ontwikkelingen worden niet opgenomen;
- Enkel de brandstofconsumptie van het autogebruik wordt beschouwd.

Naast deze modelbeperkingen werden een aantal economische aspecten van het systeem van verhandelbare rechten niet in beschouwing genomen:

- Enkel de relatieve welvaartsverliezen werden berekend;
- Een aantal transactiekosten werden niet opgenomen (kosten gerelateerd met de planning en het creëren van het wettelijk kader);
- Er werd geen onderzoek gedaan naar de optimale manier van het veilen van de rechten;

Deze beperkingen vormen dan ook de richting waarin verder onderzoek gewenst is.

CHAPTER 1 Introduction

This chapter provides the socio-economic context in which the contributions of this research are to be put. The successful introduction of the car as the preferred private transport mode has some major size effects. Furthermore, we introduce the objectives of this dissertation and provide an overview of the chapters. Finally, we present the contributions of this dissertation to the state of the art.

1.1 Challenges in private road transport

Car use plays a key role in our modern society. Jensen (1999, 32) conducted a sociological analysis on transport behaviour² and concluded:

"The car as such has become an extreme symbol of modern society. It embodies freedom, independence, power, speed, control, prestige, and consumption. The design signals modernity, it can be exhibited and brought from place to place. The car has become both a symbol, as well as an integrated part, of the cultural trends in society."

Moreover, Ong (2001) found that employment is correlated with car ownership. He suggested that policymakers should establish programs that help specific target groups to acquire, operate and maintain a car. This would ease and enlarge their job-search, increase their willingness to accept a job further away from their place of living and increase their job attendance.

There are some practical reasons why the car is the preferred mode. For long trips, the car is perceived as being cheaper and more convenient than public transport. However, for short trips, there is a large potential for a shift to other modes.

² Her quantitative study consisted of a survey among 1,000 persons and was based on 20 qualitative in-dept interviews.

Macket (2000, 347) researched³ why the car is preferred to other modes for short trips:

"The main specific reasons identified by drivers were:

- *carrying heavy goods, usually, but not always, shopping*
- *giving lifts, particularly taking children to school*
- *shortage of time*
- *because the car is needed for another trip before returning home."*

Moreover, Wright (2000) argued that owning and using cars are a fulfillment of human needs. As Table 1.1 shows, he argued that the car satisfies human needs on all levels⁴:

Table 1.1: Level of human needs and fulfillment by car

| Level of Need | Way of fulfillment by car |
|-----------------|---|
| Basic needs | Provides warmth and shelter |
| Safety needs | Provides security |
| Social needs | Might functioning as a social environment |
| Esteem | Is a powerful status symbol |
| Self-expression | Is a mean of expression and even an extension of human body (e.g. "car-tuners") |

Source: Based on Wright (2000).

However, next to private benefits to the car owner, owning and using a car generates externalities.

DeSerpa (1988, 507) defined an externality (i.e. an external economy) as

"a relevant cost or benefit that individuals fail to consider when making rational decisions"

Consequently, an externality occurs when the well being of an individual is unintentionally affected by actions of others. Although many private benefits are related to car use, Hauschildt (1990) defined only one external benefit: the social benefit of emergency services.

³ His findings were based on in-depth interviews with 377 people who made short trips by car.

⁴ He used the Maslow-ladder of human needs. People want to fulfil these needs, starting by the first level.

However, a wide range of external costs are related to car use⁵:

- Costs of transport activities, which include congestion, accidents, degradation of human health, road damage, noise, air-water and soil pollution, global warming and energy depletion;
- Costs of vehicles not in motion, which include the use of space and pollution caused by production and abatement;
- Costs related to existence of infrastructure, such as barrier effects and visual annoyance.

Many of these externalities, especially those related to the environment and human health, originate from the full dependence on fossil fuels as energy source. Until recently, the availability of fossil fuels has always been considered as abundant. However, since 1997, the academic debate of oil depletion has started. Basically, there are two streams⁶: On the one hand, the school of Adelman⁷ is arguing that oil reserves in the ground are not a stock but a flow, which is determined by production, rather than geology. Consequently, additional investments can maintain or increase this flow. Adelman and Lynch (1997) illustrated this by the example of sub-sea drilling technology. On the other hand, the school of Hubbert⁸ is arguing that oil reserves are a stock, which decreases with an increasing cumulative production. Consequently, oil production curve could be expressed by a logistic (or Gaussian) curve, which implies a bell-shaped curve. This implies that the production of oil would once

⁵ For a general discussion of external costs, we refer to Maddison et al. (1996). For an overview of external costs in Belgium, we refer to Mayeres et al. (2001). For an overview of the impact of car emissions in Belgium, we refer to Int Panis et al (2001). For an overview of congestion costs we refer to Walters (1961) and May and Nash (1996). For an overview of the road damage externalities, we refer to Newbery (1988). For an extensive literature review and an evaluation of health hazards of transport-related air pollution, we refer to WHO (2005).

⁶ Essentially, these streams can be reduced to an economist's view versus a geologist's view of oil production.

⁷ Adelman and Lynch (1997) and Lynch (2003)

⁸ Bentley (2002), Bentley (2005), Campbell (1997), Laharrère (x) and Deffeyes (x)

reach a maximum, followed by a decline⁹. Bentley (2002) considered the use of the logistic curve as a robust method for modelling future oil supply. He concluded that

"The all-world conventional oil peak is 5-10 years away, after which production will decline at ~3%/year."¹⁰

In Table 1.2, Hirsch et al. (2005) give an overview of some recent projections¹¹. Some researchers forecast the maximum within a decade; others contend it would occur later or not at all.

Table 1.2: Projections of the peaking of world oil production

| Projected Date | Source of Projection | Background |
|-----------------|----------------------------|------------------------------|
| 2006-2007 | Bakhitari, A.M.S. | Iranian Oil Executive |
| 2007-2009 | Simmons, M.R. | Investment banker |
| After 2007 | Skrebowski, C. | Petroleum journal Editor |
| Before 2009 | Deffeyes, K.S. | Oil company geologist (ret.) |
| Before 2010 | Goodstein, D. | Vice Provost, Cal Tech |
| Around 2010 | Campbell, C.J. | Oil company geologist (ret.) |
| After 2010 | World Energy Council World | Non-Government Organisation |
| 2010-2020 | Laherrere, J. | Oil company geologist (ret.) |
| 2016 | EIA nominal case | DOE analysis/ information |
| After 2020 | CERA | Energy consultants |
| 2025 or later | Shell | Major oil company |
| No visible peak | Lynch, M.C. | Energy economist |

Source: Hirsch et al. (2005)

⁹ Note that oil peaking is not the same as running out of oil: peaking implies that a maximum will be reached and that thereafter the oil production will decrease with time.

¹⁰ He expects that when oil production will decline, prices will rise and users may have to ration.

¹¹ Another overview of forecasts is given by Bentley (2005). He distinguishes three categories of researchers: A first group of researchers indicates that oil production will reach a resource-limited maximum between 1996 and 2020, while a second group forecasts oil production until 2020 or 2030 and find that the production will meet demand in that time period. A third group expects that oil market will regulate itself (i.e. a price rise of oil will increase the supply and decrease the demand).

We follow the conclusions made by Hirsch et al. (2005, 64).

- "Prediction of the peaking is extremely difficult because of geological complexities, measurement problems, pricing variations, demand elasticity and political influences."
- "Peaking will happen, but the timing is uncertain."
- "... World oil demand will continue to grow, increasing approximately two percent per year for the next few decades. This growth will be driven primarily by the transportation sector."
- "Oil peaking represents a liquid fuels problem, not an "energy crisis" in the sense that term has been used. Motor vehicles, aircraft, trains, and ships simply have no ready alternative to liquid fuels."

1.2 Research objectives

A first research objective is to evaluate the feasibility of the use of tradable permits in private road transport to reduce fuel use. More specifically, by researching tradable permits we want to broaden the set of policy instruments. A second objective is, given the policy goal to reduce fuel consumption, to analyse the relative economic welfare effects of an increase in fuel taxes, and the introduction of tradable fuel permits in Flanders. The results of this economic welfare analysis should be considered as an integral step in the choice between taxes and permits as a policy instrument to reduce fuel use. However, this analysis is not the only criterion of choosing a policy instrument¹². More specifically, this analysis focuses on the distribution of welfare effects across household categories rather than only considering the aggregate effect. Clearly, different groups of consumers may well respond in quite diverse ways. Understanding how consumers would behave or react when introducing policy measures is a critical step towards their implementation. However, such disaggregate analysis requires specific models that analyze and

¹² For a detailed overview of the different aspects of the theory of public choice, we refer to Mueller (1989).

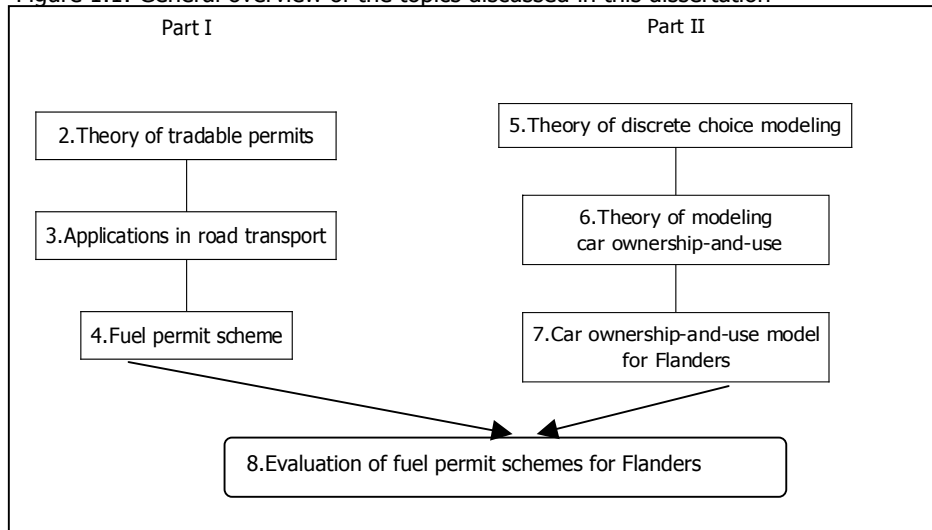
predict consumers' choice. Consequently, we develop a car ownership-and-use model for Flanders, which is based on the results of the Travel Survey Flanders 2000. This model enhances the understanding of the market functioning and welfare impact of fuel taxes and tradable fuel permits in Flanders.

This seminal work investigates the use of tradable permits in road transport on household level. In this way, it might contribute to shift the present heavy dependence upon fossil fuels of car use towards a more diversified energy economy. The basic motivation for the empirical issues raised in this dissertation can be found in the development of a European energy and transport policy and a growing interest in using market-based instruments in Europe.

1.3 *Outline of this dissertation*

In this section, we present a general overview of the topics discussed in this dissertation and their relations with respect to each other.

Figure 1.1: General overview of the topics discussed in this dissertation



This dissertation studies the use of tradable permits in private road transport. As Figure 1.1 shows, two research lines result in the evaluation of a tradable fuel permit scheme for Flanders. The first research line aims to apply tradable

permits as a policy instrument in road transport, while the second line develops a new tool for assessing policy instruments in Flemish transport policy.

Chapter 2 discusses the theory of tradable permits. Because rationing and tradable permits are considered as close alternatives, we first define them in relation to each other. Furthermore, since "rationing" has a somewhat negative connotation¹³, some of the major prejudices about setting a quantitative cap are refuted. After a short historical description of tradable permits, we discuss the design issues of tradable permits. We end this chapter by comparing tradable permits and taxes, both in a first-best and a second-best setting.

In Chapter 3, we apply this theory of tradable permits and design different permit schemes in road transport, serving different policy goals. Eventually, we select the tradable fuel permit scheme as the most promising application of tradable permits in road transport.

Chapter 4 focuses on the tradable fuel permit scheme. We discuss a plan of a tradable fuel permit scheme, which was developed in the wake of the oil crisis by the U.S. Government and even approved by the National Congress. Furthermore, we discuss the existing measures to reduce fuel use in the EU. Subsequently, we consider the effects of a policy goal to reduce fuel use, and research the specific issues related to the introduction of a permit scheme as a policy instrument to reduce fuel use. We end the first research line by describing some alternative tradable fuel permit schemes.

The second research line starts in chapter 5 with a literature overview of discrete-continuous choice modelling. More specifically, we introduce the basic concepts of discrete choice modelling, which is essential to understand the theory of car ownership-and-use modelling.

In chapter 6, this theory is applied to a disaggregate model for car ownership-and-use in Flanders. To this end, we use the results of the Household Travel Survey of Flanders 2000. This new policy tool is used in chapter 7 to evaluate a fuel permit scheme for Flanders.

¹³ Rationing reminds people to wartimes or the rationing-by-queuing in the former U.S.S.R.

Finally, chapter 8 presents the conclusions and the limitations of our research, as well as an overview of topics for future research.

1.4 *Contributions to the state of the art*

This dissertation intends to make contributions in four fields:

Firstly, the theory of tradable permits is applied on road transport. We designed seven possible schemes, each aiming other policy goals. Secondly, we research the effects of the introduction of tradable fuel permit scheme. These effects are twofold. On the one hand, we distinguish effects caused by the choice of reducing fuel use as a policy goal. On the other hand, we discuss effects that are caused by the specific choice of tradable fuel permits as the instrument to reach that policy goal. This distinction is not made in the literature and results in a better understanding of the effects of policy instruments. Thirdly, we develop a car ownership-and-use model for Flanders, which does not exist yet. Clearly, this new tool can lead to an increased objectiveness of transport and energy policy in Flanders. Finally, we use the car ownership-and-use model for Flanders to measure the impact of the introduction of a tradable fuel permit scheme in Flanders. To our knowledge, the simulation of a tradable fuel permit scheme was never described in the literature.

CHAPTER 2 Theory of tradable permits

This chapter provides the theoretical background to tradable transport permits. By issuing only a limited number of permits, governments are able to keep the usage at or below a specified level. Consumers need to reduce their current levels of usage, or obtain sufficient permits from others¹⁴. Permits can be bought and sold since they command a price like any other commodity. The structure of this chapter is as follows:

Firstly, we discuss the theory of market regulation by setting a quantitative cap. Furthermore, we describe the general structure of tradable permit schemes, which guides us to design different permit schemes in road transport. Finally, we discuss the feasibility of permits as compared to taxes.

2.1 Introduction

The most common forms of tradable permits are a cap-and-trade program or a credit program¹⁵. Stavins (1998, 5) defined credit programs as programs

"where permits or credits are assigned only when a source reduces emissions below what is required by existing, source-specific limits."

However, the most widely used tradable permit scheme is a cap-and-trade program in which the consumption of a good is capped, permits are allocated and a permit trading mechanism is established. Therefore, this dissertation only considers cap-and-trade programs as tradable permit schemes.

Firstly, we compare tradable permits with other market-based instruments. Secondly, we describe the historical background of tradable permits. Finally, we refute the major prejudices against rationing.

¹⁴ A detailed description of the functioning of tradable permits is to be found in Baumol and Oates (1988).

¹⁵ Next to cap-and-trade and credits, OECD (2001) describes two other families of permit schemes, more specifically averaging and transferable usage rights

2.1.1 Market-based instruments

Tradable permits are –together with charges¹⁶- considered as a market-based policy instrument. This means that they affect behaviour through market signals. As opposed to market-based instruments, the government can set explicit standards by introducing command-and-control measures. However, since these standards are fixed and need to be met by the different market players, they allow less flexibility in how to achieve the policy goal. Furthermore, these command-and control measures provide no incentives for consumers to perform better than the fixed standard. Consequently, market based instruments provide a higher incentive for technological innovation in comparison to command-and-control¹⁷. Moreover, an essential requirement of command-and-control regulations is that the government needs to have a thorough knowledge about emission reduction practices¹⁸. As a result, many applications of market-based instruments exist in practice. For an overview of market-based applications, we refer to Stavins (1998).

2.1.2 History of tradable permits

Since Pigou's (1920) seminal work, taxes were considered the most appropriate instrument to discourage consumption and production of goods that generate negative externalities. The tax rate should be set equal to the difference between marginal social cost and marginal private cost at the optimal level of production. According to this view, rational pollution control policy involved putting a price on pollution.

However, Coase (1960) argued that the real issue of externalities was incomplete property rights. If there are no transaction costs and property rights

¹⁶ Two other categories of market-based instruments are described in the literature, namely market barrier reduction and government subsidy reductions.

¹⁷ However, Laffont and Tirole (1996) demonstrated that the design of tradable permits is crucial towards their technological innovation power.

¹⁸ However, Stavins (1994) concluded that only in the case of low transaction costs, market based instruments are more cost effective.

are assigned, parties bargain an efficient allocation of resources, irrespectively of which party holds the property rights. He pointed out that this approach allowed the market to value the property rights, as opposed to the government in the Pigouvian approach.

Amongst the most prominent members of the Coasean school, we mention Crocker (1966), Dales (1968), Montgomery (1972) and Tietenberg¹⁹ (1980).

Permit trading has not only its merits as a theoretical concept but also in practice. Since the 1970's, the concept of permit trading has gained prominence as policy instrument in different sectors such as air and water pollution control, managing water resources and in fishery allocation. Amongst the well-studied applications, we mention the RECLAIM and the Acid Rain Reduction Program. Since the ratification of the Kyoto Protocol in February 2005, the international CO₂ emission permit program has come into force²⁰.

2.1.3 Prejudices against rationing

Rationing is a policy instrument to regulate a market by setting a quantitative cap on one or more consumption goods. Tobin (1952) distinguished between convertible rationing, in which exchange of ration currency and money is permitted, and non-convertible rationing. Tradable permits can be viewed as a system of convertible rationing. However, there exist some major prejudices against rationing:

- The collapse of the former USSR proves that rationing is not functioning;
- Rationing creates parallel money regimes;
- Rationing is a rigid policy instrument.

¹⁹ Tietenberg provides an extensive list of references in the field of tradable permits on his website (<http://www.colby.edu/personal/t/thtieten/trade.html>). The subjects covered are general background, design issues and applications in different fields. (website last accessed on August 11, 2005).

²⁰ For more details about the history and application of tradable permits, we refer to Tietenberg (2001) and Crals (2005).

Historical failure

The transition from rationing and queues to a market system in the former USSR and the Eastern European countries proves that rationing is not functioning. However, as Polterovich (1997) pointed out, there were at least three allocation systems: Rationing in many variants (i.e. uniform rationing with or without speculations), queues and black markets. Consequently, soviet-type rationing schemes are hardly comparable with tradable permits.

Parallel money

When rationing is introduced, households do not only need to pay their expenditures in money but also in ration currency. Consequently, a parallel money regime is created. In other words, the single-currency system is replaced by a multiple-currency one. However, money currency and ration currency are not the same. Tobin (1952) made some major distinctions between money and a ration currency. First of all, the size of a household ration income is independent of their labour. This means that ration allowances are more similar to transfer payments than to money wages. Secondly, since ration currencies have a limited validity, saving is not possible in ration currency. Thirdly, this multiple-currency system is asymmetrical in the sense that only in money, every commodity has a price throughout the whole productive process. Finally, using a system of convertible rationing, the single-currency regime would be restored.

Rigid policy instrument

McGillivray and Kemp (1974, 352) considered fuel rationing as administratively very cumbersome and

"a rigid policy which, if sustained over an extended period, is also likely to have strange side effects on the location of economic activity and on the land and real estate markets. It would reduce the attractiveness for the middle- and upper-income urban dweller to own a second home for

use mostly on weekends Large automobiles would become relatively unattractive”.

Thirty years later, the main objection against rationing, i.e. high transaction costs seems to be resolved, as was discussed in Crals and Vereeck (2005). Moreover, current policy goals are precisely set to promote these “strange side effects”.

Indulgences²¹

Goodin (1994) compared the use of economic incentives for environmental protection to indulgences:

- The government is selling something (the right to degrade the environment), which is not owned by the government;
- Something is for sale, which can ethically only be given away;
- These incentives legitimize acts that are morally wrong;
- The government allows permit holders to do what none ought to do.

Tietenberg (1998) refuted this criticism by arguing that the distribution of emission permits is fixed and the cap is set on the basis of ecological criteria, rather than on the basis of willingness-to-pay. Furthermore, permits are defined in terms of an “authorization to emit a certain level of pollution” rather than selling a part of the airspace.

2.2 Structure of a permit scheme

In this section, we describe the general structure of tradable permit schemes. We use the approach developed by Harrison (1999)²².

²¹ During the Middle Ages, indulgences were sold by church officials to worshippers for the remission of sins.

²² OECD (2001) followed the same approach and divided the variables into the three main groups.

He described three main issues in the organization of a tradable permit scheme²³, which are roughly in chronological order:

- The threshold issues;
- The design issues;
- The implementation issues.

In a first stage, we describe the threshold issues, which include the definition of the basic purpose of the system, the geographic area to be covered and the nature of the commodity to be traded. Secondly, these previous issues are further specified in the design issues, which comprise the geographic or temporal flexibility or restrictions, the establishment of institutions and the allocation of initial allowances. Finally, the implementation issues are discussed: the technology used, monitoring and enforcement of the system.

2.2.1 Threshold issues

Nature of the commodity to be traded

In general, two types of commodities can be traded²⁴. On the one hand, we can trade the externality as such, for instance CO₂-emission. On the other hand, we can trade the input good, which causes the externality. In our example of CO₂-emission the input good is fuel. Two decision criteria can be used. First of all, the higher the degree of uniform mixing of the pollutant, the likely is the choice of trading the input good. Secondly, there is the issue of administrative costs; the closer to the actual impact, the more complex regulation is required. An illustrating example is a system of tradable CO₂ permits. Since CO₂ pollution is independent of the location of the source, *i.e.* a uniform mixed pollutant, a more simple regulation based on fuel consumption can be developed.

²³ We will use this framework to design the different permit schemes in road transport, which we will discuss in chapter 4.

²⁴ Since we only consider cap-and-trade programs, the distinction between cap-and-trade allowances versus reduction credits is not made.

Moreover, to facilitate trading the permit must be homogenous and have a limited validity in time and space.

Level of the cap

The cap can be designed as an absolute (in x tonne) or as a relative baseline (unit rate of effluent concentration, unit rate of emission per unit of time). While an absolute cap may more limit growth, the design of a relative baseline is more complicated. More specifically, in a relative baseline design hypotheses need to be made about the amount of emissions that would have been emitted in the absence of the permit scheme.

Furthermore, to create a market, the level of the cap needs to be lower than the actual level of consumption. In theory, the efficient level of the cap is when marginal abatement costs equal the marginal benefits from the reduced emissions.

In practice, however, policymakers determine the cap by considering a combination of scientific arguments, economics and political feasibility.

2.2.2 Design issues

Initial allocation of permits

In the tradable permit literature and practice, four allocation methods are distinguished²⁵. Firstly, tradable permits can be allocated through a bidding procedure or an auction. Secondly, the permits can be given away or allocated for free to all consumers. Thirdly, the permits can be allocated to users based on their historical consumption, regardless of their current or future consumption. Finally, in an updating scheme, the allocation rule is based upon

²⁵ However, Shubik (1970) identified eight different ways in the allocation of resources:(1) Economic markets with prices;(2) Voting;(3) Bidding; (4) Bargaining;(5) Higher authority, fiat, or dictatorship; (6) Force, fraud, deceit; (7) Custom, including gifts and inheritance and(8) Chance.

information updated over time²⁶. This allocation rule is called the “grandfathering” principle .

Montgomery (1972) demonstrated that the ultimate allocation is insensitive ²⁷ to the initial way of allocation, which leaves a margin for policy makers to allocate permits based on non-economic criteria such as equity and fairness. Nevertheless, the initial allocation of permits plays a crucial role in determining the beneficiaries of the revenues. For instance, when permits are auctioned, government generates additional revenues.

Temporal and geographic flexibility or restrictions

In the determination of the compliance period of the permit scheme, there is an important trade-off between efficiency and effectiveness. When the period is long, efficiency gains can be obtained through trade. But when permits have a short duration of validity, the permit scheme is more flexible in response to changing policy options.

Moreover, policy makers can include temporal flexibility in the permit scheme. Basically, there are two ways of temporal flexibility: banking and borrowing. Banking allows transferring permits valid to a later period. Allowing banking encourages early emission reductions and can reduce compliance costs. But, banking can also delay the achievement of the emission target when banked permits are used. Borrowing authorizes the advanced use of permits, which are valid for a future period²⁸. Borrowing could act as a safety valve in case of unexpected rise of the demand in permits. But, when too much permits are used in advance, policy makers might be forced to adjust the level of the cap.

Next to the temporal flexibility or restrictions, there are also geographical limits on the permit scheme. The OECD (2001) considered three ways to achieve

²⁶ A detailed discussion of the allocation methods can be found in Crals et al. (2003)

²⁷ Based on the assumptions of perfect market information and no transaction costs.

²⁸ OECD (2001) described two more forms, namely a system of budgeting over a given period during which transfers may be made freely and a system with short-term periods of peak management.

geographical flexibility. First of all, an emission bubble consists of a well-defined geographical area for which a cap is set. The size of the bubble may vary. Examples include an industrial plant, an industrial zoning, an industrial sector, a region or a country. Secondly, a deposition bubble applies to all sources whose emissions give rise to pollution in a given target area within a country, irrespective of their geographical location. Finally, offset schemes provide transfers between several bubbles, whose individual ceilings are adjusted accordingly.

2.2.3 Implementation issues

Monitoring and enforcement

Monitoring and enforcement are strongly correlated. Firstly, there is a need to monitor compliance with the regulatory framework and to detect violations. Secondly, an adequate response to the observed violations is necessary to ensure that participants comply with the regulation.

In the literature, two levels are identified where the regulator can force the market players to hold permits. On the one hand, the monitoring can be executed at the level of producers, the so-called upstream design. On the other hand, the end-users can be monitored in a downstream design. For instance, in our example of CO₂ emissions, the monitoring can be focused respectively on fuel producers and importers or on the end-users.

Harrison and Radov (2002) argued that there is an implicit trade-off between administrative efficiency (the number of parties to be monitored) and economic efficiency (the more parties, the more cost savings the system entails).

An enforcement program for non-compliance is an essential part in a permit scheme. We distinguish non-compliance with the required number of permits from non-compliance with specific requirements of the permit scheme (for instance late or incomplete reporting). The former requires more stringent sanctions. These sanctions can take the form of permits, financial and criminal penalties. Permits can be used when it is essential to maintain the level of the

cap. For every unit of excessive emission, permits can be bought on the market or permits from the next compliance period can be depreciated based on (at least) a one-to-one rate. These penalties are similar to respectively buying and borrowing permits when not accompanied by financial or criminal penalties. The level of financial penalties should be significantly higher than the expected market price of permits. In this way, a deterrent effect for non-compliance is ensured. Moreover, financial penalties can be differentiated in time and amount depending on the level of severity of violation. In the case of recidivism or malicious violations, criminal penalties might be imposed.

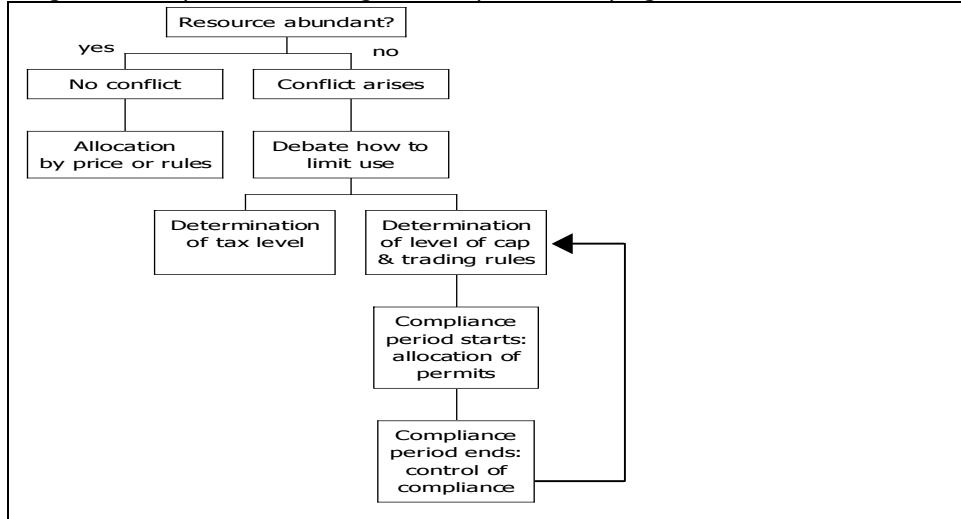
Sanctions should be commensurate with the expected impact of non-compliance, based on the classical economic approach of crime and punishment²⁹.

Implementation path

Figure 2.1 shows the different stages in implementing a cap and trade system. Once resource users can no longer maintain their customary pattern of use of a good, a system of permits or other mechanisms to limit resource use are proposed. If tradable permits are chosen as a policy measure, the government sets a cap for a specific good and defines the target group and a fixed compliance period. Then, the cap is divided into a number of permits, which are distributed amongst the consumers. A political struggle over the target level, allocation mechanism and trading rules can be expected during this stage and in the implementation stage. During the compliance period, each consumer measures his consumption and likely adapts his behaviour by changing his consumption or by buying or selling permits. At the end of the compliance period, each consumer transfers a number of permits, equivalent with his consumption to the controlling authority. In case of non-compliance, penalties might be imposed. Next, a new compliance period commence, possibly with an adapted design.

²⁹ For more details, we refer to Becker (1968).

Figure 2.1: Implementation stages of a cap-and-trade program



Source: Based on Colby (2000).

2.3 *Permits versus taxes*

In a first-best setting, which implies that there are no constraints related to legal, institutional or informational issues, taxes and permits have similar effects. To compare both, conclusions rely on several assumptions

- The same amount of emissions from different sources, have equal external costs;
- Raising revenues through environmental policies is not in itself costly or stated differently, there are no interactions with other markets (e.g. labour market);
- No uncertainty exists about cost and benefits of pollution control;
- A competitive structure prevails in both the output market and the permit market.

However, as is often the case, some of these basic assumptions contrast with the real world and need to be relaxed, the so-called second-best setting.

To compare taxes and tradable permits in a second-best setting, we follow Norregaard and Reppelin (2000) and use the Bohm and Russel (1985) criteria:

- Efficiency;
- Information intensity;
- Ease of monitoring and enforcement;
- Flexibility in the face of change;
- Dynamic incentives;
- Distributional effects.

Efficiency

Norregaard and Reppelin (2000, 9) defined efficiency as

"the ability of an instrument to reduce emissions to a predetermined level at minimum abatement costs".

In other words, efficiency reflects the achievement of the chosen goal at the lowest cost. This efficiency criterion is mostly limited to static considerations, which assumes fixed environmental goals and fixed technology allowing only for the first round of reaction to the instrument.

Firstly, we discuss efficiency in a non-competitive market structure³⁰ and limit this discussion to the main findings of Norregaard and Reppelin (2000). Based on a literature survey³¹, they concluded that when the output market is not perfectly competitive, efficiency losses occur in both schemes. However, assuming that firms are identical, taxes can be adjusted to obtain efficiency while permits do not. When this assumption does not hold, i.e. firms have different pollution technologies, efficiency losses are higher when taxes are introduced. Of course, when the permit market has a non-competitive structure, permits are socially inefficient. Their main findings are summarized in Table 2.1.

³⁰ In that case, this market failure might be caused not only by pollution externalities, but also by market power.

³¹ Their literature review included Buchanan (1969), Burrows (1981), Requate (1998) and Malueg (1990).

Table 2.1: Comparison of efficiency losses under taxes and tradable permits

| Occurrence of non-competitiveness | Emission tax | Tradable permits |
|-----------------------------------|--|---|
| In the output market | If firms are identical, efficiency can be obtained by adjusting the tax level. In the case of non-identical firms, taxes are inefficient | Inefficient, but Requate (1998) suggested that in the case of non-identical firms, efficiency losses may be smaller compared to taxes |
| In the permits market | N/A | Inefficient |

Source: Based on Norregaard and Repellin (2000).

Secondly, there are also long-term efficiency considerations, (maximisation of the net social benefits of abating emissions). The conventional approach, developed by Baumol and Oates (1988), suggested that under a tax regime, long-term efficiency could only be attained when firms pay for all infra-marginal emissions. Consequently, long-term efficiency can only be attained if for all consumers the level of the uncharged, infra-marginal quantity is zero³². However, under a permit scheme infra-marginal emissions can remain uncharged through the initial allocation of free permits. Bohm and Russel (1985) concluded that the choice of taxes or permits based on their efficiency depends on the nature of the good and the characteristics of the regional economy and environment.

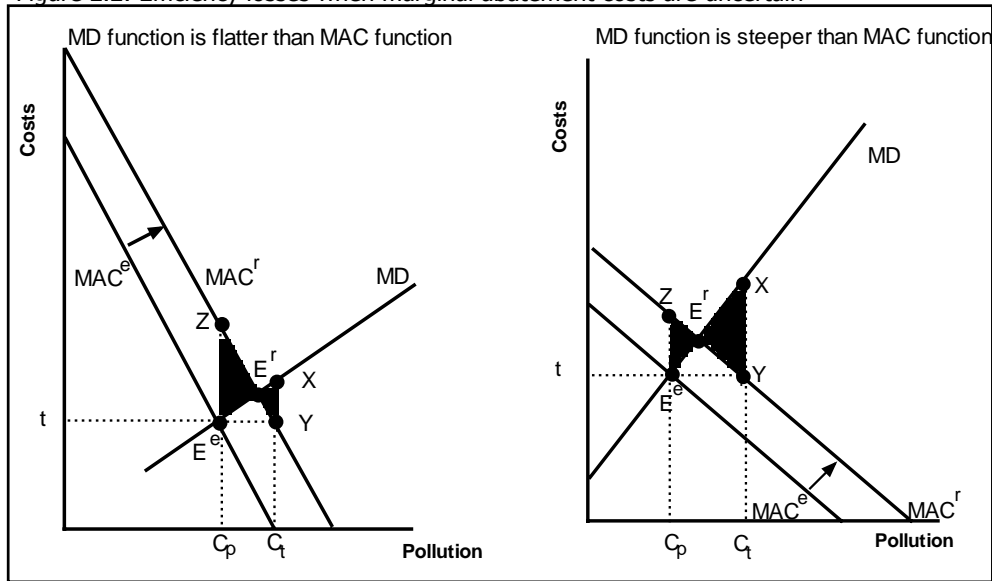
Information intensity

The information intensity is a measure of the amount of information that the pollution control agency needs to operate a tax or a tradable permit scheme. Of course, information about the marginal damage and abatement costs is essential to obtain the optimal emission level. As we discussed earlier in this chapter, a first-best setting assumes that marginal damage and marginal abatement costs are known.

³² The level of infra-marginal emissions that remains uncharged is called threshold or baseline. Next to this conventional view of the efficiency, there are two dissent views which are mentioned in Pezzey (2003).

Weitzman (1974) studied what happened when the marginal abatement cost function is uncertain. This is presented in Figure 2.2. In the first-best world, the government sets the tax level at t and the permit level at C_p in the equilibrium E^e of the expected marginal abatement cost function (MAC^e) and the marginal damage cost function (MD).

Figure 2.2: Efficiency losses when marginal abatement costs are uncertain



However, when the marginal abatement cost function is uncertain and the true marginal abatement cost function is MAC^r , then the market equilibrium shifts to E^r . Consequently, both the tax and the permit level are no longer optimal and efficiency losses occur. They are represented by respectively the area E^rXY and E^eE^rZ . We observe that, when the marginal abatement cost curve is relatively flatter than the marginal damage curve, permits have smaller efficiency losses. On the contrary, when the curve is steeper, emission taxes are preferred. Note that the pollution level under a permit scheme C_p remains unchanged at the targeted level, irrespective of the relative slope. Consequently, permits are more effective since the targeted level is in any case met.

Secondly, Baumol and Oates (1988) argued that when marginal damage costs are unknown, emission taxes and permits are equally preferred. i.e. they have the same efficiency losses³³.

Ease of monitoring and enforcement

Bohm and Russel (1985) defined this criterion as:

"the relative difficulty of making and interpreting the measurements of discharges necessary to judge compliance, prepare bills, or audit self-reporting."

Both a tax and a permit scheme require the monitoring of the emission level. In addition to this, a scheme with tradable permits requires the monitoring of the trading process.

Flexibility in the face of change

This criterion reflects the ease with which the tax or permit scheme can be adjusted to maintain the desired environmental quality as the economy changes³⁴.

Bohm and Russel (1985) argued that a permit scheme is more flexible than a pricing scheme. Indeed, a changing demand for permits due to economic growth or shrink would be reflected in the permit price, which acts as an economic stabiliser. This avoids continuous bureaucratic intervention of redefining the price level. However, they considered flexibility only from the perspective of the government. When taxes are used, the adjustment process generates high administrative costs (for the government). When permits are used, the responsibility of the adjustment and the corresponding costs are transferred to the individuals.

³³ Of course, permits are more effective since the targeted level is in any case met.

³⁴ Examples of this change include changes in tastes, technologies and resource use.

Dynamic incentives

This criterion involves the long-term actions that are encouraged by the tax or permit scheme.

In principle, incentives for technological innovation are similar whether a price or a permit scheme is used. In both cases, there is a financial incentive to change behaviour. However, in the permit scheme, the exact monetary gain is less predictable due to the variable permit price.

Orasch and Wirl (1997) concluded that energy and environmental taxes are unlikely to give rise to research and development efforts in fuel efficiency unless they are very high.

Distributional effects

The use of revenues created by a tax or permit scheme has a major income distributional effect. In addition, under a permit scheme, the initial allocation of permits determines the distributional effects.

At present, little research has been done to estimate the distributional effects of a permit scheme³⁵, let alone to compare both³⁶.

Two notable exceptions are Weitzman (1977) and Parry (2004). Weitzman analyzed under what conditions pricing is more effective than rationing to allocate a scarce good to those users who have the greatest need³⁷. He developed a model to measure the comparative effectiveness of both

³⁵ Polterovich (1997) came to similar conclusions. In his study, he compared five allocation mechanisms: the competitive market, uniform rationing, uniform rationing with speculations, queues and queues with black markets. To this end, he used the framework of Sah (1987), which includes general equilibrium models. He concluded that during transition from rationing and queues to a market system, low-income households loose.

³⁶ Of course, there exists a huge literature on the distributional effects of tax schemes. Mostly, they conclude that taxes tend to be regressive, as low-income households spend a larger share of their income than higher-income groups on taxed products.

³⁷ More specifically, he limited his analysis to the type of good whose fair distribution to those having the greatest need, is considered as a policy goal. He gave the examples of mental health service, medicine, education, basic food and shelter, and legal aid.

instruments as a function of the distribution of income and needs. He concluded that the price system is more effective than rationing when wants are more widely dispersed and income distribution is relatively egalitarian, while rationing is more effective if needs for the scarce commodity are more uniform or if there is greater income inequality. He noted that a *ceteris paribus* increase in the market-clearing price makes rationing relatively more effective because the income distribution effect gains importance. Therefore, he argued that rationing is the best way of ensuring that true needs are met. In a pricing mechanism, richer consumers increase the market-clearing price ending with more of the scarce commodity than the poorer. Such system does not fulfil real needs since it is driven by income. Finally, he suggested that one fair way to make sure that everyone has an equal chance to satisfy his wants would be to give more or less the same share to each consumer independent of his budget size.

Parry (2004) used the research by Dinan and Rogers (2002) as a starting point to compare tradable emission permits and taxes. He concluded that grandfathered emissions permits redistribute income to wealthy households. Since firms gain additional income, revenues for -typically wealthy- shareholders would be higher. Consequently, grandfathered permits can be highly regressive compared to free allocation of permits or taxes.

In this dissertation, we estimate the distributional aspects of taxes and permits by comparing the relative welfare change across different household categories. In the welfare economics theory, two theoretically sound methods are described to measure the welfare impact of policy changes on an individual: the compensating (CV) and the equivalent variation (EV)³⁸.

CV estimates the amount the consumer would have to be paid to leave his utility level unchanged by a price increase. In other words, the compensating variation is the smallest adjustment of income needed to make the consumer indifferent to the policy change.

³⁸ Note that the level of welfare is a reflection of the willingness-to-pay, which is not the same as what consumers actually pay.

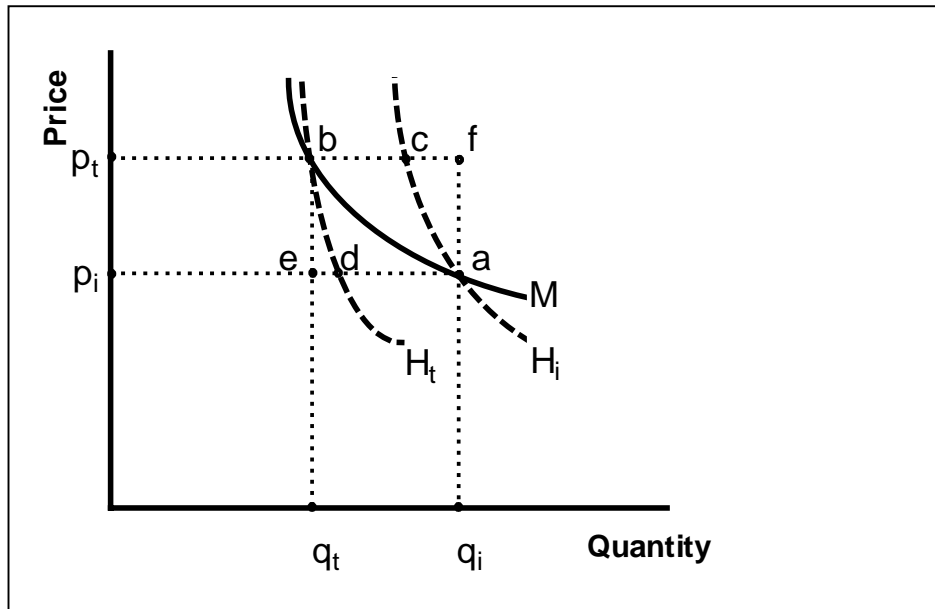
EV measures the income change, using initial prices that would be equivalent in welfare terms to the price change. In other words, it is the smallest amount of income, which, at the original prices, would just restore the consumer's original utility level.

Willig (1976) defined the distinguishing factor between both measures as:

"the level of utility the compensation is designed to reach"

Figure 2.3 depicts these two measures as areas under the demand curves.

Figure 2.3: Measures of welfare changes



Source: Based on Hicks (1939).

The consumers' uncompensated (Marshallian) demand curve is given by M. H_i and H_t are the utility compensated (Hicksian) demand curves³⁹, respectively before and after the policy change. As a result of a policy change (a tax increase), the consumption reduce from q_i to q_t and the price increase from p_i to p_t . In this figure, the CV is given by the area $p_i a c p_t$ and the EV is represented by the area $p_i d b p_t$.

³⁹ Hicks' (1939) theory implies that the income parameters include compensation, which varies with the price to keep the consumer at a constant level of utility.

Unfortunately, since the calculation of the CV and EV demand knowledge of the shape of the consumer utility curves, these estimates are not practical.

Fortunately, Willig (1976) showed that the change in consumer surplus provides a rigorous assessment of the consumer welfare if quasi-linear utility is assumed⁴⁰. As Figure 2.3 shows, the consumer surplus, which is depicted as the area $p_i a b p_t$, can be a good approximation to the welfare change that lies in the range of estimates of both CV and EV. Typically, the consumer surplus consists of two effects: the income transfer and the deadweight loss respectively represented by the area $p_t e b p_t$ and the area $e b a$. In the case of a tax increase, the income transfer reflects the income transfer from individuals that consume the taxed good to the government, while the deadweight loss indicates the net utility loss. Moreover, measuring the consumer loss is also practical because, assuming approximately constant marginal utility of income, it can be calculated based on the demand curve.

Graham and Glaister (2000) estimated the welfare cost of a price increase by simply calculating the cost of continuing to purchase the same quantity of fuel. This measure is depicted as the area $p_i a f p_t$ in Figure 2.3. Due to the high inelasticity of the fuel demand, they consider this overestimation as a reasonable estimate of the welfare costs. However, we follow Metcalf (1999), West (2004) and Sheu (2003) by calculating the loss of consumer surplus as the sum of the income transfer and the deadweight loss. In transport economics, this deadweight loss is mostly approximated by the "rule of half" whereby the deadweight is estimated by the triangle $f b a$. This gives the following formula to calculate the change in consumer surplus C_p :

$$C_p = \{(p_t - p_i)q_t\} + 0.5\{(p_t - p_i)(q_i - q_t)\} \quad (2.1)$$

This equation will be used in chapter 6 to calculate the economic welfare effects of fuel taxes amongst household categories.

⁴⁰ Quasi-linear utility implies that the consumer is risk-neutral and has zero income elasticity of demand.

Note that not all welfare issues are included, such as:

- Benefits that would be generated by additional fuel tax revenues;
- Cost to car and fuel industry and their shareholders in terms of a reduced production and employment;
- Benefits to car users and others from reduced external costs;
- Costs to those that are visited by car users: lower accessibility.

As we will illustrate in chapter 4 by the example of tradable fuel permits, the calculation of welfare effects of tradable permits is more complex due to the fact that households initially obtain an additional income by allocating free permits.

2.3.1 Combination of taxes and permits

A policy instrument mix is preferable in several situations. We discuss the ways of combining taxes and permits, namely the hybrid scheme and the subordinate schemes.

Hybrid scheme

Roberts and Spence (1976) extended Weitzman's analysis and showed that a hybrid scheme might have higher efficiency gains than a system of pure taxes or pure permits. Such a hybrid policy gives individuals the choice of either purchasing a permit in the marketplace or buying a permit from the government at a fixed price.

Such a policy might be useful in situations of uncertainty about cost and damage functions. In that case, the authorities can reach a compromise between maximal guarantees of reaching the cap and minimal compliance costs for the individuals. By doing so, the hybrid scheme acts as a safety valve since the permit price uncertainty is limited.

Subordinate schemes

Taxes can be complementary to a permit scheme and correct for some unwanted effects. Contrary to the hybrid schemes, taxes are now additional to the permit scheme. We consider three situations.

First of all, additional taxes can be used to recover windfall profits, which are gained by the individual when permits are allocated for free.

Secondly, when tradable permits are introduced to replace taxes, a subordinate tax scheme can retain part of the original tax revenues.

Finally, a tax on permit ownership can be imposed to create a well-functioning market. By doing so, strategic holdings of permits is discouraged and an efficient allocation of permits between individuals is encouraged.

2.3.2 Discussion

Scholars and international organizations have extensively studied differences between permits and taxes. They conclude that there are practical reasons for favouring either prices or quantities as planning instruments. These reasons might involve ideological, political, legal, social, historical, administrative, motivational, informational, monitoring, enforcing, or other considerations.

The set of assumptions is an essential element in comparing taxes and permits: In a first-best world, they are similar; while in a second-best setting, the assumptions determine which instrument is preferred above the other.

Many authors delineated the role of assumptions. Bohm and Russel (1985) concluded that

"the classical position that when using taxes efficiency, information economy and automatic adjustment to exogenous change can be reached at once, rest on very restrictive assumptions."

Norregaard and Repellin (2000) argued that the efficiency and flexibility superiority of the permit scheme rely on the assumption that transactions costs are low. Only then, trading can arise.

Pezzey (2001) made an interesting comparison of the different approaches towards long-term efficiency. He concluded that the conventional approach of

Baumol and Oates (1988) and his own and other dissenting views rely on different assumptions made about the thresholds or free permits built into respectively the tax and the permit scheme⁴¹.

Kaplow and Shavell (2002) emphasized that Weitzman's argumentation that quantity regulation could be superior to corrective taxes, only holds if a linear tax schedule is assumed. Furthermore, they argued that the same assumption relies on the position of Baumol and Oates (1998), which stated that quantity regulation is superior to taxes when the government is uncertain about the damage caused by an externality.

The most compelling example of the discussion about the superiority of taxes or permits can be found in the title of Kaplow and Shavell's (2002) article: "*The superiority of corrective taxes*". In their conclusions, they argue that permit schemes can be designed in such way that they are similar to corrective taxes.

We conclude that the theoretical discussion about taxes versus permits can be reduced to the discussion which assumptions are the most likely to occur. In this dissertation, we follow a practical approach by comparing the most common schemes. More specifically, these are tradable permits allocated for free (with low transaction costs) and a linear tax regime.

Based on these assumptions, we retain two main differences between permits and taxes.

- The efficiency depends on the relative slopes of the marginal benefit and marginal cost functions;
- Both schemes have different distributional effects. Under a tax regime there is a private-to-government transfer, while permits redistribute revenues amongst individuals.

⁴¹ Carlton & Loury (1980) considered the monetary value of the threshold value as subsidy, similar to the conventional approach but contrary to Pezzey (1992) and Farrow (1995), who considered it as property right. Contrary to the conventional and the approach of Pezzy and Farrow, Kling & Zhao (2000) considered the free permits as a subsidy.

CHAPTER 3 Tradable permits in road transport

Since Pigou's (1920) seminal work on the efficiency of taxes to correct negative externalities, transport economists are focusing on pricing mechanisms to reduce the environmental impact of road transport. Following Pigou, the tax rate has to be set equal to the difference between marginal social costs and marginal private cost. By minimizing their own costs, road users would simultaneously minimize the costs to society as a whole. According to this view, rational pollution control policy implies putting a price on pollution.

However, following the Coasean school, these externalities emerged because the property rights of public goods such as roads and air are undefined. According to Hau (1992), the excessive road use can be solved by an appropriate exclusion of road users, which can be realised by introducing permits. Tradable permits entitle the permit holder to a certain amount of usage, for example a certain amount of vehicle kilometres. The permit holder can be the vehicle user, owner or producer, while the facility can vary from vehicle ownership, fuel, vehicle kilometres, and access to a city or a main road during a certain time-period. This chapter reviews these different permit schemes in private road transport.

3.1 Outline of possible permit schemes

This section gives a comprehensive review of the possibilities to introduce a tradable permit scheme for the use of road infrastructure.

Our approach to define possible permit schemes is based on Hau's (1992) classification of road use charges. Table 3.1 illustrates the possible charging and tradable permit schemes. A distinction is made between direct and indirect regulation of road use. Direct regulation can be organised on specific locations (e.g. tolling) or as a continuous system. Indirect systems include the regulation

by vehicle ownership, amount of vehicle use, temporal and spatial vehicle use and a combination of the two latter mentioned systems.

Table 3.1: Economic instruments to regulate road use

| Indirect | Charging scheme | Tradable Permit scheme |
|---|--|---|
| Vehicle ownership | Purchase tax Annual license fee | Vehicle Ownership Permits |
| By amount of vehicle use | Fuel Tax Tax on vehicle parts | Fuel Permits Vehicle Kilometre Permits |
| By place & time of vehicle use | Parking charge Supplementary licensing | Parking Permits Driving Days Permits |
| By amount and place & time of vehicle use | Differential fuel taxes | Differentiated Fuel Permits |
| Direct | Charging scheme | Tradable Permit scheme |
| Point charging | Tolling, Road pricing and Cordon-Based pricing | Cordon Permits Corridor Permits |
| Continuous charging | Congestion based charging | Differentiated Vehicle Kilometre Permits |

Source: Based on Hau (1992).

However, this is a non-exhaustive list of possible permit schemes in road transport. Other permit systems are described in the literature. Verhoef et al. (1997) explored the possibilities of using tradable permits in the regulation of road transport externalities whereby a distinction is made between schemes on the demand side (user-oriented) and on the supply side (automobile and fuel industry)⁴². Since rather insignificant changes in mobility behaviour can be

⁴² Raux (2002) categorised upstream and downstream permit schemes.

expected, we exclude the latter group⁴³ in our research. Nevertheless, considerable environmental gains can be expected from such schemes⁴⁴.

3.2 Design of a tradable permit system

In this chapter, we discuss the following tradable permit schemes:

- Tradable Car Ownership Permits (TCOP);
- Tradable Fuel Permits (TFP);
- Tradable Vehicle Kilometre Permits (TVKP);
- Tradable Differentiated Vehicle Kilometre Permits (TDVKP);
- Tradable Corridor Permits (TCP);
- Tradable Cordon Entrance Permits (TCEP);
- Tradable Parking Permits (TPP).

Our discussion of the different permit schemes is based on the existing literature and best practices in this field. This helps us to design the different aspects of the schemes, for which we use the Harrison's approach (1999) as described in chapter 2. Prior to describing the threshold, design and implementation issues of the permit schemes mentioned, we discuss some general aspects, which are similar for all schemes:

- Permit allocation;
- Nature and form of permits;
- Market organization.

First of all, Rietveld et al. (1997) distinguished several groups of permits holders: households (all persons above 18 years) and the business sector, which they specify in large and small business. Annual permits are allocated to large business units based on their individual use of a reference year. For small business and households a general distribution key is used. This means that the

⁴³ This group includes a tradable permit schemes for Corporate and Sectoral Average Environmental Quality and Environmentally Weighted Car Sales, as was described in Verhoef et al. (1997)

⁴⁴According to Albrecht (2000) a simulation of tradable CO₂ permits for cars and trucks indicates a CO₂ reduction from the car fleet by 25-38% over a period of 15 years. For a further assessment, see Ahmed and Greene (2002)

total amount of available permits for these groups is divided by the number of permit holders. Since there is a significant differentiation of personal travel behaviour between age categories, we advocate distributing permits in accordance with age category: between 0 and 18 years (youngsters), between 18 and 65 years (active) and above 65 years (retired). Although Montgomery (1972) stated that the initial distribution of permits does not affect the ultimate distribution, we include this specification for fairness considerations. Another element of allocation is the freedom to receive/refuse permits. All individuals and companies have the possibility to be excluded from the free allocation, although they need permits to use the road.

Secondly, we need to define the nature and form of the permits. We opt for tradable permits, which mean they can be bought and sold. Permit holders which are able to reduce their use, can sell their excessive permits to those who require more. Further on, banking of permits is not allowed, which means that permits have a limited period of validity. This discourages speculation. The permits are materialised by using smart card technology, which allows easy and inexpensive transactions and is fraud resistant.

A third general aspect is the market organization. Four different forms of market organization of permits can be distinguished:

- Direct search markets, where buyers and sellers directly meet each other;
- Brokered markets, where buyers and sellers employ agents to seek compatible partners;
- Dealer markets, where dealers act as intermediaries holding, buying and selling product inventories;
- Auction markets, where traders such as financial institutions transact directly through a centralized intermediary.

Since established financial institutions are used, an auction market minimise the transaction costs and other operational costs. Furthermore, we expect an electronic auction market of permits: Wrigley (1997) argued that the occurrence of an electronic market depends on the nature of the good. More

specifically, an electronic market is created if the good has any of the following characteristics:

- Limited life span;
- Scarcity of the good;
- Electronically transferable;
- Geographically constrained.

Since all these factors are present in a permit market, an electronic permit market will be established.

3.2.1 Tradable Car Ownership Permits (TCOP)

Best practices

Walton (1997) described a car ownership programme for the UK, which aims to reduce the number of private cars and their amount of emission. The final objective is to challenge the dominance of the car culture and promote the use of public transport. He describes an auctioning system, whereby permits have a limited life span, in order of two or three years and their value depends on the size of the car engine.

A well-known system of vehicle ownership permits is already functioning in Singapore⁴⁵. In 1990, Singapore introduced a system of tradable vehicle ownership permits, whereby eight categories of "Certificates of Entitlement" are distinguished. Koh and Lee (1994) reported that due to rumours about huge profits made by speculators the tradability was replaced by a monthly sealed-bid tender auction.

Threshold issues

The objective of this permit scheme is to limit road transport on the European level by regulating the car ownership rate.

⁴⁵ For an overview of the transport policy in Singapore, we refer to Willoughby (2001).

Design issues

The cap is set on the total amount of vehicles for different car categories according to the Euro emission standards⁴⁶. This calculation is based on the data available at the Annual Licence Authority. The permits have a validity period of two to four years, which prevents car owners to yearly adjust their car stock in relation to the amount of their permits.

Implementation issues

In the start-up phase, sufficient permits are auctioned to allow all present cars to stay in use. This implies that an introduction of this system in year n would use year $n-1$ as a reference year.

Trade of permits takes place by insurance companies and vehicle sellers.

The Driving Vehicle Licensing Authority of each Member State is responsible for the organization and monitoring of the system. Enforcement is organised on an upstream level, more specifically by the insurance companies. However, they are not allowed to insure car owners if they fail to present a sufficient amount of permits. Car owners, which can not present valid insurance papers, are detected by the regular police controls.

3.2.2 Tradable Fuel Permits (TFP)

Best practices

A permit scheme can also be based on fuel rationing. Verhoef et al. (1997) described a system of tradable fuel permits for the Netherlands. Hofman et al. (2000) described a system on European level whereby non-fuel consuming transport modes are excluded. Keppens and Vereeck (2003a) explored the possibilities of a TFP system to realize the reduction agreed on the Kyoto

⁴⁶ The Euro 2-4 standards are different for diesel and gasoline vehicles. Diesels have lower CO standards but are allowed higher NO_x. Gasoline vehicles are exempted from PM standards.

Protocol. Raux and Marlot (2005) proposed a combined taxation and permit system, whereby motorists could voluntarily take part in the permit scheme.

However, Dobes (1998) gave three arguments against the use of tradable greenhouse emission permits in the transport sector:

- Transport is not a homogeneous good; more specifically the modes and nature of trips are variable;
- Transport generates several externalities such as congestion, noise, accidents and rather mobile sources of emissions of CO₂, NO_x and small particles;
- The transport market is distorted and petrol demand is highly inelastic.

Raux (2004) refuted these arguments by discussing a case study of an existing (non-tradable) permit scheme: the Ecopoint scheme in Austria. This scheme was designed to decrease the environmental impact of transit freight transport. He concluded permits applied to mobile sources are technically feasible at acceptable financial cost for protecting sensitive geographical areas.

Threshold issues

The basic purpose of the TFP system is to achieve an environmental goal, namely a reduction of CO₂ emissions caused by cars.

Since car related CO₂ emissions account for 12 % of the total CO₂ emissions and a further growth is forecast, this sector can no longer be neglected. Furthermore, the introduction of a permit program for individuals would be a major step towards increasing public awareness for problems addressed in the Kyoto Protocol. The system is implemented on a European scale, which allows a greater number of market players and enhance the development of the internal market.

Design issues

Since CO₂ emissions are proportional to the amount of the carbon content of the fuel, a fuel-based permit scheme could be developed.

The average CO₂ emissions factors from fuel for passenger cars are given in Table 3.2. These factors are used as distribution code for permits. This means that one TFP corresponds to one kilogram of gasoline or 3.13/3.17 kg of diesel or 3.13/3.00 kg of LPG.

Table 3.2: Average CO₂ emissions factors from fuel for passenger cars

| Fuel type | CO ₂ emissions in tonne CO ₂ /tonne Fuel |
|-----------|--|
| Gasoline | 3.13 |
| Diesel | 3.17 |
| LPG | 3.00 |

Source: Flugsrud et al. (2000)

There are no geographic restrictions, which means that TFPs can be used in the whole European Union.

To set up this system, a European institution is founded, which has three important tasks. First of all, the agency allocates the TFPs among the Member States. The different Member States then distribute these permits among their citizens. A second responsibility is to fix the level of the annual cap for each Member State. Finally, the institution controls the Member States on the correct compliance with the TFP system. These monitoring and enforcement issues will be further discussed in the next paragraph.

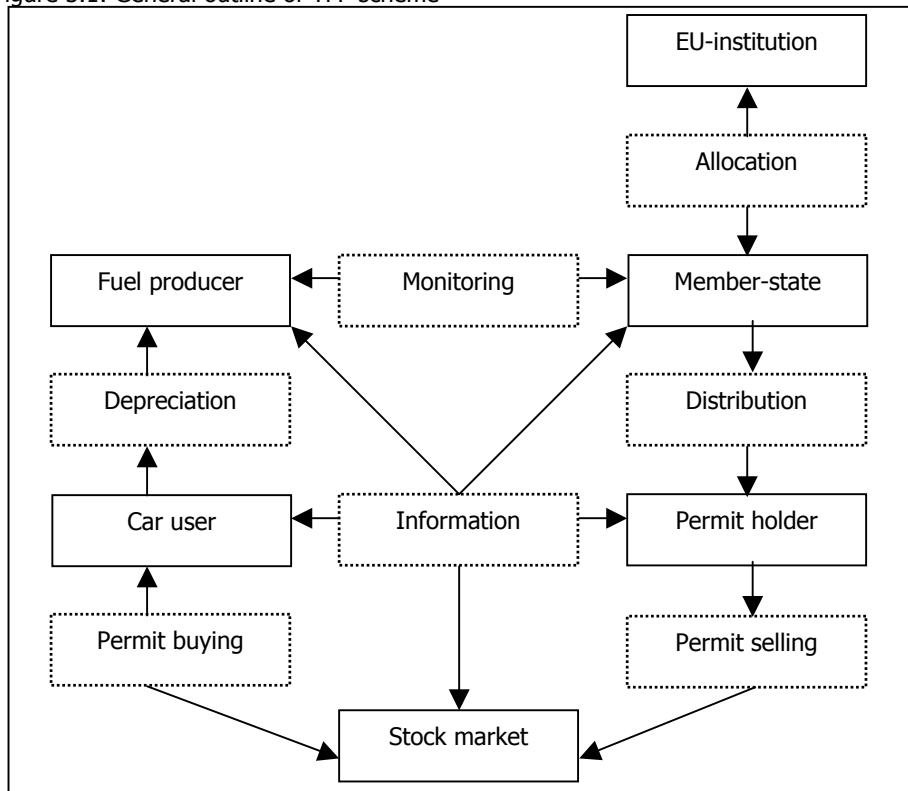
Financial institutions can act as an intermediate player between buyers and sellers. By using these existing institutions, transaction costs and other operational costs are minimized.

Implementation issues

Figure 3.1 shows the system outset of the TFP system. Four parties are involved, namely a European institution, the EU-Member States, the permit holders and the vehicle users. Furthermore, five major types of processes can be described: First of all, a European institution allocates a number of permits to the EU Member-States. Secondly, the Member-State informs the permit holder, the vehicle user and the fuel producer. Thirdly, the Member-State

distributes the permits amongst its population. Furthermore, permits are exchanged between permit holder and vehicle user. The fuel producers depreciate these permits. Finally, Member-States monitor the fuel producers.

Figure 3.1: General outline of TFP scheme



Existing technologies can be used for the implementation of a TFP-system. When refuelling, the smartcard discharges TFP at terminals, which are located at gas stations. Crucial is that it is impossible to refuel without using this card. Public transport operators can integrate the TFP into the price of the travel passes or passengers can transfer their permits by discharging their card when buying a travel pass. Recharging the card can take place at bank terminals, at sales offices and via an individual Internet account number.

Monitoring in the permit program is organized at the level of the different fuel producers and importers. For the fuel sold, they have to present a proportional amount of TFP's.

Under this permit program, the main enforcement issue is avoidance behaviour. Although the system is introduced on a European scale, there is still the problem of people crossing the border to refuel. Because it can be expected that most of the incoming transport has a full fuel tank, forcing all outgoing transport to refuel before they cross the border can solve the problem. The enforcement is organised in several ways. First of all, the smart card keeps a record of transactions, which can be checked when recharging the smart card. Furthermore, an administrative control is organised by the issuing body to verify if all vehicle owners have a permit account (black list). Finally, the terminals at fuel stations are fraud-resistant, which implies the impossibility of refuelling without registration of permits.

3.2.3 Tradable Vehicle Kilometre Permits (TVK)

Best practices

Keppens and Vereeck (2003b) discussed the system requirements for a Tradable Vehicle Kilometre permit scheme and conclude that there are no technological barriers for the implementation of the TVK scheme.

Threshold issues

The TVK permit system sets an upper limit, based on the total vehicle kilometres travelled. The target group of the TVK system is the individual European car driver. We choose for an implementation on a European scale because of the greater number of market players and to vindicate the free movement of goods and persons in the EU. Moreover, the European Commission aims at an integrated approach of the mobility problems in all the Member States.

Design issues

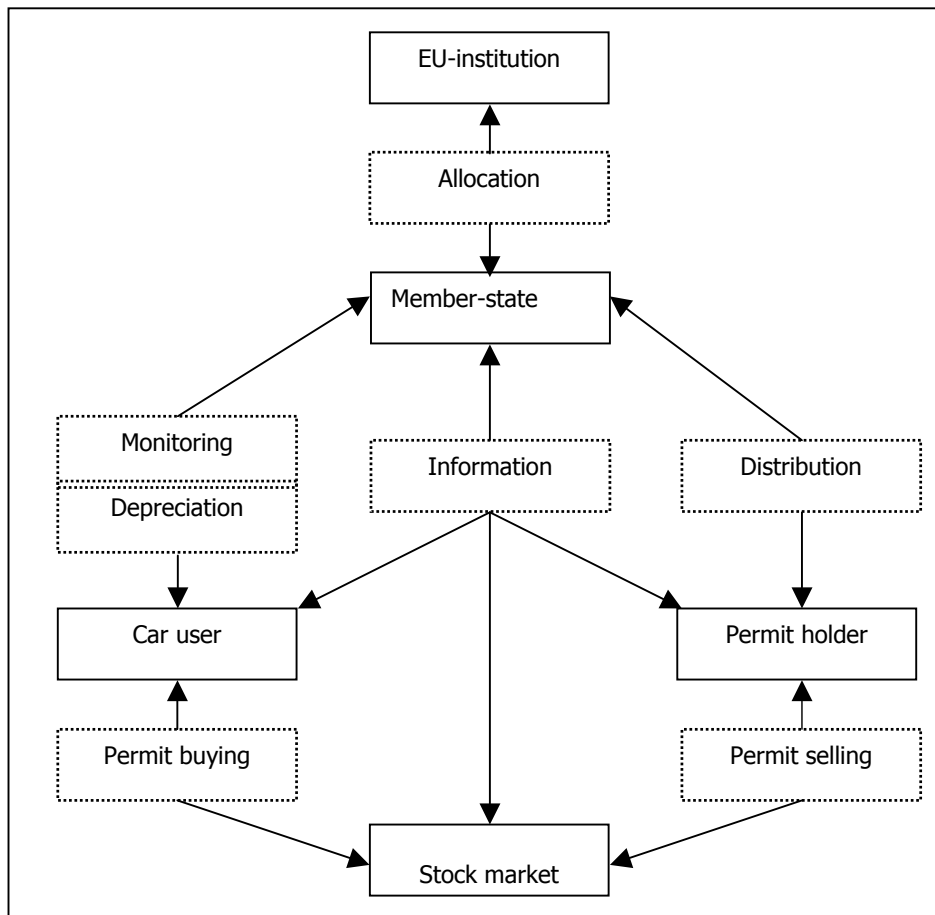
The cap of the system is set on the total vehicle kilometres of a reference year. At the beginning of the calendar year, the TVK are distributed. Financial institutions act as intermediaries between buyers and sellers. By using these existing institutions, transaction costs and other operational costs are minimized.

However, to set up this system, a European institution has to be founded similar to the tradable fuel permit scheme.

Implementation issues

Figure 3.2 shows the basic model of the TVK permit system. Hereby, we can define four parties involved in the system, namely a European institution, the EU-Member States, the permit holders and the vehicle users.

Figure 3.2: Basic model of TVK permit scheme



Furthermore, the major types of processes are similar to those of a tradable fuel permit scheme except that monitoring is organised at the level of the end-user. An On-Board Unit (OBU) registers the number of kilometres, which are depreciated at gantry points. These points are strategically located at major

traffic junctions and fuel stations. The public administration department, which is dealing with vehicle registration, is responsible for calibration, monitoring and issuing of OBU's. This allows a differentiation in relation to the vehicle type and environmental characteristics.

A fraud-proof system requires that the OBU does not allow driving without recording the distance travelled. Next to the gantry gates which are operating as check points, mobile control brigades are established.

3.2.4 Tradable Differentiated Vehicle Kilometre Permits (TDVK)

Best practices

Verhoef et al. (1997) proposed a vehicle kilometre permit scheme, which is time and space dependent. Moreover, these permits are based on vehicle weight classes. In contrary to Verhoef et al., we do not allow banking. By doing so, we ensure that the proposed target is met. At present, no such system of TDVK has been implemented.

Threshold

The objective of this system is twofold. Next to a reduction of car use, more specifically during peak-hours in congested areas, the TDVK permit scheme aims to reduce the emission level caused by private road transport in the European Union.

Design issues

The design issues are similar to the TVK permit scheme except that the cap of the system is set on the total vehicle kilometres, differentiated in time and space of a reference year.

Implementation issues

The technology is similar to the one used in road pricing, whereby each vehicle has an OBU and registration points are installed alongside the road. More specifically, the technology proposed by the Dutch experience of "Mobimiles" could be used. The system of "Mobimiles" was aimed to decrease road congestion and environmental effects of road use. The system implied a differentiation of car cost in relation to space, time and environmental car characteristics. Pieper (2003) defined six system requirements:

- Variabilise and differentiate the costs of road use;
- Ensure privacy of system users;
- Provide a reliable service, resistant to fraud and evasion;
- Establish a link between demand for and availability of the road infrastructure;
- Be attractive to the user;
- Be based on a solid system architecture.

For the organization of this system, he suggested to create a trusted third party. The technical implementation would imply a "trusted-wallet" (e.g. a chip). This "trusted wallet" would provide the following services:

- Location determination;
- Charge distribution;
- Payment;
- Enforcement.

He concluded that there were sufficient technological possibilities to implement this system, based on the existing infrastructure.

3.2.5 Tradable Corridor Permits (TCP)

Best practices

Wong (1997) suggested a booking system for highway use, similar to the airlines and rail companies. The road capacities for each road segment per time period are considered as the number of seats available on an airplane. Drivers

should book in advance. The system would check the current booking level and, if there is still capacity left, accept the request. Once the booking is accepted, the driver must follow the indicated departure time and itinerary.

Stone (2002) proposed a transit rights trading exchange for the Trans-Alpine highway freight traffic. Kornhauser and Felig (2002) suggested a system of marketable permits for Peak Hour Congestion in New Jersey's Route 1 Corridor. Verhoef et al. (1997) proposed a system of tradable road-pricing smart cards. By distributing a number of free smart cards, public acceptance of road pricing could be enhanced.

Threshold

The TCP system aims to solve the problem of traffic congestion on major highways.

Design issues

The TCP system sets an upper limit of cars driving on a certain road segment during a specific time period or a "slot". This permit scheme is used during peak-time for highly congested roads.

Depending on the geographical proximity to the corridor, a number of permits are allocated for free to all residents.

Implementation issues

The implementation issues are similar to the Differentiated Vehicle Kilometre permit scheme.

3.2.6 Tradable Cordon Entrance Permits (TCEP)

Best practices

There is not much literature in the field of Tradable Cordon Entrance permits. However, Goddard (1997) proposed a similar system. More specifically, he suggested replacing the current scheme of odd/even number plates in Mexico City by a tradable driving rights scheme. The objectives are an air quality

improvement and a congestion reduction. The allocation is based on the grandfathering principle, which allows a free one-time grant to registered vehicles. The system operates by removable cards in the windscreen.

Threshold

The basic purpose of the TFP system is to set an upper limit of cars driving into an urban area.

Design issues

One tradable permit corresponds to the entrance to the city centre during 1 working day and apply for private cars driving into the city between 7 A.M. and 8 P.M.

A number of permits are allocated for free to every citizen and are materialised by a smartcard. Depending on the total number of commuters, the urban authority can issue some additional permits.

Implementation issues

Figure 3.3 shows the system outset of the TCE permit system. Three parties are involved:

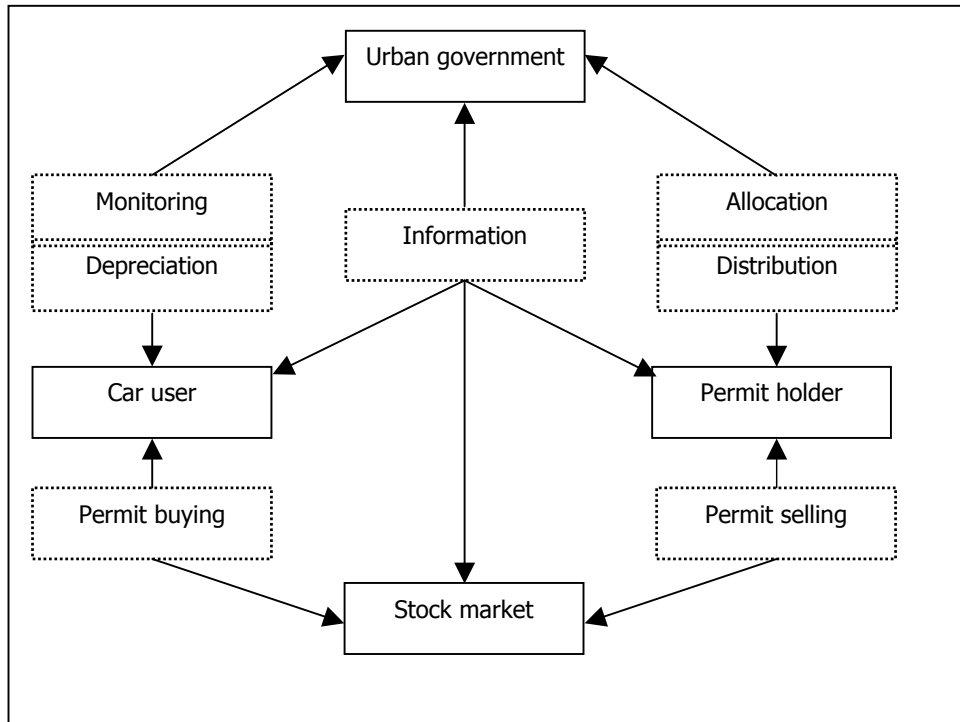
- The urban government;
- The permit holders;
- The car users.

Furthermore, five major types of processes can be described:

- The urban government allocating a number of permits and distributing them amongst their residents and commuters;
- The local authority informing the permit holder and the vehicle user;
- Permit holders sell permits at the stock market;
- Car users buy permits at the stock market;
- The local authority depreciating the permits and monitoring the car users on the gantry ports.

The monitoring has to be based on existing technologies, which are operational in London and Rome. This comprises license plate recognition and Closed Circuit Television (CCTV) camera observation at the gantry ports.

Figure 3.3: General model of the TCE permit system



3.2.7 Tradable Parking Permits (TPP)

Best practices

Verhoef et al. (1997) proposed three target groups for a system of tradable parking permits: residential parking, Central Business District (CBD) parking and parking place permits for firms. They find tradable parking permits not advisable in residential or in CBD areas. However, in case of area-wide standards of parking space for firms, tradable permits can be used.

A current parking permit program has been taken place is the California *Parking Cash Out* Experience, whereby employers allocate a number of parking privileges

to their employees. In 1992, California enacted the "parking cash-out" legislation, which requires certain employers who offer free parking to their employees to eliminate the free benefit or offer cash equivalents to employees who decline the parking privilege. The law was intended to reduce the incentive to drive to work and thereby reduce traffic congestion, air pollution and fuel consumption. Shoup (1997) pointed out that cashing-out employer-paid parking, benefits commuters, employers, taxpayers and the environment. First of all, travel behaviour changed more towards sustainable modes: single driving dropped 17 percent, carpooling increased by 64 percent, the use of public transport rose by 50 percent and bicycling and walking rose by one third. Furthermore, employers and employees considered the system fair and efficient. Thirdly, the parking cash out increased income tax revenue. Finally, carbon dioxide emissions decreased by 367 kilograms (or 12 percent) per employee per year.

Threshold

The aim of this scheme is to change commuter travel behaviour towards more sustainable transport modes. The geographical scope is limited and applies only to employees of individual firms, industrial zones or school campuses.

Design issues

The parking permit program is similar to the Cordon Entrance permit system, but is organised on company level. Depending of the size of the parking lot, every employee receives a proportional amount of parking permits.

One tradable permit corresponds to the entrance to the car park during one working day.

Implementation issues

Since the tradable parking permit scheme is organised on company level, the implementation issues are a simplification of the Cordon Entrance permit system.

3.3 *Qualitative evaluation of permit schemes*

The main purpose of tradable permits is to convey appropriate price signals to road users. They can choose a combination of measures to minimize their permit expenses. The efficiency of the system depends on the easiness to buy and sell permits. The principal implementation issue is whether an efficient market can be established.

A qualitative assessment of the permit systems shows their particular importance to regulate the transport market. Firstly, a permit system is highly effective in realising a fixed objective since it is possible to set precise and measurable targets. Secondly, since the market determines the price, it truly reflects the participant's (marginal) willingness-to-pay. Participants able to reduce their usage relatively cheaply will do so rather than purchasing permits. Thirdly, since the permit schemes do not lead to additional public revenues, the government does not have to develop a fair redistribution scheme. In the permit schemes, people with sustainable travel behaviour are rewarded. Finally, the permit schemes provide a continuing incentive for innovation.

Since the Tradable Differentiated Kilometre permit and Tradable Corridor permit schemes are differentiated in time and space, they allow an internalisation of all external costs including congestion costs. Therefore, these schemes are considered as the most promising application of tradable permits but also the most complex systems to implement. Much more research is needed to fully understand the efficiency of rationing network capacity. The research on road network rationing is very complex and is at present non-existent.

One of the design problems of tradable permit schemes is to simplify the permits market without losing efficiency. Therefore, we conclude that a Tradable Fuel Permit and a Tradable Parking Permit scheme are the most feasible systems for an implementation in the short run.

In this dissertation, we focus on tradable fuel permits. This choice is motivated and clearly illustrated by a recent report of the International Energy Agency (2005). The agency raised its concerns about the possibility of an oil supply shock and the economic impact of high oil prices. It provided an assessment of

the potential oil savings and implementation costs of emergency oil saving policies for passenger transport. Next to the regular mix of policy measures⁴⁷, they included more drastic measures such as driving bans on weekends, alternate day car-use, which are both rationing schemes. However, a fuel allocation coupon system was not included. IEA (2005, viii) considered fuel allocation coupon systems as:

*“... may be needed, but should be seen as something of a last resort.
... may provide an important complement to measures described
here.”*

They concluded that pre-planning is essential in order for transport demand restraint measures to succeed during a crisis.

⁴⁷ This mix consisted of flexible work schedules, car pooling, telecommuting, speed restrictions, tyre pressure calibration and reducing public transport tariffs.

CHAPTER 4 Tradable fuel permits

While we concluded in the previous chapter that the tradable fuel permit scheme is the most feasible system towards implementation, we ascertain that fuel is a good proxy for CO₂. This is a condition *sine quae non* for tradable fuel permits to be a valuable extension of the actual set of instruments to reduce CO₂ emission. Moreover, we demonstrate that the concept of tradable fuel permits is not entirely new: in the wake of the oil crisis of the seventies, the U.S. Department of Energy developed a Standby Gasoline Rationing Plan. Furthermore, we discuss the effects of introducing a tradable fuel permit scheme, as was described in the previous chapter. Finally, we conclude this chapter by indicating some alternative fuel permit schemes.

4.1 Fuel combustion and CO₂ production

The combustion of a hydrocarbon fuel (petrol, diesel, LPG,..) in air, follows a simple chemical reaction in ideal conditions:



However, in practice, the combustion process is more complex. First of all, not all fuel is completely combusted⁴⁸, and carbon monoxide (CO) or carbon particles (PM) are produced. Secondly, some fuel is not combusted at all and volatile organic components (VOC) are formed. Finally, nitrogen oxide (NO_x) is produced because nitrogen in the air and traces in the fuel are oxidised.

The average emissions factors from fuel combustion of cars are given in Table 4.1. We observe that each litre of fuel that is burnt, produces approximately three kilograms of CO₂, between 10 and 240 grams CO, 3 and 30 grams of VOC, 8 and 18 grams of NO_x and a variety of other emissions including PM, lead and sulphur compounds. Furthermore, we note that diesel cars emit less CO, NO_x and VOC, while gasoline cars produce less PM.

⁴⁸ In chemical terms, the incomplete combustion is called incomplete oxidation of carbon.

Table 4.1: Average emissions factors from fuel combustion of cars

| | CO ₂ | CH ₄ | N ₂ O | SO ₂ | NO _x | VOC | NH ₃ | CO | PM |
|----------|-----------------|-----------------|------------------|-----------------|-----------------|-------|-----------------|--------|------|
| | (kg/kg fuel) | (kg/ton fuel) | | | | | | | |
| Gasoline | 3.13 | 1.58 | 0.61 | 0.16 | 17.90 | 31.20 | 0.77 | 241.00 | 0.28 |
| Diesel | 3.17 | 0.09 | 0.16 | 1.20 | 8.10 | 2.90 | 0.02 | 11.00 | 3.47 |
| LPG | 3.00 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

Source: Flugsrud et al. (2000)

Generally, air pollutants from cars are classified in two groups. On the one hand, the exhaust pipe emissions⁴⁹, which come from fuel combustion in the engine, are a complex function of engine technique, catalyst performance and driving behaviour, road conditions and environmental situation. On the other hand, evaporative emissions, which occur while the car is moving, standing⁵⁰ or refuelling, are related to the outside temperature and the night-day variation, the fuel volatility, car technology and driving conditions.

As Table 4.2 shows, all of these emissions can have local, regional and global effects.

Table 4.2: Spatial effects of emission

| | PM | NH ₃ | SO ₂ | NO _x | VOC | CO | CH ₄ | CO ₂ | N ₂ O |
|----------------|----|-----------------|-----------------|-----------------|-----|----|-----------------|-----------------|------------------|
| Local level | X | X | X | X | X | X | | | |
| Regional level | | X | X | X | X | X | | | |
| Global level | | | | | | | X | X | X |

Source: Faiz, Weaver and Walsh (1996)

Firstly, local effects depend on the motorisation and urbanisation intensity of the area. These local emissions such as NO_x, CO, PM and VOC's have mainly an impact on human health. SO₂, NO_x, VOC's and NH₃ cause regional effects,

⁴⁹ Exhaust pipe emissions can be classified into start and hot emissions. Start emissions are expressed as an amount produced per trip and are related to average speed, the engine temperature, the length of the trip. Hot emissions are related to the average speed, car technology, load, road gradient, altitude, outside temperature, air conditioning and the total number of kilometres travelled in the case of a catalyst car.

⁵⁰ Fuel vapour is formed due to the daily increase in temperature compared with overnight temperature

which comprise acidification of water and soils. Finally, global effects include depletion of the ozone layer and climate change, which are caused by greenhouse gases (CO₂, NO_x, CH₄). Clearly, there is no general spatial optimum in the calculation of emission effects⁵¹. Stated otherwise, there is no simple relation between transport emissions, emissions from other sources and pollution concentrations. Moreover, there is an important effect from atmospheric chemistry⁵².

From the above discussion, it is clear that the calculation of the different emission products and their contribution to pollution is a complex task⁵³. Ross (1994) concluded that the energy use by vehicles is understood rather well, but that their emissions and consequences are poorly understood.

However, the calculation of the amount of CO₂ is quite straightforwardly. Since in equation (4.1), the total amount of carbon before and after combustion is balanced, we conclude that the amount of used fuel is a good parameter for the total amount of CO₂.

4.2 Measures to reduce CO₂ emissions

At present, there exists a wide range of instruments to reduce CO₂ emissions. In this section, we discuss general and specific measures related to road transport and consider their reduction potential.

⁵¹ The same complexity occurs in the temporal dimension. While some effects occur in peak concentrations, others act over a long time.

⁵² An example includes the complicated relation between NO_x and N₂O. As Table 4.1 showed, the majority of nitrous emissions is in the form of NO_x. However, NO_x oxides to N₂O in the atmosphere, which depends not only of the amount of NO_x but also of the quantities of oxidisers in the atmosphere such as ozone (O₃). Since the concentration of O₃ is often the limiting factor on N₂O formation, reducing the NO_x emissions will have a small impact on reducing N₂O.

⁵³ Emissions statistics in Europe are mostly based on the MEET project (Methodologies for Estimating air pollutant Emissions from Transport). This project collects the most comprehensive and up-to date information on transport vehicle emission rates and activity statistics. For more information about MEET, we refer to EC (1999).

4.2.1 General aspects

Kyoto protocol

Since February 2005, the Kyoto Treaty has come into effect. Under the Kyoto Protocol, the European Union (EU) has committed itself to limit its greenhouse gas emissions. In the period 2008 to 2012, the EU aims to reduce overall greenhouse gas emissions by eight percent below their 1990 levels.

The Protocol includes four flexible mechanisms in order to reduce the compliance cost. First of all, emissions trading which allows the exchange of 'assigned amounts' of emissions. Secondly, the Clean Development Mechanism, which enables industrialized countries to finance emissions-reduction projects in developing countries and receive credit for doing so. Thirdly, the Joint Implementation, which includes the transfer or acquisition of emission reduction units resulting from activities reducing emissions. Finally, Joint Action (bubbles) whereby members of established regional groupings such as the EU agree to achieve their reduction targets jointly, provided that their combined aggregate anthropogenic carbon dioxide equivalent emissions of greenhouse gases do not exceed their assigned commitments.

European greenhouse gas emission permit scheme

In July 2003, the EU parliament approved the directive to establish a greenhouse gas emission allowance-trading program for energy intensive sectors within the EU Member-States (CEC 2003). By linking the domestic programs and thus increasing the number of participants and market liquidity, compliance costs are reduced and a greater deployment of low emissions technology is realised.

The permit program is estimated to cover about 46 % of the EU's total CO₂ emissions by the year 2010. Six greenhouse gases are covered, including CO₂, CH₄, N₂O, hydro fluorocarbons (HFCs), per fluorocarbons (PFCs) and sulphur hexafluoride (SF₆). Starting from 1 January 2005, around 10,000 EU companies are involved in the greenhouse gas emissions trading. The program covers

about 4,000 to 5,000 installations, including power and heat generation installations. The chemical sector is excluded because of the limited importance of the CO₂ emissions and the high number of plants.

During this preliminary phase, there are no legally binding targets for the Member states and permits are allocated for free. This phase allows the EU to gain experience before the international emission trading program starts in January 2008.

4.2.2 Private road transport

In 2006, the EU-Commission will assess the coverage of the greenhouse gas emission permit scheme and possibly extend it to other sectors such as the transport sector, which is causing 24 % of the total CO₂ emissions. In 2000, transport related CO₂ emissions increased by 128 million tonnes or 18 % (European Environment Agency 2002) compared to the level of 1990. Passenger cars account for 50 % of these transport related emissions. CO₂ emissions of passenger road transport are steadily increasing. In spite of a higher fuel efficiency of present cars, this trend can be explained by the consumers' preferences for larger and more powerful cars, an increase in accessory equipment in cars and changing driving conditions. Without effective policy measures, CO₂ emissions are expected to grow further. CO₂ emissions produced by passenger transport are forecast to become twice as big in 2020 compared to the level of 1990, while other transport-related emissions, such as CO and NO_x are expected to decrease due to the introduction of new technologies and legislative measures (CEC 2003).

ACEA commitment

The cornerstone of the current European strategy to reduce emissions is an environmental agreement with the car industry to improve fuel efficiency. In 1995, the European Automobile Manufacturers' Association (ACEA) committed itself to achieve an average CO₂ emission value of 120 g/km for all new cars by

2005, or at the latest by 2010⁵⁴. The car industry should achieve this target by technological developments and market changes, while the EU promise not to introduce additional fiscal measures. In 1999, the EU recommended to the ACEA an emission target of 140g/km CO₂ (a cut of around 25 %) and postponed the target of 120g/km to 2012 (CEC (1999)). In 2000, similar agreements were made with the Korean (KAMA) and Japanese Automobile Manufacturers' Association (JAMA) to achieve the CO₂ emission objective by 2009.

However, these agreements would not be effective to actually reduce CO₂ emissions. It is expected that with full implementation of the ACEA agreement, a growth of 11 % is expected (without the agreement, CO₂ emissions would increase with 29 % (European Environment Agency (2001)). This growth can be explained by an increase in car mileage and ownership per capita as well as a tendency towards more powerful and larger cars. Consequently, other policy measures seem necessary to complement with these voluntary agreements.

Other measures to reduce CO₂

Existing measures to reduce CO₂ emissions from transport are classified by the OECD (2002) in three categories⁵⁵. First of all, an improvement of the fuel efficiency can be realised by legislation, voluntary agreement and fiscal measures. Secondly, traffic demand management comprises traffic flow management, reduction of transport demand and modal shift towards public transport. Finally, there are measures to promote the use of renewable sources or low carbon fossil fuels. Table 4.3 gives a survey of the most promising measures to reduce CO₂ emissions of car use and their expected reduction

⁵⁴ For more information about ACEA commitment, we refer to Pocklington (1998). For an analysis of the ACEA commitment, we refer to Keay-Bright (2001).

⁵⁵ Bouwman and Moll (2000) made a distinction between four categories: (1) Options emphasizing technological change; (2) Options emphasizing behavioural change; (3) Options emphasizing changes in car infrastructure comprises alternative fuel vehicles; (4) Mobility reducing options

rates. Note that contrary to the other forms of emissions, there are no technologies available to eliminate CO₂ from vehicle emissions.

Table 4.3: Policy measures to improve fuel efficiency and expected reduction rates

| | Expected reduction by 2010 (in %) | Expected reduction by 2020 (in %) |
|---|-----------------------------------|-----------------------------------|
| Introduction of on-board technology | 3-5 | |
| Maximizing fuel economy benefits of cost-effective technologies | 4-12 | 12-20 |
| Incentives for aggressive introduction of new technologies | 2-4 | 8-16 |
| Toll roads and high occupancy lanes | 3-6 | >3->6 |
| Parking-related measures | 4-7 | 5-10 |
| Low greenhouse gas alcohol fuels | 3-4 | 3-5 |
| Improving public transport | 0-1 | 0-1 |
| Promotion of non-motorized modes | 0-3 | 0-3 |
| Enhancing inspection and maintenance programs | 1-2 | 0-2 |
| Organising training programs for drivers | 0.5-1 | |
| Reducing speed limits | < 1 | |
| Subsidizing a reduction in public transport fare | 0-1 | 0-2 |
| Early scrappage programs | Small | |
| Special-purpose tax on fuel purchases | 2-4 | 3-5 |
| Corporate tax incentives for telework | 0-1 | 0-1 |
| Development of cellulosic ethanol production | 0.7-1.3 | 3.3-5 |
| Concentrated fuel infrastructure development | 0-0.5 | 0-1 |

Source: The International Energy Agency (2001). Bouwman and Moll (2000) calculated that there are considerable energy saving potentials within the private transport system. When only technological measures are taken, a 50% reduction is possible by 2020 and a 60% reduction

by 2050. However, when non-technical options are added, which require some major behavioural changes, an 80% reduction can be achieved by 2050⁵⁶.

4.3 *Standby Gasoline Rationing Plan*

In the wake of the oil crisis in the 70's, the American Government has been investigating which policy measures could be taken in case of an oil embargo. President Carter stated the importance of this policy issue as follows:

*" energy crisis: the moral equivalent of war"*⁵⁷

Not surprisingly, the Federal Energy Agency's proposal was based on a policy measure that was introduced during war times by President Roosevelt⁵⁸ and has proved its efficacy⁵⁹, namely fuel rationing. Eventually in 1980, after more than five years of heated debate, American Congress approved the introduction of the Standby Gasoline Rationing Plan⁶⁰. We discuss the plan as it was presented by the U.S. Department of Energy (1980). In our discussion of this scheme, we use the same methodology as we earlier applied in this dissertation. More specifically, we discuss the threshold, design and

⁵⁶ For an overview of the CO₂ reduction potentials in Belgium, we refer to De Vlieger et al. (2001). An overview of the reduction potentials by car and fuel technology in Flanders can be found in De Keukeleere et al. (2001).

⁵⁷ Cited in Henderson (1978, vii)

⁵⁸ In 1942, Franklin D. Roosevelt had justified his rationing policy as follows (Cited in Henderson (1978) p.19):

"that where there is not enough of any essential commodity to meet all civilian demands, those who can afford to pay more for the commodity should not be privileged over others who can not ... Where any important article becomes scarce, rationing is the democratic, equitable solution".

⁵⁹ For a description and evaluation of non-tradable gasoline rationing during World War II in the United States, we refer to Maxwell and Balcom (1946a) and Maxwell and Balcom (1946b). For a comparison of the gasoline rationing in the United States and Canada, we refer to Derber (1943). For a comparison of the rationing schemes in the United States and Great Britain, we refer to Keezer (1943).

⁶⁰ On July 30, the scheme went into standby status. However, the plan was never implemented. The Reagan administration abandoned the plan in 1981.

implementation issues. This section concludes by evaluating the Standby Gasoline Rationing Plan.

4.3.1 Threshold issues

Nature of the commodity to be traded

The plan was designed to come into force following the imposition of an oil embargo on the United States by foreign powers. Gasoline and diesel would be capped. The Plan would become operational as soon as there is a 20 % decrease in oil supply for at least 30 days.

Level of the cap

Gasoline supply would be reduced by 17 %. However, the U.S. Department of Energy calculated that the shortage of diesel during a hypothetical oil embargo would only be about eight percent. They concluded that it was unnecessary to ration diesel⁶¹. The total number of permits was determined on a State-by-State basis, taking into account their historical gasoline use.

4.3.2 Design issues

Initial allocation

Firstly, all individuals received the same basic ration to meet their occupational and personal driving needs⁶². The allocation was based on their motor vehicle registration⁶³. Four times a year, they received monthly ration checks of 42 gallons of gasoline for every vehicle, except motorcycles and mopeds. Motorcycles and mopeds owners respectively received one-fourth and one-

⁶¹ Although, the FEA started to develop a standby rationing plan for diesel fuel, assuring equity between these two types of fuel users.

⁶² The only exceptions were handicapped people who could apply for supplemental gasoline.

⁶³ The proposals to distribute permits amongst all persons over 18 years of age, or to registered voters or to individuals holding a driving license were rejected due to implementation problems.

tenth. However, only a limited number of vehicles by households were taken into account.

Secondly, firms received the same amount per vehicle. However, firms were able to apply for additional permits, based on their historical gasoline use (grandfathering principle).

Finally, priority users were defined⁶⁴. They received permits based upon their historical use of gasoline.

Temporal and spatial restrictions and flexibility

The permit scheme was an exchangeable coupon rationing system⁶⁵ in which individuals and organization were allowed to sell their entitlements to others for cash with no time limit put on coupon redemption. The coupons would be issued in series. Once a coupon became valid, it would remain valid for the duration of gasoline rationing. However, periodically old coupon series would be redeemed for newer ones to avoid having too many series valid at one time or to counteract counterfeiting activities.

4.3.3 Implementation issues

Technology and organization

Fuel consumers had to depreciate coupons for the amount of fuel they purchased⁶⁶. The government authorized a variety of financial institutions to act as coupon issuance points where checks, issued by the government were exchanged for coupons. All individuals and firms were permitted to open a

⁶⁴ The following priority activities were classified: (1) Emergency services; (2) Sanitation services; (3) Public passenger transportation; (4) Energy production; (5) The Department of Defense (6) For mail and small parcel transportation and delivery; (7) Agriculture; (8) Short-term vehicle rental; and (9) Newspaper distribution.

⁶⁵ The introduction of a white market of coupons was the main difference with the gasoline rationing during war.

⁶⁶ A system with plastic credit cards was abandoned after technical and other problems proved to be insurmountable.

permit account at participating banks⁶⁷, which enabled them to deposit and to transfer or sell permits to others. It was estimated that a driver's gasoline ration coupons would be worth as much as \$300 to \$400 per year. When refuelling the vehicle, coupons were redeemed. Gasoline sellers collect these redeemed coupons in special bank accounts, which determine the extent of their rights to fresh supplies. It was expected that gasoline retailers and wholesalers would operate local gas coupon resale exchanges. Furthermore, the major petroleum companies would create national coupon resale markets⁶⁸. Unused permits were freely transferable. To facilitate market functioning, the government could intervene by buying and selling permits. Each State should establish a State Rationing office and local boards where individuals could apply for additional permits. Furthermore, each State would be provided with a reserve of ration rights to provide for hardship needs and to alleviate inequities. Furthermore, a small national reserve should also be established to meet emergency needs and other national purposes.

Bray (1980) provided more details about the implementation duration and costs: The Department of Energy included a pre-implementation phase of 12-15 months, which would cost \$103 million. The expected full-implementation costs of this phase would mount up to \$483.8 million while the annual operational costs were estimated to cost \$2.0 billion.

⁶⁷ In Bray (1980), Van Lare, special administrator for gasoline rationing at the Department of Energy states:

"Participation by banks or other issuers would be voluntary and would involve either a contracted government reimbursement schedule or a transaction fee charged to customers by the issuers."

⁶⁸ Because nationwide petroleum marketeers were already in the gasoline distribution business, they had a competitive advantage over banks, commodity speculators, brokers and others who might be tempted to turn a profit buying and selling coupons.

Monitoring and enforcement

The monitoring was supposed to occur at the upstream level. This implied that the gasoline suppliers needed to keep an account of the amount of gasoline sold. Moreover, they needed to present a number of redemption checks, which equals the amount of gasoline sold. A number of penalties were described in case of any violation or counterfeiting.

4.3.4 Evaluation

Henderson (1978) proposed to distribute permits amongst all citizens instead of only car owners. He believed gasoline rationing is superior to prices because

- The rationing scheme makes people more aware of the issue envisaged;
- Price increases can not keep consumption at a fixed level;
- Rationing is an equitable way to distribute scarce goods, while a price increase favours the affluent.

Furthermore, he argued that rationing was successfully implemented during World War II to equitably distribute reduced supplies of basic goods. Since the coupons were not tradable, the black market for coupons was flourishing. However, counterfeiting and the black market only became a problem at the moment that consumption was reduced by forty percent within two years.

Finally, Henderson (1978, 68) argued that gasoline rationing would have a positive impact on the labour market:

"The program should create several hundred thousand new jobs as billions of dollars in purchasing power is shifted from the consumption of foreign oil (refined in highly automated plants in the U.S. and elsewhere) to more labour-intensive goods and services."

Reuter and Enholm (1980) proposed to abandon the coupon system and instead use electronic card technology. This would increase the fraud-resistance and decrease the administrative burden of the rationing scheme.

Shahabuddin and Chang (1978) conducted a survey among 1,665 people about their preferences of fuel taxes and fuel rationing. They found that income and

age variables are important factors to explain the consumer's preferences: a consumer with a higher income and younger age would likely choose price increase. Also those who drive the most are preferring price increases.

Fahrar et al. (1980) reviewed the literature⁶⁹ on public opinion about energy in the period between 1973 and 1979. They concluded that the willingness to reduce energy consumption is related to the belief in an energy crisis⁷⁰. Furthermore, Fahrar et al. (1980, 166-167) concluded that the adaptation of energy conserving practices is a function of:

"(a) their perceived effectiveness; (b) concern about any risks involved; (c) assessment of the relative advantage of doing so; (d) awareness and knowledge; (e) a favourable position toward it; (f) the availability of the necessary information and equipment; and (g) coming to decision to act."

Related to transportation, they concluded that most of the public (about 80%) is opposed to gasoline price increases; while the majority is convinced that gasoline rationing would be effective in reducing consumption. Nevertheless, they are against gasoline rationing, although it is preferred to price increases.

4.4 Effects of tradable fuel permits

We distinguish between two main effects of a tradable fuel permit scheme. On the one hand, effects created by setting the policy goal of reducing fuel use. On the other hand, effects created by the specific choice of tradable permits as an instrument to reach that policy goal.

⁶⁹ They analyzed over 190 surveys of the general adult population, 156 of national samples, and 33 of local or regional samples

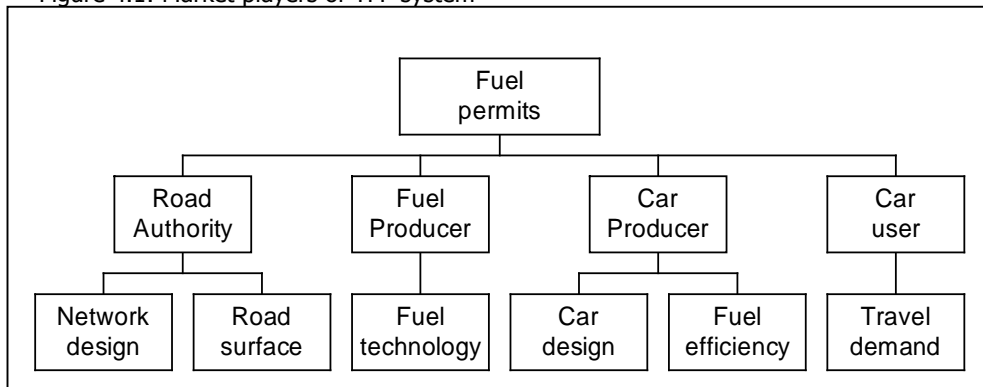
⁷⁰ Fahrar et al. (1980, 166) emphasized that the belief in an energy crisis is a function of

"(a) attribution of the energy problem to the declining availability of fossil fuels rather than to sociopolitical and economic causes; (b) negative energy-related impacts experienced or anticipated; (c) awareness of energy facts and issues; (d) environmental concern; and (e) exposure to credible information sources with high levels of factual knowledge."

4.4.1 Reducing fuel use as a policy goal

As depicted in Figure 4.1, a tradable fuel permit scheme, just like any other market-based instrument, gives all market players a lot of flexibility in how to achieve the required policy goal.

Figure 4.1: Market players of TFP system



For instance, the fuel industry can react by offering less polluting fuels; vehicle manufacturers can develop less polluting vehicles; road authorities can design fuel efficient roads and, last but not least, car users can reduce their emission production by changing their travel demand. More generally, there are three ways in which market players can influence total CO₂ emission:

- Actions related to the emissions per fuel unity;
- Changing the total amount of fuel per passenger kilometre;
- Changing the total amount of passenger kilometres.

Road authorities and the fuel and car industry can only take (indirect) measures related to car user actions. Eventually, the individual car users have to choose their preferential actions to comply with the TFP system.

Based on the research of Pargal and Heil (2000), Table 4.4 shows that the TFP system might have an impact on the fuel and vehicle choice, the number and length of trips, average speed and driving behaviour, route choice, the

occupancy rate and the modal choice⁷¹. Next, we discuss these different measures.

Table 4.4: Possible actions of the car user

| Category | Type of action |
|---|--|
| Actions related to emissions per fuel unity | <ul style="list-style-type: none"> • Choice of fuel type |
| Actions related to the total amount of fuel per passenger kilometre | <ul style="list-style-type: none"> • Choice of car type • Driving behaviour • Spatio-temporal route choice • Occupancy rate • Average speed |
| Total amount of passenger kilometres | <ul style="list-style-type: none"> • Modal choice • Number of trips • Travel distance |

Source: Based on Pargal and Heil (2000).

Fuel choice

The type of fuel and fuel efficiency influence the amount of emissions per fuel unity. It can be expected that under a TFP system, the fuel industry would search for innovative fuel types. Greene (1992) demonstrated that an improvement in fuel efficiency does not necessary lead to a decrease of total vehicle kilometres travelled. This is known as the "rebound" effect.

The use of less polluting fuels seems very attractive to car users since it does not require any change in travel demand.

⁷¹ Bento and Goulder (2003) classified the effects of a policy measure to reduce fuel (i.e. fuel tax) in three categories. First of all, there is a scale effect or an effect of the number of vehicles owned. Secondly, the effect of the type of vehicle owned is called the composition effect. Finally, the number of kilometres travelled will be affected.

Vehicle choice

The vehicle characteristics, which influence the amount of fuel per passenger kilometre, such as age and size of the car⁷², would become more important when choosing a vehicle. Car manufacturers would react to this changing preference by introducing more fuel-efficient cars. As is the case for fuel choice, this measure does not require a change in individual travel demand.

Occupancy rate

Carpooling can increase the occupancy rate and so reduce the amount of fuel per passenger kilometre.

Driving behaviour

Variations of car fuel consumption depend largely on the type of driver. An ECMT workshop (2000) on emission reduction by non-vehicle measures classified five ways of changing driving behaviour

- Slower and less acceleration and deceleration;
- Low engine revolutions (1,500-2,000 rounds per minute);
- Reducing maximum speed;
- Maintaining proper tire pressure;
- Turn engine off when idling for more than one minute.

Average speed

Everall (1968) pointed out the clear relation between fuel consumption and average speed. The form of the general relation is

$$C = A + B/V + D \cdot V^2$$

Whereby C= fuel consumption in litres/100 km

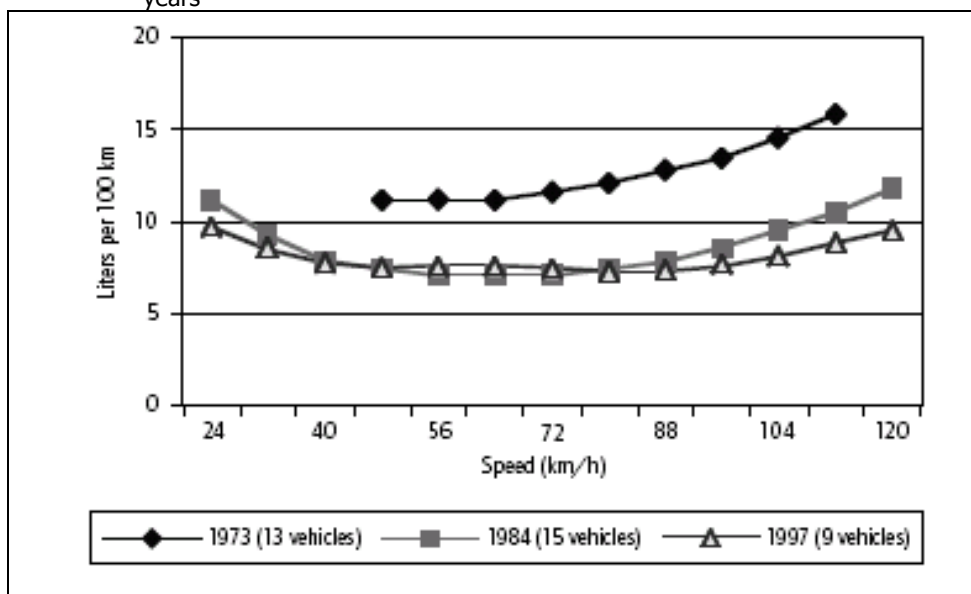
V= average vehicle speed over the road section in m/s

⁷² Essinhigh et al. (1979) showed that fuel consumption increases roughly linearly with the car weight.

A, B and D are constants, with a value for compact cars of respectively 6.11, 55.56 and 0.00518

Figure 4.2 shows the fuel consumption as a function of average car speed⁷³. The course of the graph can be explained by two physical phenomena: at low speed a large frictional power has to be overcome, while at higher speed, energy is needed to overcome the aerodynamic drag.

Figure 4.2: Fuel consumption as a function of vehicle speed: US tests in three different years



Source: ORNL (1999).

The implications of this relation for the TFP system are twofold. On the one hand, car users need more permits to drive at road sections with a low average vehicle speed. Consequently, car users need to depreciate more permits in congested areas compared to other road traffic situations. On the other hand, higher speeds correspond to a higher number of permits. Since road accidents are related to speed, an improvement of transport safety can be expected by introducing TFP system.

⁷³ For an overview of vehicle speed and emissions, we refer to André and Hammarström (2000).

Spatio-temporal route choice

Increased fuel consumption in congested traffic entails a plea for sufficient road network capacity. However, the theory of induced travel demand states that an increasing road capacity causes an increase in traffic volume. This change is mostly expressed in terms of an elasticity factor⁷⁴, more specifically the road capacity elasticity of road use. Noland (2001) suggested an elasticity factor in order of 0.3 to 0.5 in the short term and 0.9 in long term.

Another road aspect, which influences car fuel consumption, is the roughness of the road's surface. Waters (1992) found that rougher roads might increase the fuel consumption by 3% to 4%.

Finally, physical traffic calming infrastructure is also a source of higher fuel consumption. As given in Table 4.5, Van Mierlo et al. (2003) pointed out that mainly speed ramps result in higher fuel consumption.

Table 4.5: Relative increase in fuel consumption at speed ramps and roundabouts.

| | % change in fuel consumption (diesel car) | % change in fuel consumption (gasoline car) |
|-------------|---|---|
| Speed ramp | + 45 | + 55 |
| Roundabouts | +10 | - |

Source: Van Mierlo et al. (2003)

Modal choice

Car users may prefer to switch their transport mode to save TFPs, which may reduce the total amount of passenger kilometres.

⁷⁴ For more information about the elasticity concept, we refer to section 7.3.2

Travel distance

Since the amount of CO₂ emissions is related to the amount of fuel, it is obvious that a decrease in travel distance leads to lower emissions.

Number of trips

By decreasing the total number of trips, a reduction of cold start emissions would be realised.

Ancillary effects of CO₂ reduction

There is no unambiguous relation between air pollution and climate change; some emission gases such as particulate matter and atmospheric ozone have an accelerating effect on global warming, others like NO_x and SO₂ cool down the earth. However, air pollution and climate change are two problems, which cannot be dealt with separately. Several studies show that a decrease in CO₂ emission results in a reduction of other pollutants (SO₂, VOC, CO, NH₃). Syri et al. (2001) calculated the total costs to comply with the Gothenburg Convention⁷⁵. They concluded that a cost reduction of least 5 € billion could be realised, if CO₂ reduction level of the Kyoto Protocol is met.

Amann et al. (1998) calculated that the cost-effectiveness to reach the interim environmental quality targets⁷⁶ could be improved by more than 40 per cent if the energy use was restricted by 8 percent. Moreover, Agren (1999) calculated

⁷⁵ On 17 May 2005, the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone came into force. The Protocol was originally adopted on 30 November 1999 in Gothenburg (Sweden) and signed by 31 countries. The Protocol sets targets for emission cuts by 2010 for SO₂, NO_x, VOC's and NH₃.

⁷⁶ More specifically, the NEC-directive (CEC (1999)) set national emission ceilings (NEC's) for four air pollutants (SO₂, NO_x, VOC's and NH₃). This directive came into force on 27 November 2001. The following interim environmental objectives have been set for the year 2010 against a 1990 base:

- Acidification: reduction by at least 50 percent of areas where critical loads are exceeded;
- Ground-level ozone: load above critical level for human health and vegetation to be reduced by respectively two-thirds and one-third and load in any area not to exceed a specified absolute limit.

that a decrease of 15 per cent of CO₂ emissions by 2010 relative to 1990 would result in a cost reduction to comply with the Gothenburg Convention of 64 percent. This can be explained by the lower need of abatement measures, which are end-of-pipe or technological solutions.

4.4.2 Tradable permits as a policy instrument

The introduction of tradable permits as a policy instrument to reduce fuel use has some major implications. This section covers the following topics:

- Effectiveness, which is related to the threshold issues of a permit scheme;
- Redistribution and endowment effects, which are related to the design issues;
- Transaction costs which are related to all aspects of a permit scheme.

Effectiveness

The use of a permit scheme as a policy instrument guarantees the government that a specific quantitative goal will be reached. However, to fully understand the effectiveness of a permit scheme, we need to refine the definition of a goal, which is typically multidimensional of nature.

Hauschildt (1977) defined seven goal dimensions:

- *Goal object* or the phenomenon or segment of reality envisaged;
- *Goal characteristic* is the criterion by which goal attainment is to be evaluated;
- *Goal measure* is the norm to quantify the amount of goal characteristics attained;
- *Goal function* is the amount of anticipated goal attainment. Examples include maximization and reaching a threshold value;
- *Time frame* for goal attainment;
- *Initiator* of a goal;
- *Recipient* of a goal.

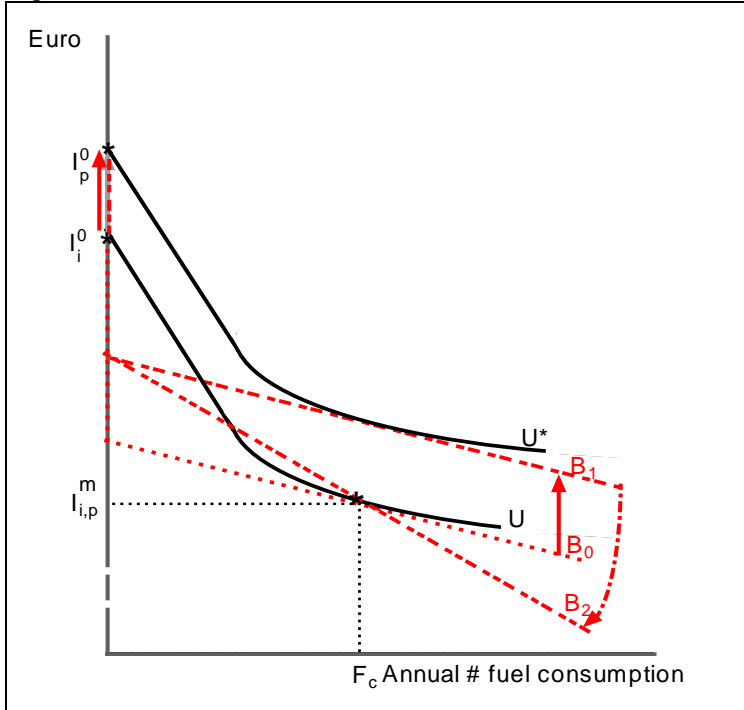
Clearly, when the government considers the goal function of utmost importance, choosing a permit scheme as policy instrument offers the greatest certitude. However, this effectiveness has its price. While under a tax regime, the costs for individuals are fixed at the tax level; the costs under a permit scheme are variable. Basically, three cost patterns can be distinguished. Individuals, who are consuming less fuel than their allocated amount of permits face negative costs, namely their benefit equals the net monetary value of their redundant permits. Others, who balanced their fuel use with the allocated amount of permits, have no financial costs. Finally, individuals need to purchase additional permits if their fuel requirement exceeds the number of allocated permits. Their costs depend on the amount of deficient permits and the permit price, which is determined by the market, hence truly reflects the participant's (marginal) willingness-to-pay.

Distributional effects

Since the TFP system does not generate additional public revenues, the government does not have to develop a redistribution program. Actually, the permit program does redistribute revenues, namely from those who pollute more to those who do less (polluter pays principle). The final redistribution of fuel depends on the consumer preference for fuel, the initial purchasing power and the additional income generated by the permit scheme.

This interaction is illustrated by Figure 4.3, whereby a household wants to maximize his utility level U under a given, non-convex budget line B_0 . In this example, two maxima occur. Firstly, a household can consume no fuel and spend his income I_i^0 on other goods. Secondly, a household can have a consumption level is F_c .

Figure 4.3: Effect of a TFP



Source: Based on de Jong (1990).

Suppose now that the cap is set on F_c and an amount of permits F_c is initially allocated. Since these permits represent a monetary value, the free allocation of permits corresponds to an increase in income, which moves the budget line from B_0 to B_1 . However, due to an additional cost of purchasing fuel (namely the permit price) the variable cost component increases. The gradient of the cost curve change from B_1 to B_2 . Let us now consider what happens with households with no fuel consumption and an initial consumption of F_c . Since households with no fuel consumption can exchange all allocated permits for money, their income level increases to I_p^0 . Consequently, a higher utility function U^* can be reached. Households with an initial consumption of F_c can still consume the same amount of fuel as the level of the cap. This means that they have neither surplus, nor deficit of permits and their income level $I_{i,p}^m$ and utility curve U remain unchanged. It is clear that through the choice of the

initial permit allocation method, a desired income distribution or transfer among different groups can be achieved.⁷⁷

The transferred amount varies with the household's fossil fuel consumption for road use; If the household consumption is lower than the initially allocated permits, we have a positive cash transfer; in the opposite case, we have a negative cash transfer. Furthermore, the greater the difference between consumption and the level of cap, the greater is the cash transfer in absolute terms.

However, as described earlier, households change their consumption behaviour in the light of the new policy goal. Figure 4.4 presents the scenario in which households reduce their original fuel consumption q_i to a new level q' that is still higher than the level of their cap q_c . We distinguish three components of the change in consumer's surplus:

First, we distinguish the change in consumer surplus, which occur by the upwards movement of the demand curve. This movement is caused by an increased households income level through the allocation of a number of permits. Consequently, this change has always a positive value and is represented by the area $bdgf$, which is similar to the area $p_p p_t bd$. Note that this type of change in consumer surplus does not occur with taxes.

Secondly, we observe the loss related by a reduction of fuel consumption and higher fuel prices, represented by the area abc . Note that this change is similar to the deadweight loss of taxes, which was shown in 2.3.

Finally, we also observe an income transfer, which is represented by the area $cdhg$. This area consists of two parts. On the one hand, the additional permit cost to consume q' , represented by the area $p_p p_i cd$, which has a negative value.

⁷⁷ The OECD (2001) defined five main determinants, which account for the distributional impact of a permit scheme:

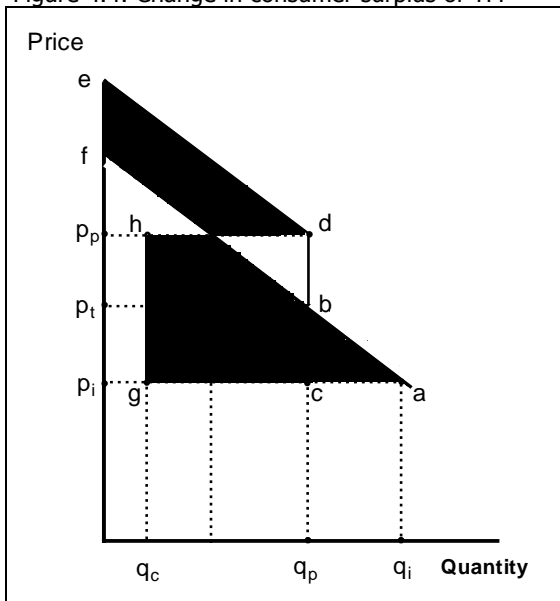
- Initial allocation rule;
- Diversification of the options for action open to decentralised agents;
- Geographical redistribution of pollution;
- Structure of permit markets (perfect or imperfect competition);
- Structure of product markets (price-elasticities of demand).

On the other hand, the income effect related to the free allocation of permits need to be taken into account. In his discussion about the calculation of consumer surplus and income effects, Harberger (1974) mentioned:

"I believe that ... new resources (gifts from outside) ... are the only ones for which estimated first-order income effects must be added..."

This income effect is represented by the area $p_p p_t g h$

Figure 4.4: Change in consumer surplus of TFP



Consequently, the change in consumer surplus C_p is calculated as the sum of the surplus generated by the movement of the demand curve, the deadweight loss and the income transfer. This gives the following equation:

$$C_p = (p_p - p_t) q_p - 0.5(p_t - p_i)(q_i - q_p) - (p_p - p_i)(q_p - q_c) \quad (4.1)$$

This equation will be used in chapter 6 to calculate the economic welfare effects of fuel permits amongst different household categories.

Note that the following welfare issues are not included:

- Cost to car and fuel industry and their shareholders in terms of a reduced production and employment;
- Benefits to car users and others from reduced external costs;
- Costs to those that are visited by car users: lower accessibility.

It is clear that through the choice of the initial permit allocation method, a desired income distribution or transfer among different groups can be achieved.⁷⁸ However, the calculation of these effects requires knowledge of how households change their consumption behaviour in the light of the new policy goal. To this end, we will develop in chapter 5 and 6 a model to estimate and predict household's behaviour.

Moreover, when individuals receive an amount of permits, a specific behavioural change occurs: the endowment effect, which will be discussed hereafter.

Endowment effect

Thaler (1980) termed the finding that people demand more money as compensation for giving up a good than they are willing to pay for purchasing the same good as the "endowment effect"⁷⁹. Stated simply, when people get or have something, they are keen to keep it. Kahneman et al. (1990) concluded that the endowment effect only exist for consumption goods. However, van Dijk & van Knippenberg (1996) demonstrated that an endowment effect might be observed in exchange goods when exchange rates are uncertain because people are less likely or able to compute the net gains.

Kahneman and Tversky (1984), argued that the endowment effect is caused by an asymmetry of value, called loss aversion⁸⁰. More specifically, the disutility of

⁷⁸ The OECD (2001) defined five main determinants, which account for the distributional impact of a permit scheme:

- Initial allocation rule;
- Diversification of the options for action open to decentralised agents;
- Geographical redistribution of pollution;
- Structure of permit markets (perfect or imperfect competition);
- Structure of product markets (price-elasticities of demand).

⁷⁹ The endowment effect has been demonstrated in various studies (Knetsch and Sinden (1984), Knetsch (1989), Kahneman et al. (1990), Loewenstein and Adler (1995), Franciosi et al. (1996), van Dijk and van Knippenberg (1996) and Van Boven et al. (2003))

⁸⁰ Another implication of loss aversion is that individuals have a strong tendency to remain at the status quo, because the benefit of acquiring a good is outweighed by the loss of the owned good.

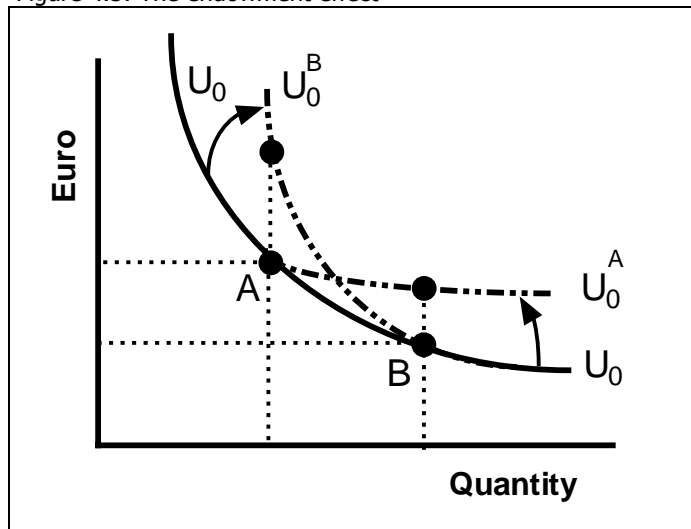
giving up an object (or willingness to accept) is greater than the utility to purchase it (or willingness to buy).

The endowment effect is inconsistent with the standard microeconomic theory, which suggests that two indifference curves can never intersect. This classical proposition is based on the assumption that indifference curves are reversible. This means that when an individual owns *good 1* and is indifferent between keeping it and trading it for *good 2*, he is indifferent between keeping and trading *good 2* for *good 1* when he owns good 1. However, Knetsch (1989) demonstrated that this reversibility assumption does not longer hold when loss aversion occurred.

Morrison (1997) incorporated the endowment effect in a utility function $U=f(\epsilon, X, \text{loss})$, where ϵ is the wealth of an individual and X is the quantity he holds of the good being valued. The utility that an individual assigns to a bundle of goods is a positive function of the quantities of the goods comprising the bundle and a negative function of any real or hypothetical loss. This mechanism is depicted in Figure 4.5. When an individual does not own bundle A, neither bundle B, the utility U_0 is a function of each of the bundles and the individual is indifferent between bundle A and B. Once the individual owns bundle A or bundle B, the utility curve pivots from point A or B such that the owned bundle has a higher utility than the other bundle (respectively U_0^A and U_0^B).

In contingent valuation, this effect is called the status quo bias and involves that an alternative become more attractive when it is presented as the status quo.

Figure 4.5: The endowment effect



Source: Morrison (1997)

There are two major implications of the endowment effect. First of all, people treat opportunity costs differently than "out-of pocket" costs. Foregone gains are less painful than perceived losses. This means that eliminating a discount (a reduction of a gain) is preferred above imposing a surcharge. Secondly, Kahneman et al. (1990) refined the Coase theorem, which states that - assuming no transaction cost- the allocation of resources to individuals is independent of initial property rights. However, when endowment occurs, the individual who is allocated or "endowed" the property right to a good likes to keep it. Consequently, the existence of endowment effects reduces the gains from trade and so the volume of trade.

Kahneman et al. (1990) predicted that endowment effects also exist when transferable pollution permits are introduced.

We expect that endowment effect in the tradable fuel permit scheme occurs in two ways:

First of all, endowment effect will affect the trade of permits. Individuals with a surplus of permits are keener to keep them, which reduces trade volume.

Secondly, the endowment effect will reduce the use of permits. Individuals having permits are keen to keep them instead of using them to buy fuel. This might become an impetus for fuel-saving behaviour.

Transaction costs

Using a permit scheme as a policy instrument generates transaction costs different from other policy instruments. Cralis and Vereeck (2005) distinguished between the following transaction cost categories:

- Information and planning costs;
- Legislative costs including lobbying and public support costs;
- Negotiation and contracting costs;
- Administrative cost;
- Monitoring, enforcement and compliance costs.

Not surprisingly, low transaction costs are crucial for a successful implementation of a permit scheme. Cason and Gangadharan (2003) pointed out that the regulator could influence the magnitude and nature of transaction costs through the permit scheme design⁸¹. This is not surprising because the design of the scheme needs to reconcile the behaviour of the consumers and the diligence of the policymaker, while taking into account the complex nature of the traded good. Although the calculation of transaction costs is not the main subject of this dissertation, we estimate the major cost components of a tradable fuel permit scheme in Flanders⁸². This estimation will be discussed in chapter 6 (scenario 2).

⁸¹ For instance, Stavins (1994) pointed out that transaction costs depend on the initial distribution of permits.

⁸² The design of this tradable fuel permit scheme was discussed in chapter 3.

4.5 Alternative schemes of tradable fuel permits

In the previous section, we discussed the tradable fuel permit scheme, aiming to reduce fuel consumption to the level of a reference year (1990). The implementation path of this scheme is on a medium term (from 5-20 years) time scale. However, as we discuss in this section, many variations exist. To this end, we use the "Harrison" framework, which we described in chapter 2 and applied in chapters 3 and 4.

4.5.1 Threshold issues

Level of the cap

Next to the Kyoto scenario, we postulate two other visions of future policy goals:

- "Crisis" or "Middle East" scenario, whereby governments are forced to limit fossil fuel use due to limited supply. The permit scheme is implemented for a short time period (less than five years) and short term behavioural changes are expected;
- "Fossil-fuel free" or "Icelandic" scenario, whereby governments are striving towards a fossil fuel independent society over a long term (20-50 years).

Nature of the commodity

First of all, the TFP system can be extended to other emission gases, transport modes and sources in other sectors. First of all, other types of emissions such as CO, N₂O, HC, SO₂ and volatile organic compounds (VOC) can be included in the permit scheme. Due to the complicated nature of transport emissions, the impact of the TFP system on local pollution control requires complex modelling work.

Secondly, this scheme can be extended to other transport modes. For instance, public transport operators can integrate the permit scheme into the ticket price or passengers can transfer their permits by discharging their card when buying a ticket. Finally, the TFP system can be extended to other household activities: Verhoef et al. describe a tradable CO₂ permit scheme for the Netherlands, which includes CO₂ emissions of inland shipping and railway use and those produced by household energy consumption such as central heating of houses. Fleming (1997) proposed a similar tradable quota system to shift national economies away from their dependence on fossil fuels.

4.5.2 Design issues

Allocation of permits

As we discussed in chapter 2, different criteria for allocating permits amongst inhabitants could be used. Next to an equal allocation to all inhabitants, we define the following allocation keys:

- The socio-economic situation (by their age, working status or place of living);
- The number of cars owned;
- Possession of a driving license;
- Priority groups;
- Individual CO₂ balance⁸³.

Trading rules

Next to allocating permits for free, the permits could also be auctioned. In this way, the government can generate additional revenues.

Another modification could involve that individuals, who never use permits, could sell their permits to the government.

⁸³ For instance, land and forest owners could be compensated for their CO₂ consumption.

Temporal and spatial flexibility

The geographical area could be restricted to specific regions. However, as we argued in chapter 2, this would complicate enforcement.

The validity period of a permit could be changed and banking and borrowing could be allowed.

4.5.3 Implementation issues

Monitoring and enforcement

In this chapter we described an upstream monitoring scheme. However, monitoring could be organised on the level of the individual fuel user. In that case, monitoring would be similar to the organization of tradable car kilometre permits.

CHAPTER 5 Literature review of car ownership-and-use modelling

A household facing travel choice typically has to make two interrelated choices: how many and which type of cars to own, and how many kilometres to drive. This situation of interrelated choices can be modelled by using a discrete-continuous choice model. To better understand these models, we first discuss the main aspects of discrete choice modelling. Subsequently, we review the literature of car ownership-and-use modelling.

5.1 *Discrete choice modelling*

In the formulation of a discrete model of for instance car ownership some specific assumptions about the decision maker, the alternatives, the attributes and the decision rules are put forward. In this respect, it is important to note that different assumptions lead to different models. Particularly relevant in the context of this dissertation are the Random Utility models, more specifically those models that are assuming a logit distribution. We discuss these models in the next paragraphs.

5.1.1 Model formulation

Decision-maker

The decision-maker is assumed to be an individual. However, this assumption is not restrictive and can be easily extended to a group of persons. By assuming that the household is the decision-maker, all intra-household decisions (for example, potential negotiations between parents and children or amongst them) are excluded and a household is considered to act as an integrated unity.

Alternatives

The alternatives are the possible options the decision-maker can take into consideration. The set of these alternatives is called the choice set. In the case of car ownership-and-use modelling, the household choose amongst a finite number of cars to own. Subsequent to this discrete choice modelling, we model the choice how many kilometres to drive the car(s), which is a continuous choice.

Attributes

An alternative in the discrete choice set is characterized by a set of quantitative and qualitative attributes that are likely to affect the choice of car type. The analyst defines these attributes in terms of a directly observed quantity or indirectly in function of the available data. Furthermore, these attributes may be specific to an alternative or applicable to all alternatives. In car ownership models, the most common used attributes are cylinder capacity, age, brand, fuel type, fuel consumption and acquisition status. Household's attributes include family size, income, living area, age and sex of the household head.

Decision rules

The decision rules describe the process how the decision-maker arrives at a unique choice. Although there are several categories⁸⁴ of decision rules, we focus on the utility as a decision rule.

The neoclassical economic theory assumes that each decision-maker has a perfect discernment capability and is able to compare two alternatives based on a value, which is called utility. The alternative with the highest utility will be chosen. Since no level of uncertainty is admitted, the neoclassical economic theory does not cover the complexity of human behaviour. This imposes strong limitations for practical applications. Probabilistic choice mechanisms were

⁸⁴ Ben-Akiva and Lerman (1985) classified four categories: dominance, satisfaction, lexicographic rules and utility.

introduced to deal with these uncertainties. Depending on the assumptions about the source of uncertainty, two approaches can be distinguished. On the one hand, there is the constant utility approach, which includes stochastic decision rules. This approach was proposed by Luce (1959) based on the assumption of a deterministic utility and a probabilistic decision process⁸⁵. On the other hand, uncertainty can be captured by random variables. This approach is known as the random utility models, which are discussed in the next paragraph.

5.1.2 Random utility models

General structure

Random utility models are based on the deterministic decision rules from the neoclassical economic theory, where uncertainty⁸⁶ is captured by random variables representing utilities. More specifically, the utility that individual i is associating with alternative a is given by:

$$U_a^i = V_a^i + \varepsilon_a^i \quad (5.1)$$

where V_a^i is the deterministic part of the utility and ε_a^i is the stochastic part capturing uncertainty. Similarly to neoclassical economic theory, the alternative with the highest utility is chosen. Therefore, the probability P that alternative a is chosen by the decision-maker i within choice set C is given by:

$$P_C^i(a) = P[U_a^i = \max U_b^i] \quad (5.2)$$

We now discuss the assumptions about the deterministic term V_a^i and the assumptions about the mean, the variance and the functional form of the error term ε_a^i . As we now discuss, different assumptions produce specific models.

⁸⁵ For more details we refer the reader to Bierlaire (1997).

⁸⁶ Manski and Lerman (1977) identified four different sources of uncertainty: unobserved alternative attributes, unobserved taste variations or individual attributes, measurement errors and proxy or instrumental variables.

Assumptions about the deterministic part of utility

We assume that the deterministic part of the utility of each alternative is a linear function of the attributes of the alternative itself and/or of the decision-maker. This assumption of linear-in-parameters simplifies model specification and estimation. Nevertheless, non-linear effects can still be captured by an appropriate and a priori transformation of the attributes (for instance by using quadratic forms).

Assumptions about the error term

First of all, the mean of the random term is for practical reasons usually assumed to be zero. A simple example shows that this assumption is not restrictive.

Consider a choice between two alternatives, which gives the choice set $C=(1,2)$. Using equations (5.1) and (5.2) gives the probability for a given decision-maker i to choose alternative 1:

$$\begin{aligned} P_{\{1,2\}}^i(1) &= P[U_1^i \geq U_2^i] \\ &= P[V_1^i + \varepsilon_1^i \geq V_2^i + \varepsilon_2^i] \\ &= P[V_1^i - V_2^i \geq \varepsilon_2^i - \varepsilon_1^i] \end{aligned} \quad (5.3)$$

Denoting the mean of the error term of each alternative by:

$$\varepsilon_1^i = m_1^i + \varepsilon_1^{i'} \text{ and } \varepsilon_2^i = m_2^i + \varepsilon_2^{i'} \quad (5.4)$$

where $\varepsilon_1^{i'}$ and $\varepsilon_2^{i'}$ are random variables with zero mean.

Substituting equation (5.4) in (5.3) gives

$$\begin{aligned} P_{\{1,2\}}^i(1) &= P[V_1^i - V_2^i \geq (m_2^i + \varepsilon_2^{i'}) - (m_1^i + \varepsilon_1^{i'})] \\ &= P[(V_1^i + m_1^i) - (V_2^i + m_2^i) \geq \varepsilon_2^{i'} - \varepsilon_1^{i'}] \end{aligned} \quad (5.5)$$

The terms m_1^i and m_2^i , which are called the Alternative Specific Constants (ASC's), are capturing the mean of the error term. Therefore, it can be assumed, without loss of generality, that the error terms have zero mean if the utility function of each alternative includes an ASC.

In practice, it is impossible to estimate the value of all ASC's from observed data. Only the difference between the two ASC's can be identified. It is common practice to constrain one ASC in the model to zero.

Secondly, before discussing the assumption about the variance of the random term, we show that the scale of the utility may be arbitrarily chosen. Suppose for any $\alpha \in \mathfrak{R}, \alpha > 0$

$$\begin{aligned} P_{\{1,2\}}^i(1) &= P[U_1^i \geq U_2^i] \\ &= P[\alpha U_1^i \geq \alpha U_2^i] \\ &= P[\alpha V_1^i - \alpha V_2^i \geq \alpha(\varepsilon_2^i - \varepsilon_1^i)] \end{aligned} \quad (5.6)$$

Similar to the arbitrary decision of " , we assume a particular variance ν of the distribution of the error term. Indeed, if

$$\nu = \text{Var}[" (>_2 - >_1)] \quad (5.7)$$

We also have

$$\alpha = \frac{\nu}{\sqrt{\text{Var}[(\varepsilon_2 - \varepsilon_1)]}} \quad (5.8)$$

Bierlaire (1997) illustrated this relationship with several examples.

Finally, we need to discuss assumptions about the functional form of the distribution of the error term. Depending of the assumptions of the functional form, different models such as the linear, probit and logit distributions can be distinguished⁸⁷. Due to its widespread use in practical cases, we focus on the logit or logistic unit models. They are described in the next paragraph.

⁸⁷ We refer to Lerman and Ben-Akiva (1985) for other functional forms such as the arctan and the truncated exponential models.

5.1.3 Logit distribution

Main assumptions

In logit models, the main assumption⁸⁸ is that the distribution of the error term of the alternatives is *independent and identically distributed* (IID) with the Gumbel distribution⁸⁹. The independence restriction implies that there are no common unobserved factors that affect the utilities of the different alternatives, while the restriction of identically distributed disturbances implies that the variation in unobserved factors is the same across all alternatives. The IID assumption underlies the closed-form mathematical structure of the logit models. When the logit distribution is assumed in binary choice models, they are called Binary Logit Models, while the term Multinomial logit (MNL)⁹⁰ is used when the choice set consists of more than two alternatives.

Multinomial logit model

In MNL, the independence and equal variance of error terms across alternatives leads to the property of the Independence of irrelevant alternatives IIA .

Ben-Akiva and Lerman (1985, 108) define the IIA property as

⁸⁸ Next to the assumption of IID, two other assumptions are made. Firstly, the logit model assumes *response homogeneity*, which means that the logit formulation does not allow taste variations to an attribute. Random taste variation can be included in Mixed multinomial logit (MMNL). Secondly, the logit model assumes error variance-covariance homogeneity structure or identical variance across individuals.

⁸⁹ When ε has Gumbel ($0, \mu$) distribution, then $f(\varepsilon) = \mu e^{-\mu(\varepsilon-\mu)} e^{-e^{-\mu(\varepsilon-\mu)}}$ with variance $\pi^2/6$ and mean $0 + \gamma/\mu$, whereby γ is Euler constant ($\sim 0,577$).

⁹⁰ The term "multinomial logit models" is used for a variety of models. In consumer behavioural studies, a distinction is made on the basis of the nature of the characteristics. When the choice is a function of the characteristics of the alternatives, conditional logit models are used, while generalized logit models are used when the choice is a function of the characteristics of the decision-maker.

"The ratio of the choice probabilities of any two alternatives is entirely unaffected by the systematic utilities of any other alternatives."

Koppelman and Sethi (2000, 213) give an equivalent definition

"... the relative probability of choosing any pair of alternatives is independent of the presence or attributes of any other alternatives."

The IIA property of Multinomial Logit Models can be a limitation for some practical applications. This is typically illustrated by the red bus/blue bus paradox, which was described in Ben-Akiva and Lerman (1985).

Generalised extreme value distribution

The need to relax the independence assumption of the error term has led to the generalized extreme value or GEV distribution. McFadden (1978) derived the GEV distribution from the random utility model. The GEV family includes closed-form utility maximization formulations based on the extreme value distribution with equal variance across alternatives. Consequently, a GEV model is used when the set of alternatives faced by a decision-maker can be partitioned into subsets such that the ratio of probabilities for any two alternatives that are in the same subset is independent of the existence or characteristics of other alternatives. Several models are based on the extreme value error distribution, amongst them the Multinomial Logit (MNL), Nested Logit (NL), Cross-Nested Logit (CNL) and Mixed multinomial logit (MMNL). An overview is given in Ben-Akiva and Lerman (1985), Koppelman and Sethi (2000), Ben-Akiva and Bierlaire (2003) and Train (2003).

5.2 Conventional approach of car ownership-and-use modelling

Archibald and Gillingham (1981) were the first to study fuel demand on household or disaggregate level⁹¹. Their model was based on the household production theory⁹². Their short-run, log-linear estimation for fuel demand was based on ordinary least squares (OLS) regression.

While the earliest study by Archibald and Gillingham (1981) and adaptations of this model by Dahl and Sterner (1991) treated the vehicle choice of the household as exogenous to the household's demand for fuel, the household's choice of vehicle stock and of demand for fuel are interrelated choices and depend on many of the same factors.

Because conventional models do not account for this fact, estimates based on these models have two major limitations: endogeneity and sample selection bias.

5.3 Limitations of conventional models

Linking a discrete and a continuous choice model causes problems for both the discrete and continuous choice estimation. These problems are respectively endogeneity bias and sample selection bias.

5.3.1 Endogeneity bias

Problem formulation

The choice of a specific vehicle type may also reveal the household's preferences for the intensity of car use. For instance, commuters may prefer a larger car because they travel long-distance trips. A demand model that

⁹¹ Since we are interested in household behaviour, aggregate models fall out of the scope of this research. An excellent overview of these models is given by Dahl (1979) and, more recently, by Glaister (2004).

⁹² For a comprehensive overview of utility maximisation theory, see Train (1986).

explains car use as a function of car ownership without taking into account such additional "feedback" equations is subject to *endogeneity bias*.

Endogeneity occurs when endogenous variables are treated as exogenous in the estimation of the demand equation, i.e. the independent variables are potentially a choice variable correlated with the error term. Standard linear regression models assume that errors in the dependent variable are uncorrelated with the independent variable. Because of the correlation of an explanatory variable and the equation error, an ordinary least squares estimation of car use leads to biased results.

Solution

The problem of endogeneity could be remedied by first replacing the endogenous explanatory variables by consistently estimated functions of exogenous variables, i.e. uncorrelated with the error terms. In a second stage, those computed values are used to estimate a linear regression model of the dependent variable. This estimation technique is called the instrumental variables or two-stage least squares regression.

5.3.2 Sample selection bias

Problem formulation

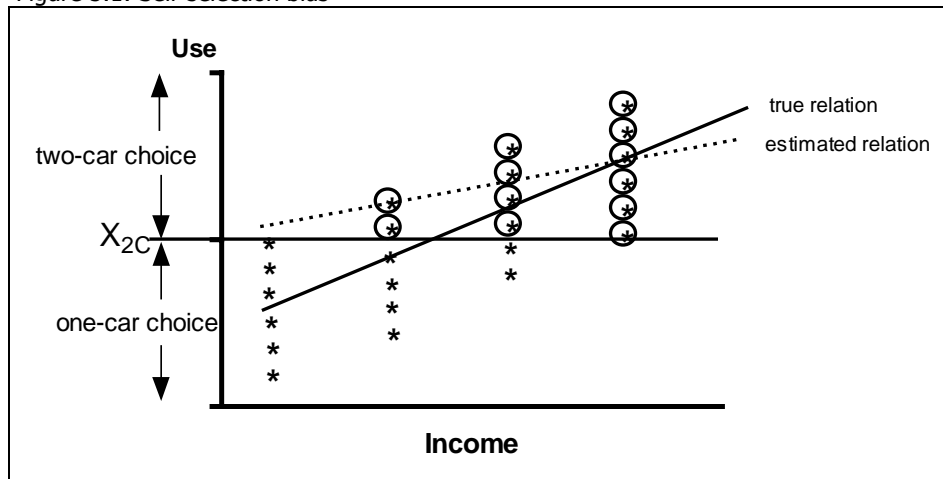
Sample or self-selection bias arises when the existence of data on a continuous variable depends on a discrete choice or, as Train (1986, 93) formulated

"... because the estimation is performed on a sub-sample of households that, through their choice of alternative, essentially selected themselves to be included in estimation."

For instance, consider Figure 5.1 whereby the sample of car use is segmented based on owning one or two cars. Assume a positive relation of use X and income y . Furthermore, suppose that households choose two cars when its level of use exceeds X_{2c} . The data points indicated by asterisks represent the observations for all households of the amount of use of two cars, irrespective of

their actual choice of number of cars. For any given income level, there would be a distribution of use around the true relation. However, if the relation is estimated only on the sub-sample of households who actually own two cars, the only data points used in the regression are those above X_{2c} , which are represented by the circled asterisks. Low-income households have a low probability of owning two cars due to the increased costs. Hence, if a low income household chooses to own two cars, then there must be unobserved factors (such as inaccessibility to public transport that makes it more cost efficient to drive a second car) that induced the household to do so. These same unobserved factors would also generate a high level of car use (inaccessibility to public transportation necessitates use of vehicle for commutes and other needs). Thus, when y is low for a household that chose to own two cars, the only observed data points are those above the true line, i.e. the expected error e is positive. Since negative errors become likely and larger in magnitude when the income level increases, the line that best fits the data points used in the regression has a downwardly biased slope. In other words, the problem is that the expectation of e is not zero for each observation, thus violating a fundamental requirement for ordinary least squares regression.

Figure 5.1: Self-selection bias



Source: Based on Train (1986).

Solution

Heckman (1976) developed a two-stage estimation method that links a discrete choice model with a related continuous demand equation that is conditional on the choice probabilities from the discrete-choice estimation⁹³. He derived expressions for the expectation of the error in the use equations by using the choice probabilities. This is known as the *selectivity correction factor* and was extended by Dubin and McFadden (1984). We discuss their approach in the following paragraph.

5.4 Dubin-McFadden approach

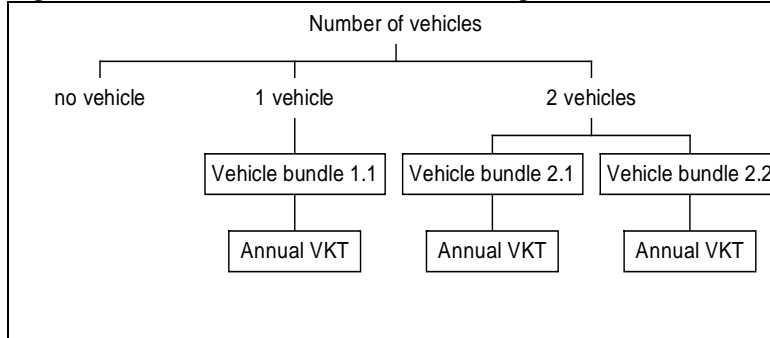
5.4.1 Introduction

Dubin and McFadden (1978) derived a two-step model to estimate the joint demand for household appliances and energy use (e.g. the electricity consumption) in a sequential estimations framework. First, they apply a logit model to estimate the discrete choice of appliance. Secondly, they derive a continuous electricity demand function, which is conditional on the chosen appliance and linear in prices and net income. The link between these two decisions has been taken into account through the inclusion of the correction of the selectivity bias in the model specification.

Figure 5.2 shows a two-step model of the joint discrete choice of vehicle type and the continuous choice of annual vehicle kilometres.

⁹³ Heckman's 2-steps methode wordt nauwelijks meer gebruikt omdat methoden voor simultane schatting (FIML) in diverse pakketten zitten.

Figure 5.2: Discrete-continuous choice modelling



First of all, we discuss the discrete choice sub-models of how many and which cars to own. Then, we discuss the continuous choice of distance driven by car. This discussion is based on the modelling work by Train (1986).

5.4.2 Model specification

Discrete choice modelling of car ownership

Assume that households face a discrete choice amongst a set of mutually exclusive, exhaustive vehicle types, which consist of the number of vehicles to own (i.e. none, one or two) and the type of vehicle characterised by the fuel type and the engine size of each vehicle. This choice would maximize the household's utility and reflect their purchasing power, need and willingness to buy vehicles. Therefore, the household's choice of how many cars to own can be determined by comparing the utility that each potential vehicle type would generate.

For each vehicle type, at given prices and income, a conditional indirect⁹⁴ utility function can be drawn:

$$V_{nb_n} = f(Y, p_{nb_n}, r_{nb_n}, h, \varepsilon) \quad (5.9)$$

⁹⁴ Train (1986) explains the difference between a direct and an indirect utility function, while Varian (1978) pointed out that a household's preference can be represented by either a direct or an indirect utility function. Since deriving demand functions from indirect utility functions is more practicable, we opt for using this technique.

Where

n is the number of vehicles

b_n is the fuel type/engine combination of each of the n vehicles (i.e. b_n is a vector with length n , denoting the fuel type/engine size combination of the vehicles)

V_{nb_n} is the conditional indirect utility of the household, given that it owns n vehicles of vehicle type b_n

Y is the income of the household

p_{nb_n} is the cost per kilometre travelled by n vehicles with vehicle type b_n

r_{nb_n} are the fixed costs of n vehicles with vehicle type b_n

h are observed household characteristics

ε is the error term, which consists of unobserved household characteristics and vehicle attributes.

The utility maximization theory postulates that households are assumed to maximize this indirect utility function and choose type b if the conditional indirect utility for that type is higher than for each of the other types

$$V_{nb_n^*} > V_{nb_n} \text{ for all } nb_n \text{ other than } nb_n^* \quad (5.10)$$

Train (1986) argues to use a linear-in-parameters approximation since the conditional indirect utility function is nonlinear in parameters of observed variables.

Utility for households with no vehicles,

$$V_{0b_0} = 0, \text{ by normalization;} \quad (5.11)$$

Utility for households owning one vehicle,

$$V_{1b_n} = \chi_1 + \delta_1 \cdot Y + \phi_1 \cdot r_{nb_n} + \varphi_1 p_{nb_n} + \gamma_1 \cdot h + \varepsilon_1 \quad (5.12)$$

Utility for households owning two vehicles,

$$V_{2b_n} = \chi_2 + \delta_2 \cdot Y + \phi_2 \cdot r_{nb_n} + \varphi_2 \cdot p_{nb_n} + \gamma_2 \cdot h + \varepsilon_2 \quad (5.13)$$

where

ε_k (for $k = \{1, 2\}$) are the error terms.

$\chi_k, \delta_k, \phi_k, \varphi_k$ and γ_k , (for $k = \{1, 2\}$) are vectors of parameters.

These utilities can be estimated by using a MNL model, whereby the probabilities of the different alternatives follow a logit distribution:

Probability of owning one vehicle,

$$P_1 = \frac{e^{V_{1b_n}}}{(e^{V_{1b_n}} + e^{V_{2b_n}} + 1)} \quad (5.14)$$

Probability of owning two vehicles,

$$P_2 = \frac{e^{V_{2b_n}}}{(e^{V_{1b_n}} + e^{V_{2b_n}} + 1)} \quad (5.15)$$

Probability of owning no vehicles,

$$P_0 = 1 - P_1 - P_2 = \frac{1}{(e^{V_{1b_n}} + e^{V_{2b_n}} + 1)} \quad (5.16)$$

Now, we need to adjust these probabilities for selection and endogeneity bias. We follow the approach of Dubin and McFadden (1984). They have shown that, if the choice probabilities are logit and the expected errors are normally distributed, then the selectivity correction is:

$$E(\varepsilon_m) = \sum_{b_n \neq m} -\left(\frac{\sqrt{6\sigma^2}}{\pi}\right) \cdot \rho_{b_n} \left[\frac{P_{b_n} \ln P_{b_n}}{1 - P_{b_n}} + \ln P_m \right] \quad (5.17)$$

where

m represents the vehicle number (1 or 2) that the household actually chooses,

P_{b_n} are estimated choice probabilities of owning each vehicle type,

σ^2 is the variance in ε_m in the entire population and

ρ_{b_n} corresponds to the correlation of ε_m with the unobserved utility associated with the vehicle type m .

We can rewrite (5.17) as:

$$E(\varepsilon_m) = \lambda_i \cdot C_m \quad (5.18)$$

Where

$$\lambda_i = \sum_{b_n \neq m} -\left(\frac{\sqrt{6\sigma^2}}{\pi}\right) \cdot \rho_{b^n} \quad (5.19)$$

and

$$C_m = \left[\frac{P_{b^n} \ln P_{b^n}}{1 - P_{b^n}} + \ln P_m \right] \text{ for } m = \{1, 2\} \quad (5.20)$$

which is known as the selectivity correction term.

Incorporating the selectivity correction term provides a consistent estimate of each parameter, which will be entered into the VKT demand equation in the next stage.

Continuous choice modelling of car use

This continuous decision is modelled separately for each type of household according to the number of cars owned. This sequencing is more convenient for the researcher⁹⁵, rather than an assumption that households make their decisions sequentially. As stated earlier, these choices are interrelated.

Following Hausman (1981)⁹⁶, we translate the conditional indirect utility function of vehicle ownership into a VKT demand function by using Roy's identity. Given n and b_n , the number of vehicle kilometres travelled by the household in the i -th vehicle is, given by Roy's identity, the negative of the derivative of the conditional indirect utility function with respect to the price per VKT divided by the derivative with respect to income⁹⁷. Let this partial differential equation be denoted as g^j

⁹⁵ Fullerton and Gan (2004) estimated the car ownership-and-use choices simultaneously by using General Method of Moments (GMM).

⁹⁶ Hausman was mainly researching labour participation models.

⁹⁷ A proof of Roy's identity is given in Train (1986).

$$VKT_{nb_n}^i = - \frac{\left(\frac{\partial V_{nb_n}^i}{\partial p_{nb_n}^i} \right)}{\left(\frac{\partial V_{nb_n}^i}{\partial y} \right)} = g^i(p_{nb_n}, Y, h_n, \varepsilon), \quad (5.21)$$

where

$VKT_{nb_n}^i$ represents the kilometres travelled in the i -th vehicle, given that the household owns n vehicles of vehicle type b_n and

$p_{nb_n}^i$ is the cost per kilometre travelled, given that the household owns n vehicles of vehicle type b_n

Equation (5.21) represents the household's demand for VKT in each vehicle i , as a function of the cost of driving, the income of the household net of fixed vehicle costs and other observed and unobserved characteristics of the household.

Similar to the previous stage, the specified nonlinear conditional indirect utility function is approximated by a linear-in-parameters demand function, which now estimates the VKT conditional on vehicle i :

$$VKT_{nb_n}^i = a + \alpha \cdot p_{nb_n}^i + \beta \cdot Y + \gamma \cdot h + \varepsilon \quad (5.22)$$

This equation is called the "Reduced Form Method" in Dubin and McFadden (1984).

To achieve consistent estimates of the parameters, the selectivity correction term is added to the VKT equation. Since this term differs between households choosing one- and two-vehicles, separate VKT equations are estimated for each type:

For one-vehicle households, the demand equation is

$$VKT_{1b_n}^i = a + \alpha \cdot p_{1b_n}^i + \beta(y - r_{1b_n}) + \gamma \cdot h + \sum_{i \neq 1} \lambda_i \cdot C_1 + \varepsilon \quad (5.23)$$

for two-vehicle households, the demand equation is

$$VKT_{2b_n}^i = a + \alpha \cdot p_{2b_n}^i + \beta(y - r_{2b_n}) + \gamma \cdot h + \sum_{i \neq 2} \lambda_i \cdot C_2 + \varepsilon \quad (5.24)$$

Where

ε is an error term due to unobserved attributes,

$\alpha, \beta, \lambda_i'$ are the parameters to be estimated.

Now a standard linear regression technique, such as ordinary least squares regression, can be used to estimate these parameters.

5.4.3 Applications of the Dubin-McFadden model

Several researchers applied the Dubin-McFadden framework to study fuel or VKT demand⁹⁸. An overview can be found in Hensher *et al.* (1992) and Choo and Moktharian (2000). We limit our discussion to these studies, which were not included in these reviews.

Sheu (2004) estimated a multinomial logit model to explain whether a household owns zero, one or two vehicles. Then she estimated separate vehicle miles travelled (VMT) demand equations per vehicle for households that own one or two vehicles.

Fullerton *et al.* (2004) developed a model, which has two distinguishing characteristics compared with the Dubin-McFadden model. Firstly, due to the lack of micro level data showing individual choices, they had to deal with aggregate data. Secondly, they built a model to estimate the discrete choice of vehicles and continuous demand for distance at the same time by using general method of moments.

West (2004) applied their model to discrete choice of vehicle and continuous choice of distance. She performed a nested logit estimation of households' choices from among vehicle types classified according to the number of vehicles, vintage, and engine size. Price elasticities were estimated by income deciles.

Bento *et al.* (2004) used the two-stage model to study the impact of urban configuration and public transit supply on the annual miles driven of households living in urban areas.

⁹⁸ An excellent literature review of car ownership models is given by Rand Europe (2001).

5.5 *Limitations of MNL modelling*

All of the previous described studies use standard choice models (multinomial logit or nested logit) for the vehicle type dimension and a continuous linear regression model for the vehicle use dimension. Multiple vehicles choices are modelled by treating all possible combinations of vehicle types as alternatives. Bhat and Sen (2005) raised three problems when using this approach.

Firstly, these studies do not take into account that households might own a mix of vehicle types to satisfy different functional or variety-seeking needs. Secondly, considering all possible combinations of vehicle types leads to an explosion in the number of alternatives in the choice set. Third, modelling the continuous dimension of vehicle use becomes very cumbersome.

Consequently, there exist many others and more advanced modelling techniques. An overview can be found in Cambridge Systematics (1997), Bunch (2000) and Train (2003)⁹⁹.

Although the advanced models are considered by Cambridge Systematics (1997) to be theoretically superior, they also emphasized that these models require detailed survey data and the use of complex estimation and computational procedures. As discussed in chapter 5.1.3, two main assumptions of MNL are the nature of the substitution patterns across alternatives, and the absence of random taste heterogeneity across decision-makers, of which the first assumption was eased by the introduction of the GEV models. Using the MNP model or the MMNL model can capture the taste heterogeneity. However, since we used a neo-classical approach for our cost calculation (i.e. we calculate the actual costs, rather than the perceived costs), we adapt in this

⁹⁹ We mention a recently developed model by Rouwendal and Pommer (2004). They extended an existing model for single car ownership-and-use to a multiple car ownership-and-use model. Therefore, they used the rationing model developed by Neary and Roberts (1980). Their model is based on the idea that limited substitutability between desired car use of different households members is the driving force between multiple car ownership.

dissertation the “traditional” approach of Dubin and McFadden’s (1984) by using -the most widely used- multinomial logit MNL¹⁰⁰.

¹⁰⁰ Undeniably, the use of more advanced models is one of the topics for further research.

CHAPTER 6 A discrete-continuous model of car ownership-and-use for Flanders

In chapter 4, we described the design of a tradable fuel permit scheme. In this chapter, we develop a model to estimate, evaluate and predict the effects of such a scheme on household behaviour and CO₂ emissions in Flanders.

To this end, we reviewed in the previous chapter the relevant literature in the areas of discrete choice modelling and car ownership-and-use modelling techniques. Now, we elaborate a disaggregate car ownership-and-use model for Flanders, which estimates the household demands for vehicles, vehicle kilometres travelled (hereafter denoted as VKT), fuel use and resulting CO₂ emissions.

6.1 Introduction of car ownership-and use modelling

A household behavioural model provides a thorough knowledge of the economic behaviour of different households. As was shown in table 4.4, consumers with different mobility needs, income levels or demographic characteristics will adapt their behaviour in different ways, as required by economic efficiency.

Household decisions about fuel use essentially depend on the fuel price, household income, household structure, residential location and other socio-economic variables. At the same time, most of these variables also influence vehicle ownership, which in turn is another determinant of fuel use. Consequently, the demand model should include both the discrete choice about the type of cars to own and the linked continuous choice about how much to drive, which are both conditional on the number of vehicles owned.

Moreover, this model can be used in a wide range of policy strategies as illustrated by the following list of examples.

- Whereas the present road transport system is inextricably dependent of fossil fuels, projections of future fuel consumption and the impact of different types of government interventions need to be based on car demand and fuel use.
- Furthermore, since car related taxes are an important source of public revenues¹⁰¹, an efficient estimation of car use and demand is a crucial step in drawing up the Public Budget. In this context, the variabilisation of the fixed costs is a highly relevant policy issue.
- Moreover, since car emissions form a major part of local, regional and worldwide pollution, air quality standards and policies are based upon car use projections.
- A sustainable transport policy requires multiple and flexible measures. Therefore, policy makers need to know which households groups would be affected by, or interested in a policy measure. For instance, a subsidy to buy new and cleaner vehicles might be regressive if only high-income groups with a high willingness to buy new vehicles would be interested in this measure.

¹⁰¹ Federauto (2001) estimated that 9,56 billion euro of Belgian tax revenues in 2000 was generated by car-related taxes.

6.2 Data sources

6.2.1 Household Travel Survey of Flanders

Our model input is based on a sample of 3,028 households, which were inquired in the Household Travel Survey (HTS) of Flanders in 2000. This survey was funded by the Flemish Government and carried out by the "Provinciale Hogeschool Limburg". Details of this survey can be found in Zwerts and Nuyts (2002a,b).

Information was obtained about the socio-economic situation of each household and its vehicle fleet. Socio-economic data included the household size and the number of children younger than 6 years. Moreover, the following categorical variables were included: age and sex of household head, household income, living area and availability of public transport. Vehicle-related variables included vehicle type, make and model, engine power, vintage, purchase year and condition, fuel type, principal car driver, total number of kilometres of the car (the odometer reader) and number of kilometres driven in the previous twelve months.

6.2.2 Other sources

The data of the HTS were enriched with data from other sources. First of all, we consulted different volumes of "Automagazine"¹⁰² which includes an inventory of new and used cars, their technical specifications and an estimation of their purchase prices.

Additional fuel consumption and car maintenance and repair data were obtained by "Auto-enquête", a yearly-performed inquiry of the Belgian

¹⁰² More specifically, we consult Automagazine (2000) and Automagazine (1994), which provide us information for almost the entire household car stock.

Consumer Organization "Verbruikersunie". More details of this inquiry can be found in Verbruikersunie (1997).

6.3 *Data manipulation*

6.3.1 Item non-response

Problem formulation

It is common practice in surveys that some of the respondents do not reply to all items being asked. This phenomenon is called item non-response¹⁰³. It gives rise to less efficient estimates and possible biases because the respondents are often significantly different from the non-respondents.

Zmud and Arce (1997) identified five major causes of item non-response:

- Knowledge and recall gaps;
- Comprehension gaps;
- An excessive perceived or real survey burden;
- Privacy concerns;
- Deliberate mis-reporting.

Solutions

The literature describes four approaches to deal with item non-response.¹⁰⁴

Firstly, records with any missing data can be removed. This is the most extreme and wasteful way of data editing, but results in a "clean data set" (i.e. without any missing data).

Secondly, every record, which has a missing value for any of the required attributes, can be ignored in the performed analysis. This results in different

¹⁰³ Definitions of non-response can be found in Zimowski et al. (1997), Zmud and Arce (2000) and Rubin (1987).

¹⁰⁴ Since we are only using the results of a previous performed survey, we will not discuss approaches for preventing item non-response. For transport surveys, see Zmud and Arce (2000) and Richardson (2000).

distribution totals and cross-tabulations because in each calculation another data matrix is used.

Thirdly, the data of the respondent sample can be reweighted.

Finally, values of missing data can be estimated or imputed, based on other sources of information. This is the preferred method since all data in the existing data set are used. Moreover, these data need to be performed only once and results in a clean data set matrix for analysis. The literature¹⁰⁵ distinguishes four main categories of imputation methods.

First of all, in the deductive imputation method, a missing value can be replaced by a perfect prediction, based on a logical conclusion drawn from other attributes.

Furthermore, the overall or class mean of that attribute can be used to substitute a missing value. These methods reduce estimates of the variance, especially in the case of overall mean imputation.

A third and more powerful imputation method involve the estimation of a regression equation, which is used to predict the missing value.

Finally, in the hot-deck imputation, missing responses are substituted by finding a record within the data set¹⁰⁶, which is similar in all respect to the one with the missing value.

Imputation methods used in HTS

We identified three major areas of non-response in the HTS: items related to household characteristics, items related to the technical car specifications and non-reported kilometres.

First of all, for the household variables there were - except for the income variable - less than one percent of missing values. For the income variable, the share of missing values mounted to almost seven percent (6,8%). This is not surprising, since respondents are concerned about their privacy. Moreover,

¹⁰⁵ See Armoogum and Madre (1997).

¹⁰⁶ When data from other sources are consulted, the term "cold-deck imputation" is used.

questions related to income are not always easy and unambiguous to answer¹⁰⁷.

Deductive and hot-deck imputation methods were used to replace these missing values. Some illustrative examples:

When the household head is a female and older than 65, we deduce that there is only one household member and there are no children younger than 6 years. For the categorical income variable the hot-deck imputation method was used.¹⁰⁸ Donor records were identified based on the number of cars, family size, area of living and age of household head.

Second, variables related to the technical car specifications were very vulnerable to item non-response. Different reasons explain this phenomenon

On the one hand, respondents were asked to choose the make and type of their vehicle. Since it is quite impossible to provide an exhaustive list of all vehicle makes and types, the survey included an "other" option. On the other hand, respondents have limited knowledge of technical issues such as engine size, vintage and fuel consumption.

For these technical car specification variables, different techniques were applied to deal with these missing data:

- Class mean imputation was used for missing values of fuel consumption. Classes were identified based on the fuel type, make and model of the car;
- Missing data of engine size, fuel type and vintage were imputed by hot or cold-deck methods;
- Records with missing data of the make or model of car were mostly¹⁰⁹ removed;

¹⁰⁷ Richardson (2000) reported that the US Bureau of Census uses twenty-five questions to obtain estimates of income.

¹⁰⁸ If the income variable was continuous, we would have used the regression imputation.

¹⁰⁹ When make, engine size and fuel type were known, cold-deck imputation was used for the variable 'model of car'.

- Records with missing data on the total number of kilometres were removed, unless the car was bought new, or the purchase year was identical to the car vintage. In that case, the total number of kilometres was deduced by multiplying the annual number of kilometres by the number of years the car was owned.

Finally, records with non-reported annual number of kilometres were consistently removed, taking into account the utmost importance of this variable for our research.

Table 6.1 summarizes how we handled the problem of missing data.

Table 6.1: Employed methods to handle item non-response

| <i>Variable with missing values</i> | <i>Used technique</i> |
|-------------------------------------|---|
| Income | Hot-deck imputation |
| Other socio-economic variables | Deductive imputation |
| Fuel consumption | Class mean imputation |
| Engine size, fuel type and vintage | Hot- or cold-deck imputation |
| Make and type of car | Records removed |
| Total number of kilometres | Deductive imputation or records removed |
| Total annual kilometres | Records removed |

6.4 Cost calculation

We want to calculate the households' car-related expenditures in 2000. The number of cars owned, the car specifications and the total kilometres travelled were inferred from the dataset of the Household Travel Survey 2000. Furthermore, we use the cost calculation of Test-Aankoop Magazine (1997) as a starting point. However, while they calculated initial costs, fixed operation costs and variable costs¹¹⁰, we only distinguish fixed and variable costs.

6.4.1 Fixed costs

The calculation of the fixed annual costs includes all costs related to owning a car, which is allowed and able to be used in road transport. We discern depreciation costs, insurance premiums, taxes, costs related to the annual car inspection, annual service and interest loss¹¹¹.

Depreciation

The literature describes three methods of depreciation. First of all, Hotelling (1925) developed the implicit interest depreciation method¹¹². However, practitioners rarely use this "economic" method. Instead, they use "accounting" methods such as straight line and declining balance depreciation. Although Hisher and McGowan (1983) advocated the use of the economic method for all types of goods, Peles (1988) found that the two "accounting" methods are superior to the "economic" method in describing true depreciation of cars. He considered an increasing maintenance cost, a decreasing reliability and obsolescence as the major factors explaining the declining benefit function of the car's life. We use the declining balance or accelerated method of

¹¹⁰ Initial costs are considered as once-only costs while fixed operational costs are annual costs.

¹¹¹ These are not all costs related to car use. However, we assume that car-wash, rent of a garage and radio taxes are zero.

¹¹² This method implies an increasing benefit function.

depreciation, which is given in the following formula in the calculation of the depreciation costs D_i^{2000} for a car with specifications i during the year 2000:

$$D_i^{2000} = P_i(R^x - R^{(x-1)}) \quad (6.1)$$

Where

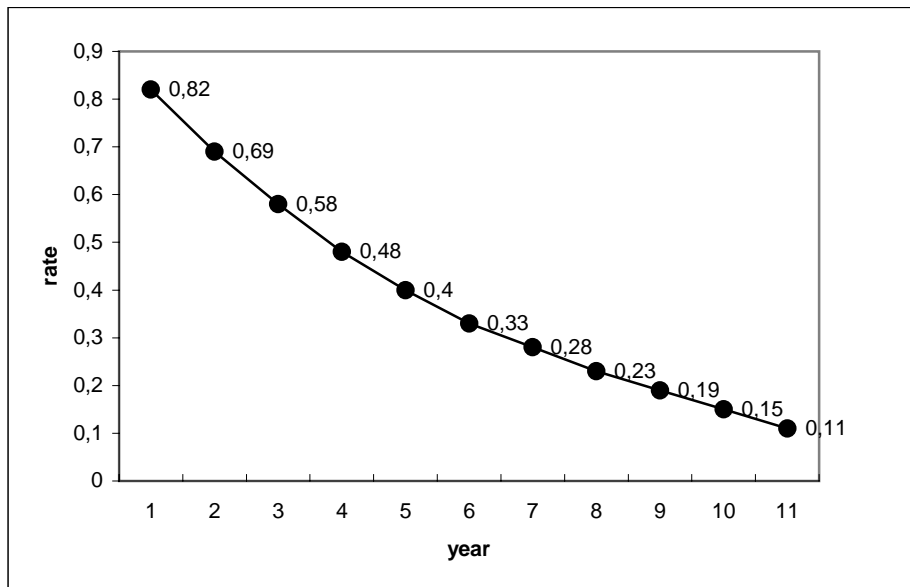
i is the technical specification of the car, including make, type, engine size, fuel type, kWatt power and horsepower.

P_i is the new purchase price¹¹³ of car i in the year 2000

R^x is the depreciation rate for a car, aged x years.

To determine the value of R , we use the depreciation pattern as was calculated by the Dutch Government (2004) to determine the registration taxes on used cars as shown in Figure 6.1.

Figure 6.1: Evolution of depreciation rates of cars by age



We value P_i as the recommended new purchase price in June 2000, which was reported by Automagazine (2000). However, the determination of the value of

¹¹³ We consider the registration charge for new cars, which amounts to 61.97 euro, as part of the purchase price. Therefore, we do not include this charge as a separate cost item in our calculation.

P_i is not as straightforward as prima facie seems. Indeed, contrary to other research¹¹⁴, we do include used cars in our cost calculation. This complicates the calculation since many used cars were no longer available as new cars in 2000. For these cars, we use the recommended prices of June 1994¹¹⁵ and actualize these prices to June 2000 by using the price index of new cars, reported by Federale Overheidsdienst Economie, KMO, Middenstand en Energie (2004).

It is obvious that our depreciation cost calculation does not take all sources of variation into account. Firstly, since we use recommended prices, variations amongst car dealers, bargained discounts or temporal promotions are not included. Secondly, we use standard car prices, which implies that options or other additional costs are not accounted for. Furthermore, we also use a single depreciation rate, which means that variations amongst makes and types are not taken into consideration. This means that the depreciation costs of makes with a high resale value, such as the German makes, are overestimated. Subsequently, we fix maximum vintage of cars at ten years, which means that the depreciation costs of older cars are underestimated.¹¹⁶

Finally, we consider all cars, bought in 2000, as if they were bought on the first of January. This means that depreciation cost of cars bought in the course of 2000, are somewhat overestimated.

Insurance premium

Legally, an insurance premium consists of two parts, namely one for providing legal assistance and the other covering civil liability. Additionally, this can be complemented with an all-risk or *omnium* insurance.

The premium for providing legal assistance is a fixed amount. In 2000, it was set on 45.86 euro.

The determination of the civil liability premiums is based on several criteria.

¹¹⁴ An example for Flanders is De Ceuster (2004).

¹¹⁵ These prices were reported in Automagazine (1994).

¹¹⁶ For instance, we use the same depreciation rate of a car of ten years as a car of 15 years old.

Until 1998, premiums were roughly based on three parameters:

- *Bonus/Malus* score, which reflects the driving experience and accident rate of the main driver;
- Engine power, expressed in kWatt;
- Living area, divided into three zones.

After 1998, the living area parameter was further detailed and a parameter representing the risk for inexperienced and young drivers was included¹¹⁷.

For our cost calculation, it is convenient to use the less detailed calculation. To this end, we use the cost calculation employed by Royale Belge, the main car insurance company in Belgium. Since we only have calculation rates of 1995¹¹⁸, we actualize these rates to June 2000 by using the price index of car insurances, as reported by "Federale Overheidsdienst Economie, KMO, Middenstand en Energie" (2004).

To determine the Bonus/Malus score of the car owner in the household, we use the average value of 2000, namely 3. Figure 6.2 shows the distribution of the Bonus/Malus degree amongst insured car owners in 2000.

The final component of the insurance premium is the *omnium* part. The level of the omnium insurance fully depends on the actual value of the car.

Although we could calculate the *omnium* premium, we exclude this from our cost calculation. There are two interrelated motivations for this approach.

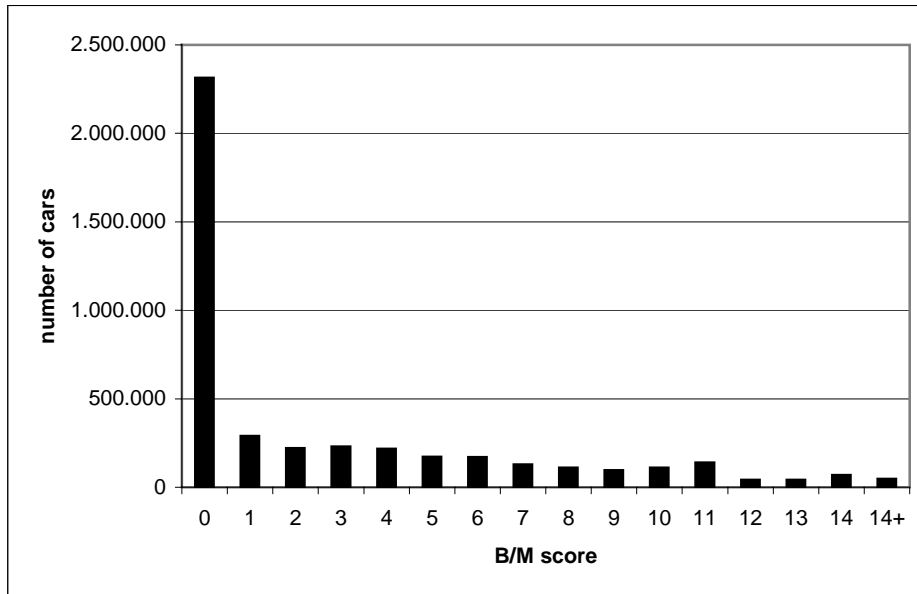
Firstly, optional *omnium* insurance is taken out mainly for new cars. However, not all car users who purchase a new car have this insurance. Secondly, an *omnium* insurance covers part of the depreciation of a car.¹¹⁹ By excluding the *omnium* insurance, we avoid double counting.

¹¹⁷ We would like to stress that we outline the premium calculation only in broad terms.

¹¹⁸ These rates were applied in Test-aankoop magazine (1997).

¹¹⁹ For instance, the monthly depreciation rate of a car in an *omnium* policy is typically set at one percent. However, we use a depreciation rate of eighteen percent after the first year and thirty-one after the second year.

Figure 6.2: Distribution of insured car owners according to Bonus/Malus score in 2000 in Belgium



Source : BVVO (2001).

Car inspection

Annual car inspection is obligatory for cars aged four years or older or for younger cars when bought second-hand. We value the annual car inspection costs at 32.97 euro. For reasons of simplicity, we assume that all cars pass after the first inspection. This is likely to lead to a small underestimation.

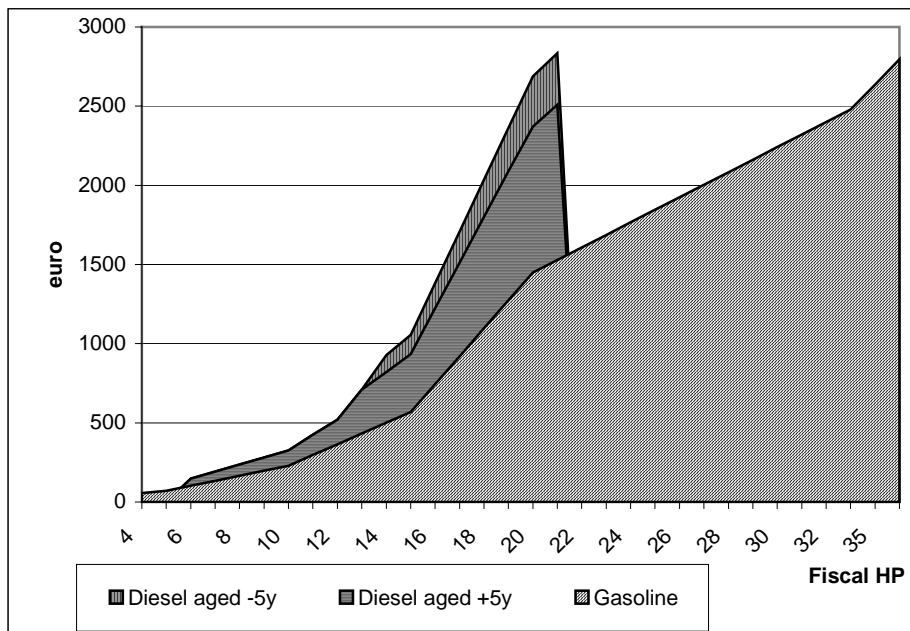
Maintenance

We consider one small maintenance service a year as necessary to keep the car operational. We apply the same maintenance rates as used in Verbruikersunie (1997) and actualize these rates to June 2000 by using the price index of car maintenance, as reported by "Federale Overheidsdienst Economie, KMO, Middenstand en Energie" (2004). Note that these values are make-specific and vary from 54.65 euro for a Toyota to 89.98 euro for a BMW.

Road Taxes

Figure 6.3 shows the annual road tax in Belgium¹²⁰ for the year 2000. The tax level depends on the fiscal horsepower¹²¹, the fuel type and in case of a diesel car the car vintage.

Figure 6.3: Road tax level in 2000 in Belgium



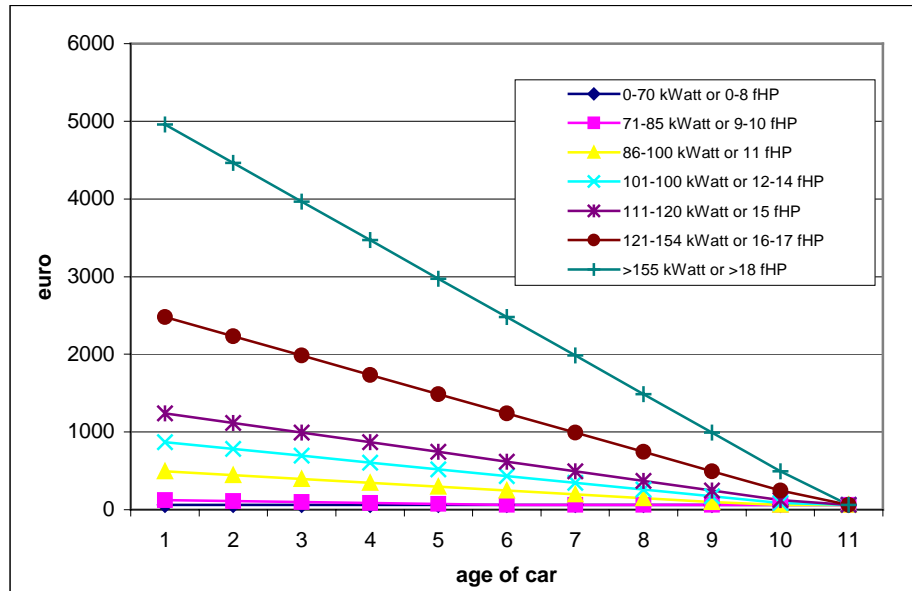
Registration tax

The registration tax is due when a new or a second-hand car is purchased. As Figure 6.4 shows, the level of this tax depends on the age and power of the car.

¹²⁰ For an overview of car use and ownership taxes in other EU countries, we refer to COWI(2001).

¹²¹ The fiscal horsepower of a car has a value between 3 and 24, depending on the engine size and power of the car.

Figure 6.4 Level of registration tax in 2000 in Belgium



Interest loss

The interest loss is related to the purchase price. Although some studies¹²² include these costs in their calculation, we exclude them¹²³ because the interest loss costs can basically be considered as opportunity costs rather than real expenditures.

¹²² For instance, Test-aankoop magazine (1997), Bento et al. (2003) and Sheu (2003) use this approach.

¹²³ However, we calculated the interest loss and applied an interest rate of four percent. We obtained an average value of 723 euro, mounting up to 4,241 euro. This maximum occurred when a household bought a new and expensive car more than ten years ago. The minimum value observed was 46 euro. In that case, it involved an old, second-hand car that was recently bought.

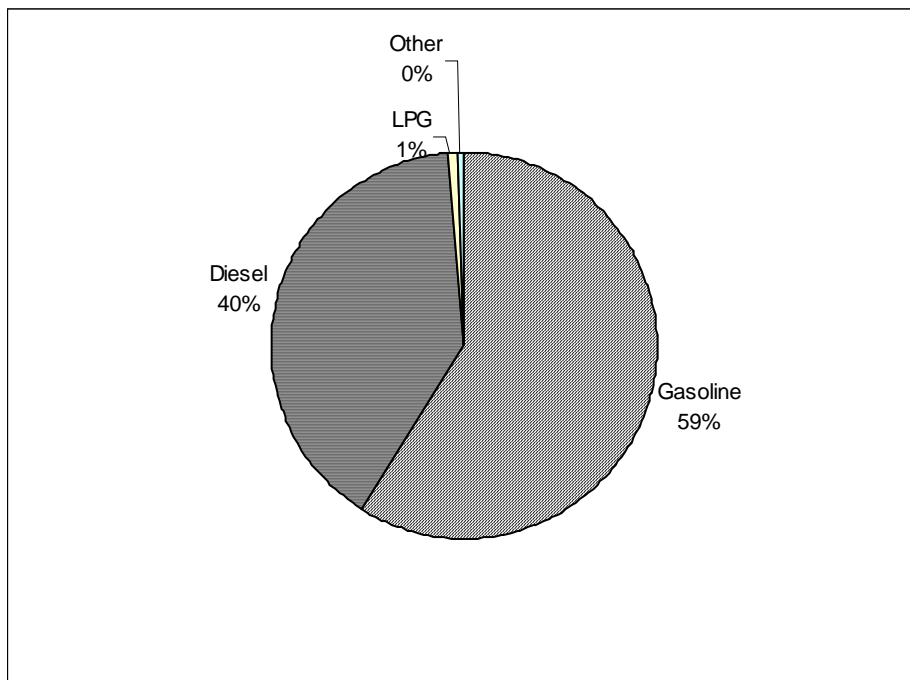
6.4.2 Variable costs

The calculation of the variable costs comprises all costs related to the number of kilometres driven. We distinguish fuel costs, maintenance costs, repair costs and costs related to worn-out tyres.

Fuel

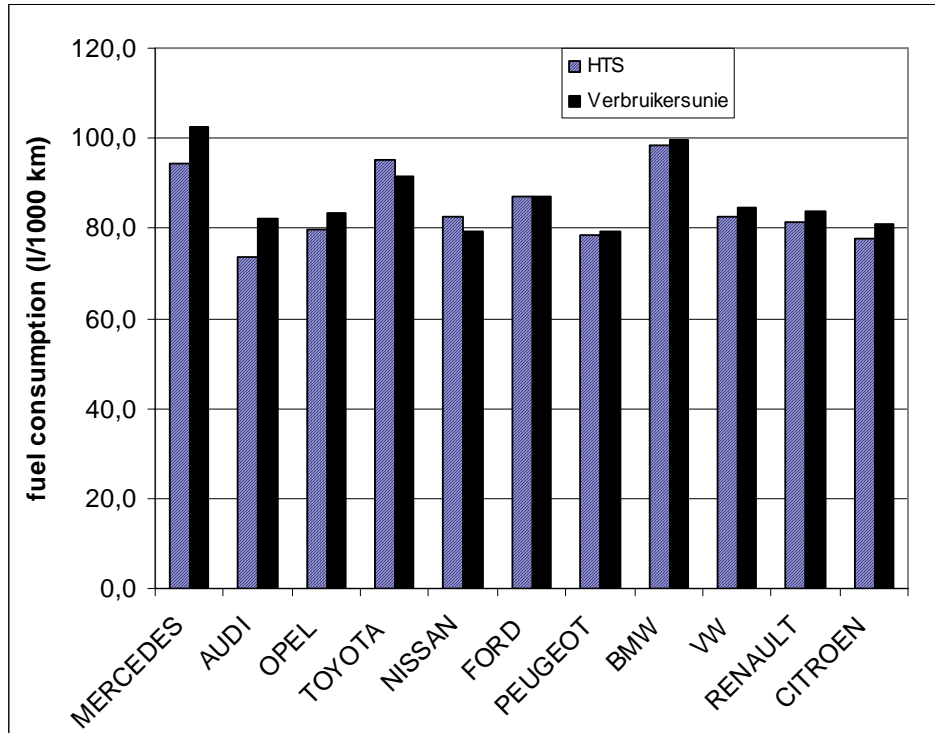
As Figure 6.5 presents, the vast majority of cars runs on gasoline or diesel. Therefore, we exclude LPG as a fuel type in our calculation and consider them as gasoline cars. We use the average unleaded gasoline and diesel price of 2000, respectively 1.087 euro and 0.811 euro.

Figure 6.5: Relative distribution of cars according to fuel type in 2000 in Belgium



As we previously discussed, we imputed missing values of fuel consumption by average class mean imputation from the HTS. Classes were identified based on the fuel type, make and model of the car. Figure 6.6 compares those data of the HTS with these of Verbruikersunie (1997) for the main car makes. We observe a small variance, i.e. less than 1 l per 100 km, between both surveys.

Figure 6.6: Comparison of fuel consumption by make observed in HTS(2000) and Verbruikersunie (1997)



Repair

We follow the approach of Verbruikersunie (1997) and consider the major wearing parts of a car, namely clutch, front and rear brakes, battery, dampers and exhaust equipment. The number of kilometres when a part a needs to be replaced X_i^a and their related costs Y_i^a are make-specific i . Furthermore, we assume that these costs are recurrent.

We use the following algorithm to calculate replacement costs R^a for a repair part a of a car with an annual number of kilometres driven A and a total number of kilometres T :

If $T < X_i^a$ than $R^a = 0$

else if $T < 2 X_i^a$ than if $A < (T - X_i^a)$ than $R^a = 0 < f$

else $R^a = Y_i^a$

else if $T < 3 X_i^a$ than if $A < (T - 2X_i^a)$ than $R^a = 0$

else $R^a = Y_i^a$

If $T > x X_i^a$ than end

Subsequently, applying this algorithm for all parts a , we obtain the total repair

$$\text{costs } R = \sum_1^{a=6} R^a$$

Other small maintenance services

As we previously discussed, we consider one small maintenance service as necessary to keep the car operational. To calculate the other small maintenance services costs, we adopt the assumption by Verbruikersunie (1997) and assume that the small service frequency is equal for all makes i . More specifically, the number of kilometres X_i^b when a car needs to be serviced is set on 12,500 km. This service involves oil replacement, revision of brakes and other small revisions. However, the service costs are make-specific and denoted as Y_i^b .

We use the following algorithm to calculate small services costs S for a car of make i with an annual number of kilometres driven A :

If $A < X_i^b$ than $S = 0$,

Else $S = (Y_i^b * (A / X_i^b)) - Y_i^b$

Extended maintenance services

Following Verbruikersunie (1997), we assume that the extended service frequency is equal for all makes i . More specifically, the number of kilometres

X_i^c when a car needs to be serviced is set on 30,000 km. However, the service costs are considered as make-specific and denoted as Y_i^c

We use the following formula to calculate the extended services costs Z for a car of make i with an annual number of kilometres driven A :

$$Z = (Y_i^c * (A / X_i^c))$$

Tyres

Similarly, we assume that the full set of tyres of a car of type j needs to be replaced when a car has driven X_j^d kilometres. This value is set on 50,000 km for all car types j . However, the tyre price varies according to car type j . Table 6.2 presents the cost of replacing a full set of tyres Y_j^d and tyre cost per km.

Table 6.2: Tyre set price values according to car type

| Car Type | Tyre price in euro | Tyre cost per km in euro |
|----------|--------------------|--------------------------|
| Small | 226.20 | 0.00452 |
| Medium | 277.60 | 0.00555 |
| Family | 329.04 | 0.00658 |
| Large | 380.44 | 0.00761 |

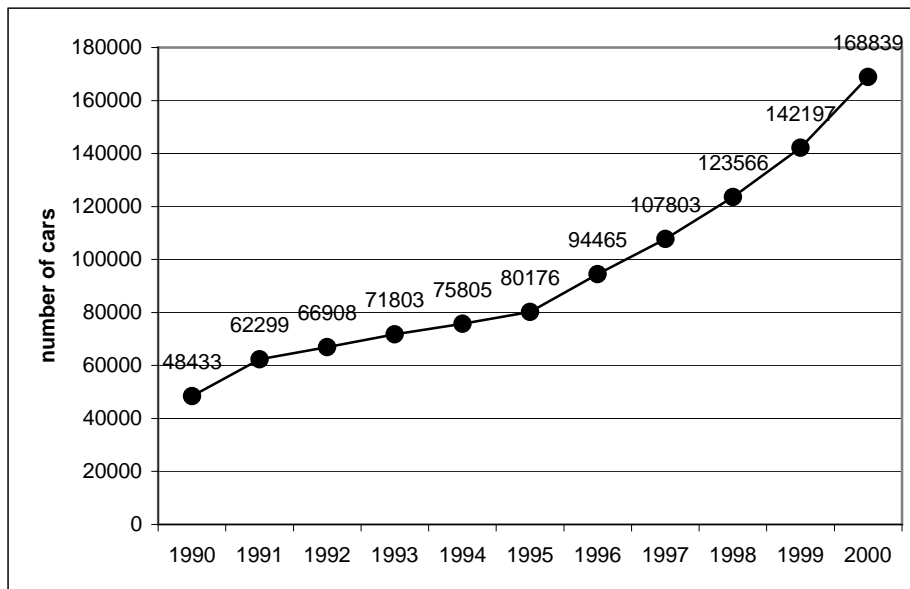
We use the following formula to calculate tyre costs W for a car with an annual number of kilometres driven A :

$$W = (Y_j^d * (A / X_j^d))$$

6.4.3 Company car

We define a company car as a car purchased or leased by a company and used for both business and private trips. As Figure 5.1 shows, the fleet of leased cars is steadily growing in Belgium.

Figure 6.7: Evolution of leased company cars in Belgium

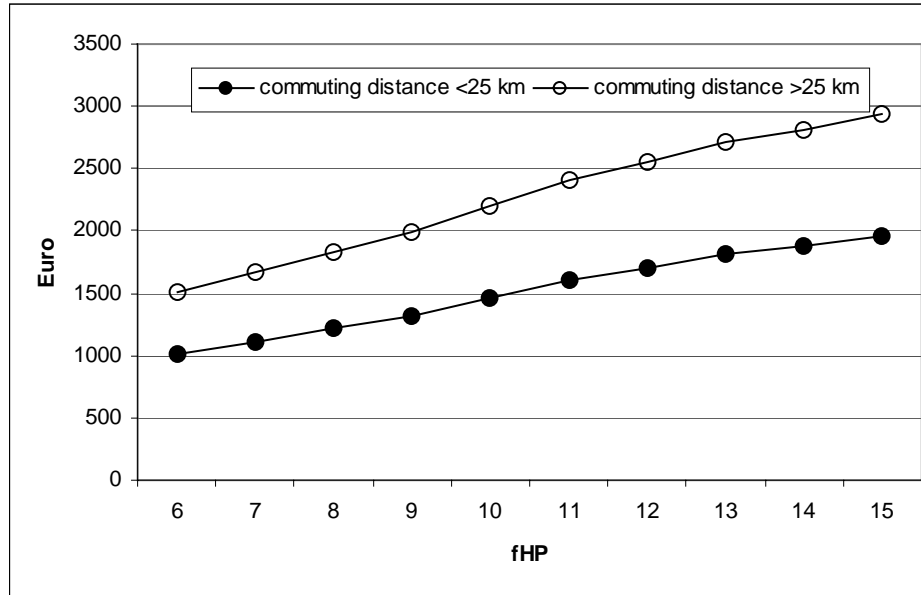


Source: OBVV (2001).

In the calculation of the households' costs of using a company car, the traditional approach of fixed and variable costs does not longer holds. Instead, we use the rates applied by the Ministry of Finance since 2004. These rates are employed to calculate the employee's cost of using a company car. Figure 6.8 shows that this rate is related to fiscal horsepower of the car and the commuting distance of the employee. Although the average commuting distance in Belgium values 19 km¹²⁴, we use the highest rate to avoid underestimation of the households' costs of using a company car.

¹²⁴Source: Zwerts and Nuyts (2002b).

Figure 6.8: Calculation method of company car's allowance



6.5 Summary statistics

This section presents the descriptive statistics of our sample. First, we discuss the results of the cost calculation of the total sample of cars. Secondly, we present the descriptive statistics of the household sample in relation to car ownership. Finally, we describe the summary statistics of the household sample in relation to their car use.

6.5.1 Car costs

Fixed costs

Figure 6.9 depicts the distribution of average fixed costs according to the main cost parameters¹²⁵. We discern respectively depreciation costs, insurance premium, road tax, annual service costs, car tax, car inspection costs and the

¹²⁵ In this calculation, we exclude company cars.

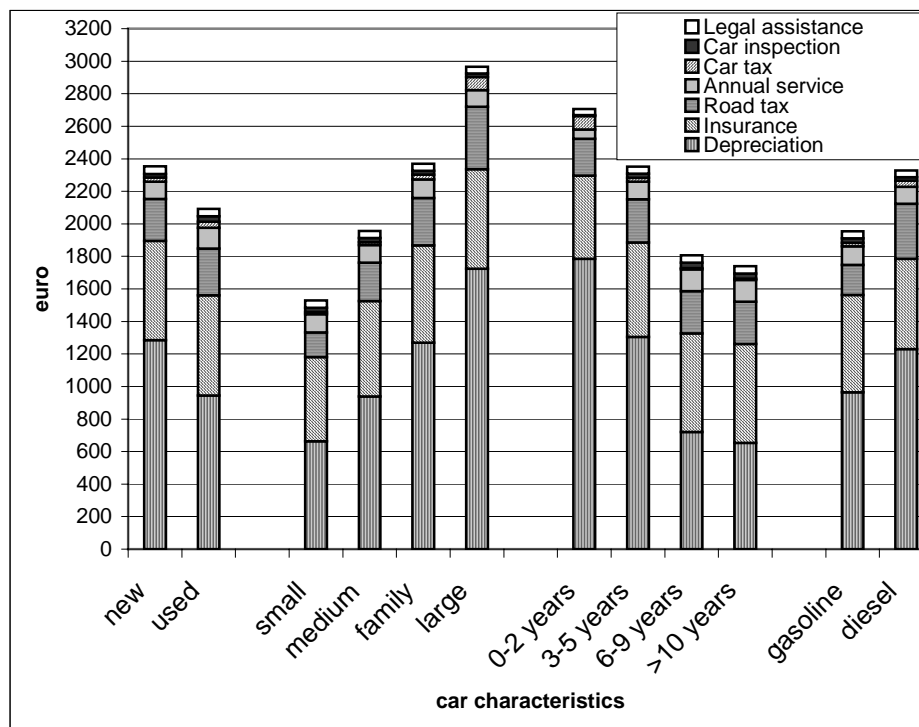
legal assistance premium¹²⁶. Based on a two-side t-test with a level of significance of 0.05, we can draw the following conclusions:

Although road tax, annual service and car inspection costs are lower for new-bought cars, the total average fixed costs are higher due to higher depreciation costs. Not surprisingly, the same trend can be observed for recent cars.

Since the major cost parameters, namely depreciation costs, insurance premium and road taxes are related to the car type, the total average fixed costs are positively related to the size of the car.

Gasoline cars have lower total fixed costs than diesel cars, due to their lower depreciation costs, civil liability premium and road taxes

Figure 6.9: Fixed cost distribution according to main car characteristics.

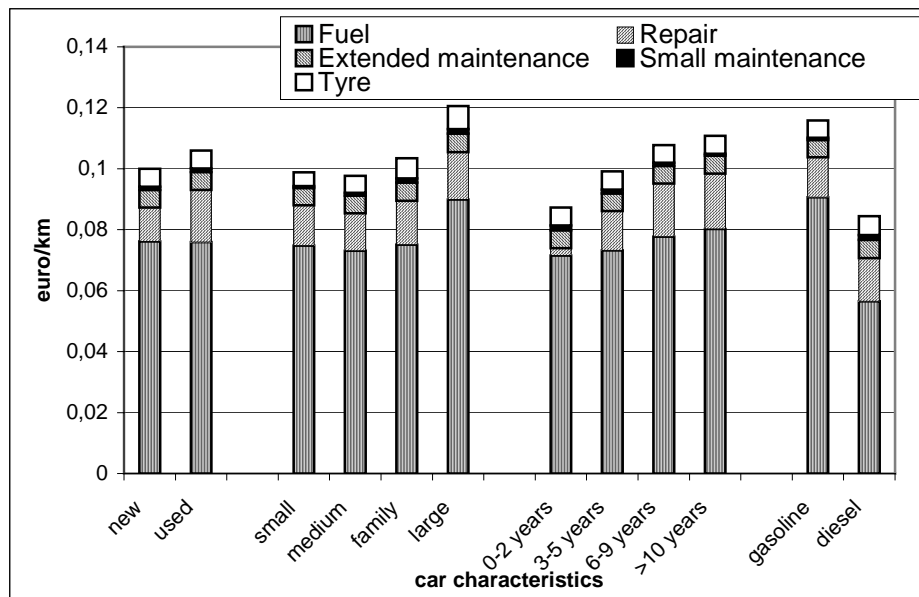


¹²⁶ We also distributed the mean of annual kilometres driven and the average according to these characteristics. Although these results are not shown, we incorporate them in our discussion.

Variable costs

Figure 6.10 depicts the distribution of the average variable kilometre costs according to their cost parameters¹²⁷. We discern respectively the fuel costs, repair costs, large and small services and tyre costs¹²⁸.

Figure 6.10: Variable kilometre cost distribution according to main car characteristics



Based on a two-side t-test with a level of significance of 0.05, we can draw the following conclusions related to the average variable kilometre costs:

First of all, the costs for used cars are higher than for new cars due to higher repair, extended service and tyre costs.

Secondly, the costs increase with an increasing type size, mainly due to higher maintenance, tyre and fuel costs. However, fuel costs of small, medium and family cars are similar and repair costs are similar for all car types.

Furthermore, the costs increase with an increasing car age, which can be explained by higher repair and fuel costs.

¹²⁷ In this calculation, we exclude company cars.

¹²⁸ We also distributed the mean of annual kilometres driven and the average according to these characteristics. Although these results are not shown, we incorporate them in our discussion.

Finally, diesel cars have lower costs than gasoline cars, mainly due to lower fuel costs. Nevertheless, gasoline cars have lower maintenance and tyre costs.

Total costs

Table 6.3 compares the households' cost structure of the sub-samples of company cars and the other cars. We observe that total costs of company cars are lower than the total costs for the other cars (i.e. with a total cost of respectively 2,252.15 euro and 3,822.54 eurocent per km). Since both car categories have similar fixed costs, this is simply and solely related to the fact that the variable cost of company cars is zero. Consequently, company cars drive more kilometres than other cars (35,758.66 annual kilometres travelled versus 15,677.80 km), which results that the total kilometre cost of company cars is four times lower than for other cars (i.e. respectively 9.45 eurocent per kilometre and 39.22 eurocent)

Table 6.3: Summary statistics of cost structure of car sample

| | Total sample | Sub-sample exclusive company cars | Sub-sample company cars |
|-----------------------------------|---------------------------|--------------------------------------|----------------------------|
| Number of observations | 2,065.00 | 1,951.00 | 114.00 |
| | Mean (Standard deviation) | | |
| Fixed costs (in €/year) | 2,247.93 (873.51) | 2,247.68 (896.88) | 2,252.15 (236.09) |
| Variable cost (in €/year) | 1,421.16 (1,060.59) | 1,574.86 (1,076.36) | 0.00 (0.00) |
| Total cost (in €/year) | 3,669.09 (1,529.64) | 3,822.54 (1,575.87) | 2,252.15 (236.09) |
| Annual km travelled | 16,786.38 (11,779.59) | 15,677.80 (1,0196.15) | 35,758.66 (18,871.19) |
| Variable km cost (in €/100 km) | 9.26 (3.66) | 10.24 (2.99) | 0.00 (0.00) |
| Total km cost (in €/100 km) | 37.16 (30.94) | 39.22 (31.01) | 9.45 (8.8) |

Figure 6.11: Total cost distribution according to main car characteristics

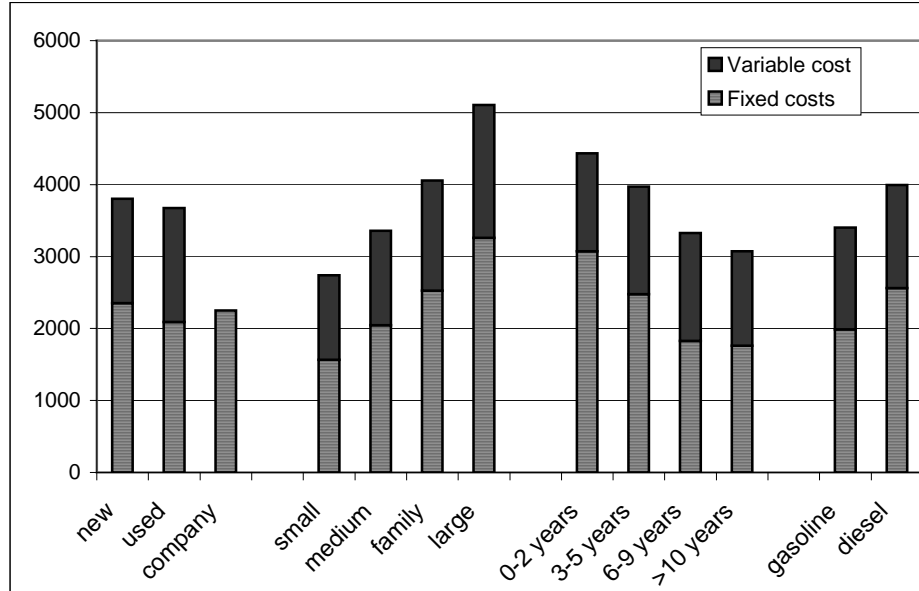


Figure 6.11 depicts the distribution of average fixed and variable costs according to the main vehicle characteristics¹²⁹. We discern respectively the purchase condition, car size, vintage and fuel type. Based on a two-side t-test with a level of significance of 0.05, we can draw the following conclusions:

First of all, since variable costs of a company car are zero, they are lower than the variable costs of new cars, which are for their part lower than used cars. However, fixed costs and average kilometre costs of new cars are higher than those of used or company cars. We also found that company cars drive more than a new or a used car.

Secondly, the fixed and variable costs, as well the total amount of kilometres driven can be categorised according to the type of the car. As a result the average kilometre costs is for all types similar, except the small cars' costs that are lower than those for large cars.

Thirdly, the fixed and total costs, as well the total amount of kilometres driven can be ordered according to their vintage. Although the variable costs of an old

¹²⁹ We also distributed the mean of annual kilometres driven and the average according to these characteristics. Although these results are not shown, we incorporate them in our discussion.

car are lower than these costs for young or medium cars (but not for recent cars), the average kilometre cost is the highest for old cars.

Finally, the fixed and total costs of a gasoline car are lower than those for a diesel car. However, since diesel cars drive more than a gasoline car, the total cost per kilometre driven in a diesel car is lower than a gasoline car.

To conclude the summary statistics of the car sample, Table 6.4 ranks the calculated cost values across different percentile levels. We observe that twenty-five percent of the cars in our sample have a total annual cost of more than 4,395 euro. Moreover, the total km cost of five percent of the cars in our sample is more than 0.85 euro per kilometre, reaching a maximum value of more than four euro.

Table 6.4: Percentile ranking of car sample

| | Min. value | 5% value | 25% value | Median value | 75% value | 95% value | Max. value |
|--------------------------------|---------------|-------------|--------------|-----------------|--------------|--------------|---------------|
| Fixed costs (in €/year) | 938.06 | 1,234.23 | 1,665.6 | 2,047.74 | 2,638.17 | 3,852.93 | 7,618.51 |
| Variable cost (in €/year) | 0.00 | 0.00 | 712.28 | 1,230.82 | 1,895.72 | 3,392.51 | 9,003.37 |
| Total cost (in €/year) | 1,245.36 | 1,889.15 | 2,539.31 | 3,388.77 | 4,395.48 | 6,592.03 | 12,206.93 |
| Annual km travelled | 900 | 3,786 | 9,532 | 14,908 | 21,000 | 40,000 | 86,000 |
| Var. km cost (in €/100 km) | 0.00 | 0.00 | 7.40 | 9.19 | 11.05 | 14.86 | 38.57 |
| Total km cost (in €/100 km) | 2.55 | 13.16 | 22.35 | 29.75 | 41.15 | 85.45 | 403.95 |

6.5.2 Car ownership

Number of cars owned and household characteristics

Table 6.5: Summary statistics of households and number and car

| | "No-car" sub-sample | "One-car" sub-sample | "Two-cars" sub-sample | "Three-cars" sub-sample | Total sample |
|------------------------------|---------------------------|-------------------------|--------------------------|----------------------------|--------------------------|
| Number of observations | 280.00 | 1,073.00 | 394.00 | 39.00 | 1786.00 |
| | Mean (Standard deviation) | | | | |
| Annual income (in €) | 13,920.21 (6,105.17) | 21,778.27 (9,288.63) | 33,590.35 (11,769.79) | 46,604.10 (15,165.56) | 23,694.23 (11,971.35) |
| Average size | 1.53 (0.87) | 2.45 (1.12) | 3.34 (1.05) | 3.69 (1.06) | 2.53 (1.21) |
| % with size ≤ 2 members | 62.86 | 17.33 | 0.25 | 2.56 | 20.38 |
| % with size > 2 members | 9.29 | 37.19 | 74.87 | 92.31 | 42.33 |
| % with children < 6 years | 2.50 | 12.95 | 22.08 | 0.00 | 13.04 |
| % with head ≥ 65 years | 48.57 | 22.46 | 5.08 | 5.13 | 22.34 |
| % with head <25 years | 7.50 | 15.00 | 21.32 | 2.56 | 14.95 |
| % living in urban area | 28.21 | 21.81 | 17.01 | 25.64 | 21.84 |
| % living in rural area | 54.29 | 59.18 | 66.50 | 58.97 | 60.02 |
| % with male head | 53.21 | 85.83 | 94.92 | 92.31 | 82.86 |

Table 6.5 presents the distribution of households based on car ownership. The average household in our sample consists of 2.53 members and has an annual

income of 23,694.23 euro. On the one hand, we see that car ownership is more prevalent as a household's income increases (i.e. the income of a no-car household is less than 14,000 euro, while three-car households have an income of almost 47,000 euro). Next to the income, there is also a positive relation between car ownership and the household's size (i.e. more than sixty percent of the no-car households are singles, while more than ninety percent of the three-car households consist of more than two members). On the other hand, owning no car is likely to occur when the household's head is an elderly or a female.

Number of cars owned and car use and costs

Table 6.6 presents the self-reported average costs and use across the number of cars owned¹³⁰.

Table 6.6: Summary statistics of number of cars, their use and costs

| | "One-car" sub-sample | "Two-cars" sub-sample | "Three-cars" sub-sample | Total sample |
|---------------------------------------|---------------------------|--------------------------|----------------------------|--------------------------|
| | Mean (Standard deviation) | | | |
| Annual fixed car costs (in €) | 2,245.22 (847.02) | 4,436.54 (1,189.32) | 6,913.01 (1,928.57) | 2,478.57 (1,758.89) |
| Annual variable car costs (in €) | 1,402.55 (1,000.32) | 2,801.12 (1,608.6) | 4,917.48 (1,894.19) | 1,567.95 (1,493.29) |
| Annual kilometres driven | 14,393.69 (8,668.76) | 35,996.25 (16,859.54) | 56,024.22 (18,783.4) | 18,509.29 (17,328.77) |
| Variable km cost (in €/100 km) | 9.59 (3.38) | 8.39 (3.47) | 9.03 (2.77) | 7.81 (4.61) |
| Total km cost (in €/100 km) | 31.7 (21.79) | 23.12 (9.39) | 22.46 (6.1) | 24.64 (20.76) |
| Annual fuel consumption (in litre) | 1,189.81 (837.22) | 2,715.93 (1,252.43) | 4,233.11 (1,341.66) | 1,406.40 (1,302.38) |

¹³⁰ Note that the no-car household's category is not displayed since all use and cost values are zero. However, this category has been taken into account to calculate the average values of the entire sample.

The average household in our sample reports to drive annually 18,509.29 kilometres at a total kilometre cost of 24.64 eurocent. Furthermore, the reported fixed costs are higher than the variable costs (i.e. 2,478.57 versus 1,567.95). Finally, the average household's car use consumes 1,406.40 litres of fuel per year. When we consider car use within the different sub-samples of car ownership, we see that the total kilometre cost is the highest for one-car households (i.e. 31.70 eurocent). This is a result of a lower use of the single car, compared to the use of an average car in two-car and three-car households.

6.5.3 Car use and costs

Car use and costs according to annual household's income level

Table 6.7 relates the car use, total car cost and fuel consumption across the household's income level. We observe that households with a higher income are likely to drive more, thus spend more money and consume more fuel.

Table 6.7: Summary statistics of car use and costs by household's income

| Annual Income (in euro) | N° observations | Annual total cost (in euro) | Annual kilometres travelled (in km) | | Annual fuel consumption (in km) |
|-------------------------|-----------------|-----------------------------|-------------------------------------|----------------------|---------------------------------|
| | | | Mean | (standard deviation) | |
| 0,00 - 8924,16 | 119 | 564.84 (1,033.37) | 2,908.02 | (5,875.81) | 228.57 (471.44) |
| 8924,52 - 22310,4 | 851 | 1,873.31 (1,374.40) | 12,110.72 | (13,084.52) | 926.11 (994.75) |
| 22310,76 - 37184,04 | 636 | 3,044.93 (1,421.84) | 24,577.88 | (16,594.23) | 1,848.78 (1,226.81) |
| 37184,04 - 59494,44 | 154 | 4,482.21 (1,693.57) | 37,355.97 | (18,870.44) | 2,845.15 (1,342.09) |
| >59494,44 | 26 | 5,218.10 (3,441.02) | 44,400.04 | (29,355.56) | 3,536.37 (2,357.84) |

Car use and costs according to age category of household's head

Table 6.8 presents the car use, total car cost and fuel consumption according to the age category of the household's head. We observe that households with young or elderly heads are likely to consume less fuel.

Table 6.8: Summary statistics of car use and costs by age of household's head

| Age of household's head | N° observations | Annual total cost | Annual kilometres travelled (in km) | Annual fuel consumption (in km) |
|---------------------------|-----------------|---------------------|-------------------------------------|---------------------------------|
| | | (in euro) | | |
| Mean (standard deviation) | | | | |
| <25 years | 14 | 1,471.26 (1,175.31) | 18,928.57 (18,857.62) | 1,302.29 (1,160.85) |
| 25-34 years | 253 | 2,807.35 (1,453.89) | 24,776.8 (17,568.85) | 1,803.89 (1,264.04) |
| 35-44 years | 370 | 2,924.63 (1,639.44) | 23,586.86 (16,963.36) | 1,801.56 (1,306.20) |
| 45-64 years | 750 | 2,659.37 (1,877.22) | 19,874.55 (18,945.13) | 1,520.01 (1,429.74) |
| ≥65 years | 399 | 1,544.90 (1,457.77) | 7,580.07 (9,227.04) | 601.60 (732.20) |

Car use and costs according to sex of household's head

Table 6.9 presents the car use, total car cost and fuel consumption according to the sex of the household's head. We observe that car use and fuel consumption of households with a female head are half as much as households with a male head.

Table 6.9: Summary statistics of car use and costs by sex of household's head

| Sex of household's head | N° observations | Annual total cost | Annual kilometres travelled (in km) | Annual fuel consumption (in km) |
|---------------------------|-----------------|---------------------|-------------------------------------|---------------------------------|
| | | (in euro) | | |
| Mean (standard deviation) | | | | |
| Male | 1,481 | 2,719.95 (1,727.12) | 20,383.45 (17,698.97) | 1,552.36 (1,333.35) |
| Female | 305 | 1,297.27 (1,391.37) | 9,846.36 (14,970.81) | 728.53 (1,084.16) |

Car use and costs according to household's size

Table 6.10 presents the relationship between car use and the household's size. Clearly, there exists a positive relation between them in our sample: while singles consume 632.87 litres of fuel, households with more than four members consume 2,297.76 litres. Furthermore, we observe that for households with less

than four members, the fuel consumption per person is quite equal (± 600 liters).

Table 6.10: Summary statistics of car use and costs by household's size

| Household's size | N° observations | Annual total cost | Annual kilometres travelled (in km) | Annual fuel consumption (in km) |
|------------------|-----------------|---------------------|-------------------------------------|---------------------------------|
| | | (in euro) | Mean (standard deviation) | |
| one-member | 364 | 1,106.85 (1,245.23) | 8,521.87 (14,360.35) | 632.87 (1,051.54) |
| two-members | 666 | 2,335.19 (1,455.14) | 15,036.23 (13,778.81) | 1,157.73 (1,042.51) |
| three-members | 343 | 3,128.33 (1,880.32) | 24,872.64 (18,385.51) | 1,883.07 (1,403.18) |
| four-members | 297 | 3,315.63 (1,697.07) | 27,362.43 (18,344.19) | 2,045.09 (1,336.22) |
| >four-members | 116 | 3,517.45 (1,630.78) | 29,456.73 (20,452.59) | 2,297.76 (1,571.39) |

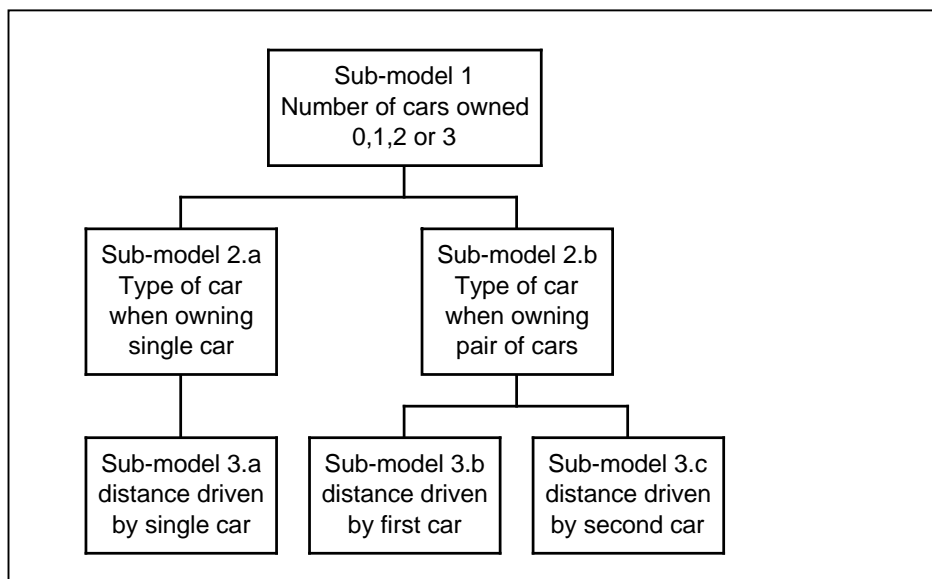
6.6 Model specification

6.6.1 General structure

Figure 6.12 shows the outline of the full model, which consists of six sub-models. They estimate:

- The number of cars owned by each household;
- The type of car owned by the household owning one car;
- The type of car for each car (up to two) owned by households with two or more cars;
- The number of kilometres travelled by households owning one car;
- The number of kilometres travelled by households owning two cars.

Figure 6.12: Outline of car ownership-and-use model



6.6.2 Model formulation

Decision-maker

The decision-maker or unit of analysis for all sub-models is the household. In sub-model 1, the sample consists of 1,786 households, while in the sub-models

of owning one and two cars respectively 1,073 and 433 households are taken into consideration.

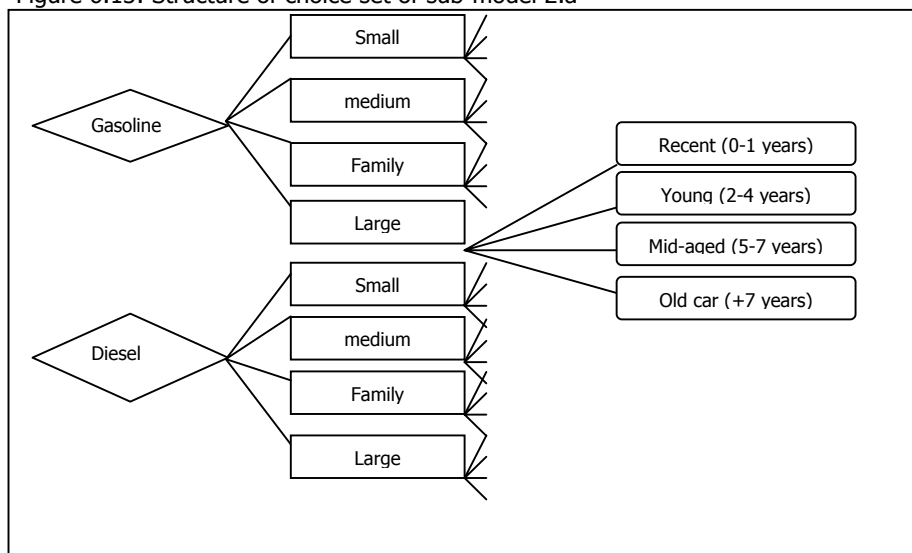
Although our model predicts choices of individual households, our ultimate goal is to estimate aggregate forecasts. In Chapter 7, we will discuss how we obtain aggregate results.

Alternatives

Since we are using the result of the HTS, the household's actual choice is observed. In the first sub-model, the discrete choice set consists of four alternatives, namely to own no, one, two and three cars.

Figure 6.13 presents the choice set of the second sub-model, which contains 32 car type alternatives. Each vehicle type consists of the fuel type, car type and age. We only consider gasoline and diesel as fuel types¹³¹. Furthermore four car types can be distinguished: small, medium family and large cars. Finally, we include four age categories: recent, young, mid-aged and old cars. Note that, although available, we do not include make and model characteristics as choice alternatives. This can be motivated by our research objective, which is aimed at estimating fuel consumption, rather than developing a make choice model.

Figure 6.13: Structure of choice set of sub-model 2.a

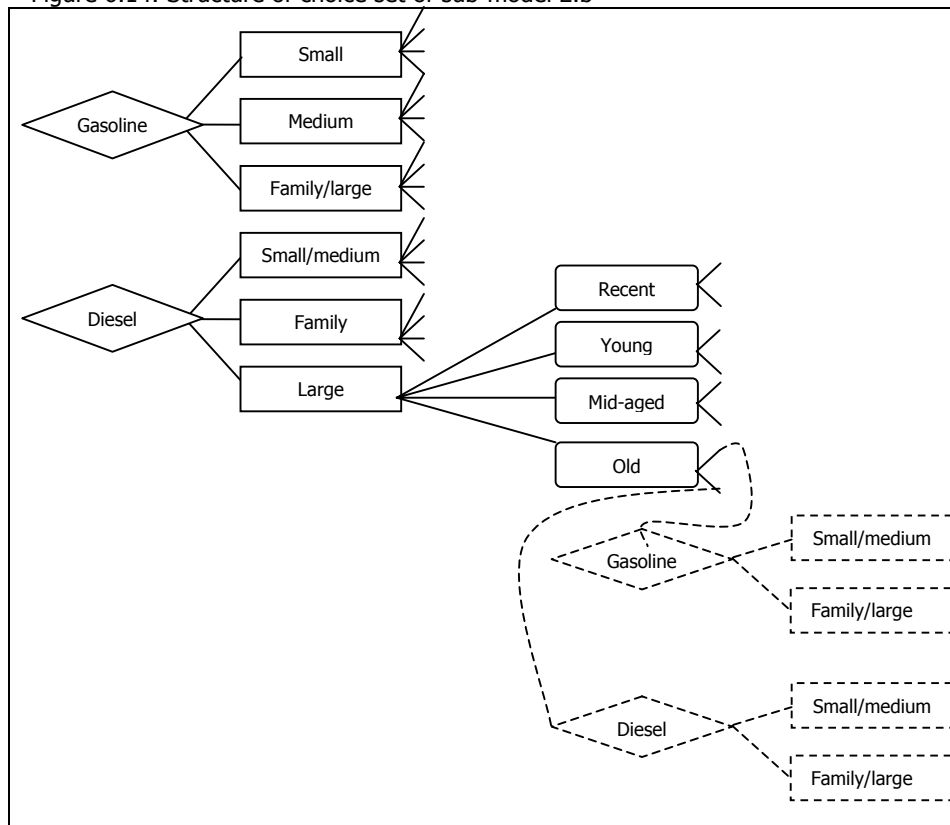


¹³¹ Due to its limited market share, LPG is not taken into account.

In sub-model 2.b, households choose amongst pairs of cars. The cars are categorised according to their annual number of kilometres driven, which implies that the mostly used car is considered as the first car. The first car has the same characteristics as in the first sub-model (i.e. fuel type, car type and vintage) while the second car characteristics consist of two fuel types and two size types (i.e. small or medium and large or family). This gives us 192 possible pairs. Due to the limited sample size, only 105 alternatives were taken into consideration. An example of an alternative includes: a pair of a recent large diesel car and a family or large gasoline car.

Figure 6.14 depicts the building process of the choice set. Note that the dotted line represents characteristics of the second car.

Figure 6.14: Structure of choice set of sub-model 2.b



Attributes

Train (1986) and Choo and Mokhtarian (2004) gave an overview of which attributes were taken into account in different car type choice models. Train concluded that on the one hand, price, variable costs, vintage and some measure of size appear the main vehicle attributes affecting consumers' choices, while on the other hand engine power plays little or no part in households' decisions which car to own. Furthermore, he found that the models are quite consistent in their selection of households' characteristics; namely income, number of household members, age of household head and the number of cars owned were significantly determining the choice of car type.

We consider the annual fixed costs, the variable costs and the socio-economic variables of the HTS as potential attributes of the first sub-model of car ownership.

As given in Table 6.11, we use the socio-economic variables age and sex of household's head, household's size, area of living, place of residence and availability¹³² of public transport as categorical variables.

Table 6.11: Value of socio-economic categorical data in HTS

| | Age category of head | Sex of head | Number of members | Area of living | Place of residence | Availability of public transport |
|---|----------------------|-------------|-------------------|--|---------------------|----------------------------------|
| 1 | <25 years | Male | One | Town centre | Rural area | 0-249 m |
| 2 | 25-34 years | Female | Two | Not in town centre, neither in remote area | Urban area | 250-499 m |
| 3 | 35-44 years | | Three | Remote area | Large agglomeration | 500-999 m |
| 4 | 45-64 years | | Four | | | 1 km-1,999 km |
| 5 | >64 years | | More than four | | | 2 -5 km |
| 6 | | | | | | More than 5 km |
| 7 | | | | | | no idea |

¹³² Note that the "Area of living"-variable is based on the perception of the inquired households while the "Place of residence" is based on the postal code.

We now transform these socio-economic variables into several dummy variables. Table 6.12 summarizes these transformations.

Table 6.12: Definition of socio-economic dummy variables

| HTS variable | Transformation rule | Attribute |
|----------------------------------|--|--|
| Age category of household's head | If age category =1 If age category =5 else | Dummy young =1 Dummy elderly =1 Dummy midlife =1 |
| Household's size | If size=1 If size =2 | Dummy single =1 Dummy duo =1 |
| Number of children | If number >0 | Dummy child = 1 |
| Area of living | If area of living =1 If area of living =3 | Dummy urban =1 Dummy rural =1 |
| Place of residence | If place of residence=1 If place of residence=3 | Dummy urban2 =1 Dummy rural2 =1 |
| Availability of public transport | If availability < 3 | Dummy public transport=1 |
| Sex of household | If sex = male | Dummy male =1 |

In the sub-models of car type choice and car use, we include the same socio-economic attributes of the first sub-model, complemented with car-related variables the fixed costs and the average car kilometre costs.

Table 6.13 shows the car-related variables, which were transformed in dummy variables. We distinguish dummy variables for the make, vintage, size and purchase condition of both the first as the second car.

Table 6.13: Definition of car-related dummy variables

| HTS variable | Transformation rule | Attribute |
|--------------------|--|--|
| Make of car | If Make = Volkswagen, Opel, BMW, Audi or Mercedes If Make = Peugeot, Citroën or Renault If Make = Nissan or Toyota Else and not Ford, | Dummy German =1 Dummy French =1 Dummy Japan =1 Dummy other=1 |
| Vintage | If Age = 0-1 year If Age = more than seven years | Dummy recent =1 Dummy old =1 |
| Purchase condition | If car is bought second-hand If car is company car If car is new-bought | Dummy second-hand = 1 Dummy company car = 1 Dummy new-bought = 1 |
| Size | If car is family car If car is a small car | Dummy family car =1 Dummy small car =1 |

Decision rules

As described in the previous chapter, we use the random utility theory and estimate the discrete choice of how many and which cars to own by multinomial logit. In the following paragraph, we describe the estimation results of each sub-model.

Estimation process

The most commonly used method of MNL model coefficients estimation is the maximum likelihood approach. The likelihood function is the probability (density) of obtaining the observed values, from a certain population, when this probability (density) is regarded as a function of the parameter(s) of the population and not as a function of the sample data. In other words, maximum likelihood estimates are that set of population parameters that generates the observed sample most often¹³³. A searching algorithm to optimize the likelihood function¹³⁴ is used to maximize the probability that the observed values are realized. Standard statistical software packages can perform such a maximum likelihood fit. However, they are not able to deal with alternative-specific parameters. Since the literature describes that the number and types of cars owned is affected by generic parameters (i.e. household characteristics) as well as alternative-specific parameters (car characteristics), we use the statistical software program Biogeme¹³⁵, which was developed to estimate GEV models.

We use the following criteria to evaluate our parameter estimates:

- The adjusted parameter of multiple determination (adjusted F^2 -value) to measure the degree of association between the observed and

¹³³ For a detailed discussion of the statistical estimation procedures of the MNL model and the maximum likelihood, we refer to Louviere, Hensher and Swait (2003) or Ben-Akiva and Lerman (1985).

¹³⁴ For instance, Biogeme can use four different optimization algorithms: CFSQP, DONLP2, SOLVOPT and BIO.

¹³⁵ For more information about Biogeme, we refer to Bierlaire (2003).

expected values of the dependent variable. Hereby it is important to note that the adjusted F^2 -value of discrete choice models is not comparable with the R^2 -value of ordinary least squares (OLS) regression. While the OLS R^2 -value explains the degree to which the dependent variable is explained by the estimated model, the F^2 -value of discrete choice models is based on the relationship among the log-likelihood values. Although this value is of limited value in assessing the quality of an estimated model, we use this value to compare several models with the same data and with the same set of alternatives, whereby the model with the highest F^2 -value fits the data best and is preferred to the others. Clearly, F^2 -values as high as R^2 -values should not be expected. Although there exists no guidelines for a "good" F^2 -value, IT Transport (2005,29) states:

"A F^2 -value between 0.2 to 0.4 as can be considered to be an extremely good fit."

- We use the log-likelihood ratio (LR) test as a model selection criterion, more specifically to compare two models with the same data and choice set, but a different number of estimated parameters. The statistic used is χ -squared distributed with the difference in number of estimated parameters as the degrees of freedom. If the value of the LR-test exceeds the critical chi-squared value then the restricted model is rejected.
- The sign and magnitudes of the parameters. Are they as expected by the researcher and in line with the literature?
- We use the t-test hypothesis to determine statistical significance of the parameters, more specifically a threshold value of 1.96 (.95 level of significance)

For the estimation of the demand equation (annual number of kilometres travelled) we use the instrumental variable approach¹³⁶. To this end, we employ a standard statistical software package, more specifically, SPSS.

6.7 Estimation results

In this section we discuss the estimation results of our car ownership-and-use model, more specifically the following sub-models:

- Sub-model 1: Number of cars owned;
- Sub-model 2.a: Type of single car owned;
- Sub-model 2.b: Type of pair of cars owned;
- Sub-model 3.a: Use of a single car;
- Sub-model 3.b: Use of first car;
- Sub-model 3.c: Use of second car

In our discussion, we first consider the general results of the model estimations. Subsequently, we discuss the results of the parameter estimations. Note that different model specifications were tested (for instance linear versus logarithmic variables), but only the best models are presented.

6.7.1 Sub-model 1: Number of cars owned

General estimation results (sub-model 1)

This sub-model estimates the utility functions for owning zero, one, two or three cars. As was shown in (5.14) and (5.16), these utilities are used to calculate the probability that a household choose one, and only one, of these alternatives. Table 6.14 reports the general results of the maximum likelihood estimation of this sub-model. The Null log-likelihood, which is the log-likelihood of the sample for a MNL Logit model where all parameters are zero, has a value of -2,474.54. The log-likelihood of the sample for our estimated model, which is

¹³⁶ We also used an ordinary least squares estimation and employed a correction term to account for correlation of the variables with the error term. However, this correction term turned out to be insignificant.

called the Final log-likelihood, values -1,248.94. Consequently, the adjusted F^2 -value, calculated as one minus the ratio of the Null and Final log-likelihood is 0.49.

Table 6.14: General estimation results (sub-model 1)

| Model | Multinomial Logit |
|--------------------------------|-------------------|
| Number of estimated parameters | 19.00 |
| Sample size | 1,785.00 |
| Number of alternatives | 4.00 |
| Null log-likelihood | -2,474.54 |
| Final log-likelihood | -1,248.94 |
| Adjusted F^2 -value | 0.49 |

Parameter estimation results (sub-model 1)

Table 6.15 presents the variables entering the first sub-model and their estimated parameters:

- The estimated values of the income parameter for car ownership are positive, which implies that a rise in household's income results in an increase in the probability of owning one or more cars. Moreover, the value for the three-car is larger (i.e. 0.00030) than that for the two-car (i.e. 0.00024) and one-car alternative (i.e. 0.00016). This indicates, as expected, that an increase in a household's income would increase its probability of choosing three over two cars, two over one car and one over no car.
- The variable kilometre cost is expressed as eurocent per kilometre. This variable enters the utility functions as the natural logarithm of the variable kilometre cost. The estimates value -0.20094 for owning one car, -1.18074 for owning two cars and -2.96777 for owning three cars. We observe an opposite effect compared to the income variable: higher variable costs reduces the probability of owning three cars over two, two over one and one over none.
- The fixed cost enters the utility functions of car ownership as the natural logarithm of the fixed costs. The estimated value is negative, which implies that a rise in household's income results in a decrease of the probability of owning one or more cars.
- The sex of the household's head enters the utility functions of car ownership as a dummy variable male head, with a positive sign. This implies that households with a male head have a higher probability of owning one or more cars.
- The dummy for elderly household's head has a more negative value for the three-car (i.e. -2.07336) than that for the two-car (i.e. -2.04895) and one-car alternative (i.e. -0.66143). Consequently, when the household's head is an elderly, there is a decreasing probability of owning three cars over two, two over one and one over none cars.

- The dummies for singles have a negative sign. This implies that singles have a higher probability of owning no cars.
- The dummies for duo's and households with a middle-aged head have a negative sign for the two-car and three-car utility functions. Consequently, they have a higher probability of owning zero or one car over owning two or more cars. Moreover, duos have a higher probability of owning two cars than owning three cars.
- Somewhat surprisingly, we observe a negative sign of the dummy variable for children of the three-car utility function. An explanation is that we only take into consideration children aged below six years. This means that these households are rather young households, which implies that there are no other household members except the parents that require a car.
- The parameter of dummy variable for the no-car utility function has a positive sign, which implies that households living in urban areas are less likely to own cars. This is not surprisingly, since urban areas have a better public transport service and activity zones are more concentrated compared to rural areas.

Table 6.15: Values of estimated parameters (sub-model 1)

| Variable | Parameters of one-car alternative | Parameters of two-car alternative | Parameters of three-car alternative | Parameters of no-car alternative |
|-----------------------|-----------------------------------|-----------------------------------|-------------------------------------|----------------------------------|
| Income | 0.00016 | 0.00024 | 0.00030 | |
| Ln (variable km cost) | -0.20094 | -1.18074 | -2.96777 | |
| Ln (fixed cost) | -0.11086 | -0.11086 | -0.11086 | |
| Dummy male head | 0.84976 | 0.84976 | 0.84976 | |
| Dummy elderly | -0.66143 | -2.04895 | -2.07336 | |
| Dummy single | -1.00646 | -5.35481 | -4.41610 | |
| Dummy duo | | -0.73725 | -2.70496 | |
| Dummy midlife | | -0.52067 | -0.52067 | |
| Dummy child | | | -8.03982 | |
| Dummy urban area | | | | 0.39198 |

Table 6.16 presents the corresponding t-test of the estimated parameters¹³⁷. We observe that all estimates are statistically significant on 95% level of confidence (i.e. they all values above 1.96), except for the parameter for the natural logarithm of the fixed cost, which is significant on 90% level on confidence¹³⁸ (t-value=-1.6839).

Table 6.16: t-values of estimated parameters (sub-model 1)

| Variable | t-values of no- car alternative | t-values of one-car alternative | t-values of three-car alternative | t-values of three-car alternative |
|-----------------------|---------------------------------------|---------------------------------------|---|---|
| Income | | 5.7639 | 8.2601 | 9.2323 |
| Ln (variable km cost) | | -4.8927 | -10.6251 | -9.6950 |
| Ln (fixed cost) | | -1.6839 | -1.6839 | -1.6839 |
| Dummy male head | | 4.5698 | 4.5698 | 4.5698 |
| Dummy elderly | | -4.1349 | -6.3227 | -2.4172 |
| Dummy single | | -5.3391 | -4.9755 | -3.4202 |
| Dummy duo | | | -4.7635 | -3.3064 |
| Dummy midlife | | | -3.0587 | -3.0587 |
| Dummy child | | | | -30.8251 |
| Dummy urban area | 2.2093 | | | |

¹³⁷ These are the robust t-test values. Results of a robust t-test are based on a variance-covariance matrix, which is made robust against misspecification errors related with the characteristics of the postulated error term distributions. For more information, we refer to Greene (1997).

¹³⁸ However, this estimate passed on 95 % level the t-test (t-value= -2.2002), but failed for the robust t-test.

6.7.2 Sub-model 2.a: Type of a single car owned

General estimation results (sub-model 2.a)

A one-car household has a choice of which type of car to own. This sub-model calculates the probability that a one-car household owns a specific type of car. These estimation results enable us to calculate the fuel efficiency of a car owned by one-car households. Table 6.17 presents an adjusted F^2 -value of 0.07. The high number of alternatives and the limited sample size can explain this low value. If we perform a LR-test and compare the full model with the null model, the null model is rejected:

$$(3,718.33-3,471.62)=247.11 > \chi(.95, 12)=21.03$$

Table 6.17: General estimation results (sub-model 2.a)

| Model | Multinomial Logit |
|--------------------------------|-------------------|
| Number of estimated parameters | 12.00 |
| Sample size | 1,073.00 |
| Number of alternatives | 32.00 |
| Null log-likelihood | -3,718.73 |
| Final log-likelihood | -3,471.62 |
| Adjusted F^2 -value | 0.07 |

Parameter estimation results (sub-model 2.a)

Table 6.18 presents the variables entering the sub-model, their estimated parameters, their standard error term and the corresponding robust t-test.

First, we discuss the sign and magnitude of the estimated parameters:

- We observe a positive value for the household's income parameter (i.e. 0,00006) and a negative value for the variable kilometre cost parameter (i.e. -14.91374). The positive income parameter indicates that an increase in income increases the household's probability of choosing that alternative, while the negative variable cost parameter would have the opposite effect.

- The negative sign of the fixed cost parameters for both diesel and gasoline cars indicate that an increase in fixed costs decreases the probability that households choose that alternative. The value for gasoline cars is lower (i.e. -0.00067) than for diesel cars (i.e. -0.00017), indicating that an increase in fixed costs decreases the probability of choosing gasoline cars more than for diesel cars.
- There is a higher probability that families choose diesel car alternatives compared to gasoline cars (dummy variable values 0.42383), while German and French cars are preferred as diesel cars compared to other car makes: the dummy variable for German cars values 0.93008 for diesel cars, while the dummy variable for French cars has a negative value for gasoline cars (i.e. -0.69842).
- There is a higher probability that households with an elderly household's head choose gasoline cars compared to households of middle-aged household's head. Moreover, the latter households have a higher probability to choose gasoline cars compared to households with a young household's head: the dummy variable elderly household's head has a higher positive value for gasoline cars (i.e. 2.91796) compared to the dummy variable midlife (i.e. 2.28855). The young household's head has a negative value for diesel cars (i.e. -1.91875).
- As expected, we observe a positive value for the second-hand parameter (i.e. 1.38942), which indicates that if the car is second-hand, the probability increases of owning a car older than two years.
- The negative value for the newly bought parameter (i.e. -1.89855) indicates that if the car is newly bought car, the probability increases of owning a small, recent gasoline car.

Finally, as given by Table 6.18, we observe that all values for the robust t-test are higher than 1.96, which implies that the estimates are statistically significant on 95% level.

Table 6.18: Detailed estimation results (sub-model 2.a)

| | Parameter estimate | Standard error | Robust t-test |
|--|--------------------|----------------|---------------|
| Variable kilometre cost | -14.91374 | 4.92977 | -3.02524 |
| Income | 0.00006 | 0.00001 | 10.84065 |
| Fixed cost (gasoline car alternatives) | -0.00067 | 0.00009 | -7.36353 |
| Fixed cost (diesel car alternatives) | -0.00017 | 0.00007 | -2.22917 |
| Dummy household's size > 2 (diesel car alternatives) | 0.42383 | 0.13759 | 3.08026 |
| Dummy German car (diesel car alternatives) | 0.93008 | 0.15357 | 6.05662 |
| Dummy French car (gasoline car alternatives) | -0.69842 | 0.20136 | -3.46859 |
| Dummy young household head (diesel car alternatives) | -1.91875 | 0.31688 | -6.05507 |
| Dummy midlife household head (gasoline car alternatives) | 2.28855 | 0.28304 | 8.08548 |
| Dummy elderly household's head (gasoline car alternatives) | 2.91796 | 0.30946 | 9.42931 |
| Dummy second-hand car (alternatives vintage > 2 years) | 1.38942 | 0.22430 | 6.19447 |
| Dummy newly-bought car (if not a small gasoline car aged < 3 years) | -1.89855 | 0.24726 | -7.67841 |

6.7.3 Sub-model 2.b: Type of pair of cars owned

General estimation results of (sub-model 2.b)

A two-car household has a choice of which pair of cars to own. This sub-model estimates the probability that a two-car household chooses to own that particular pair of cars. Due to the limited sample size, the three-car households are not estimated separately. Therefore, we include them in our two-car household's sample. Our estimation results enable us to calculate the fuel efficiency of a pair of cars. For three-car households, we apply the same fuel efficiency values as estimated for a pair of cars.

As given in Table 6.19, the adjusted F^2 -value is 0.05. Similar to sub-model 2.a, the high number of alternatives and the limited sample size explain this low value. If we perform a LR-test and compare the full model with the null model, the null model is rejected:

$$(2,015.16-1,913.00)=102.16 > \chi(.95, 10)=18.31$$

Table 6.19: General estimation results (sub-model 2.b)

| Model | Multinomial Logit |
|--------------------------------|-------------------|
| Number of estimated parameters | 10.00 |
| Sample size | 433.00 |
| Number of alternatives | 105.00 |
| Null log-likelihood | -2,015.16 |
| Final log-likelihood | -1,913.00 |
| Adjusted F^2 -value | 0.05 |

Parameter estimation results (sub-model 2.b)

Table 6.20 presents the variables entering this sub-model, their estimated parameters, their standard error term and the corresponding robust t-test. Let us first discuss the values of the estimated parameters:

- Fixed cost variables are defined as the sum of the costs of both cars of that pair. We distinguish three different fixed costs parameter estimates in our estimation:
- Parameter of fixed costs if first car is younger than five years values -0.00015
- Parameter of fixed costs if first car is older than five years and second car is a gasoline car values -0.00022
- Parameter of fixed costs if first is older than five years and second car is a diesel car values -0.00037

Consequently, an increase in the fixed costs for young car alternatives would decrease the probability of owning young cars not as much as compared to a similar increase in fixed costs for owning old cars. Moreover, for these older car alternatives, an increase in the fixed costs would decrease the probability in the case the second car is a gasoline car not as much as compared to the alternatives of a second diesel car.

Table 6.20: Detailed estimation results (sub-model 2.b)

| | Parameter estimate | Standard error | t-test |
|--|--------------------|----------------|----------|
| Income | 0.00002 | 0.00000 | 4.43051 |
| Variable km cost | -5.98043 | 2.29817 | -2.60226 |
| Fixed costs (for alternatives of a first car younger than five years) | -0.00015 | 0.00006 | -2.38512 |
| Fixed costs (for alternatives of a first car older than five years and second car is a gasoline car) | -0.00022 | 0.00008 | -2.60514 |
| Fixed costs (for alternatives of a first car older than five years and second car is a diesel car) | -0.00037 | 0.00008 | -4.41673 |
| Dummy second car is German | -0.44926 | 0.20227 | -2.22112 |
| Dummy first car is second-hand | 1.17614 | 0.24851 | 4.73268 |
| Dummy second car is other brand | 1.42891 | 0.27950 | 5.11245 |
| Dummy first car is company gasoline car | -1.67909 | 0.37285 | -4.50340 |
| Dummy children (for alternatives of a small or medium sized second car) | 0.95925 | 0.27091 | 3.54090 |

6.7.4 Sub-model 3.a: Use of a single car

General estimation results (sub-model 3.a)

Table 6.21 describes the general estimation results of this sub-model. We define the natural logarithm of the annual kilometres travelled as the dependent variable.

Table 6.21: General estimation results (sub-model 3.a)

| Model | Two-step least squares |
|--------------------------------------|--|
| Number of estimated parameters | 12.00 |
| Dependent variable | Ln (annual kilometres travelled by single car) |
| Sample size | 1,073.00 |
| F ² -value ¹³⁹ | 0.9964 |

Parameter estimation results (sub-model 3.a)

The parameters were estimated with an instrumental variables approach or two-step least squares estimation, which is required to deal with endogenous variables such as variable kilometre cost.

¹³⁹ The F²-value of the estimation of car use can not be compared to the F²-value of the previous models. Moreover, since we use a regression through the origin (the no-intercept model), these values can not be compared to R-square for models that include an intercept.

Table 6.22 presents the variables entering the sub-model, their estimated parameters, their standard error term and the corresponding t-test. We distinguish three categories of variables:

- Cost variables, which include the natural logarithms of the variable kilometre cost, the fixed costs for low-income (i.e. annual income below 15,617.45 euro) and the fixed costs for high-income households. We observe a positive value for the fixed costs parameters, which implies that increasing the fixed costs, increases the total number of kilometres travelled. Moreover, this increase is larger for high-income households compared to low-income households (values are respectively 0.55260 and 0.56128)
- Socio-economic characteristics of households, which include the natural logarithm of household's annual income and dummy variables for households with more than two members, for households living in urban area and for households with an elderly household's head and a dummy variable for households with a young household's head. We see that households with an elderly household's head drive less, while households with a young household's head drive more (values are respectively -0.24501 and 0.17939)
- Car characteristics, which includes the natural logarithm of the total kilometres travelled by the car and dummy variables for recent and old cars, for family or large cars and a dummy variable for diesel cars. We observe that recent cars drive more (i.e. parameter estimate has a value of 0.40029) while older cars drive less (value of -0.17368). Next to the vintage of the car, also the total kilometres travelled by the car is a significant variable and has a positive value of 0.25869.

Since the values of the t-test are always lower than 0.05, we conclude that all parameter estimates are significant on 95% level.

Table 6.22: Detailed estimation results (sub-model 3.a)

| Independent variable | Parameter estimate | Standard error | t-test |
|--|--------------------|----------------|--------|
| Ln (variable km cost) | -0.07947 | 0.01338 | 0.0000 |
| Ln (fixed cost for low-income households) | 0.55260 | 0.07550 | 0.0000 |
| Ln (fixed cost for high-income households) | 0.56128 | 0.08120 | 0.0000 |
| Ln (household's income) | 0.24353 | 0.06422 | 0.0002 |
| Dummy household's size >2 members | 0.08332 | 0.04059 | 0.0404 |
| Dummy elderly household's head | -0.24501 | 0.04609 | 0.0000 |
| Dummy young household's head | 0.17939 | 0.05077 | 0.0004 |
| Dummy diesel car | 0.12080 | 0.04107 | 0.0033 |
| Ln (total kilometres travelled by the car) | 0.25869 | 0.02140 | 0.0000 |
| Dummy recent car | 0.40029 | 0.06497 | 0.0000 |
| Dummy old car | -0.17368 | 0.04576 | 0.0002 |
| Dummy family or large car | -0.10556 | 0.04402 | 0.0167 |

6.7.5 Sub-model 3.b: Use of first car

General estimation results (sub-model 3.b)

Table 6.23 presents the general estimation results of the annual number of kilometres travelled by the first car of two-car households. Recall that the sample size is 433 due to the fact that we include also the three-car households. In the case of owning three cars, we only estimate the first and the second car. The kilometres travelled by the third car or not estimated by our model. Instead, we use the average value of kilometres travelled by the third car.

Table 6.23: General estimation results (sub-model 3.b)

| Model | Two-step least squares |
|--------------------------------|---|
| Number of estimated parameters | 10.00 |
| Dependent variable | Ln (annual kilometres travelled by first car) |
| Sample size | 433.00 |
| F ² -value | 0.9982 |

Parameter estimation results (sub-model 3.b)

Table 6.24 presents the variables entering the sub-model, their estimated parameters, their standard error term and the corresponding robust t-test.

We observe the same cost variables as in the previous sub-model. However, the boundary between the low and high-income categories is now set on 29,747.37 euro. Next to the socio-economic household's characteristics and car characteristics, we now also include a characteristic of the second car, which is a significant variable for the annual kilometres travelled by the first car: the dummy variable for a family or large car has a positive value (0.10232). This implies that two-car households drive more kilometres with their first car if their second car is a family or a large car. This indicates that households prefer their most fuel-efficient car.

Table 6.24: Detailed estimation results (sub-model 3.b)

| Independent variable | Parameter estimate | Standard error | t-test |
|--|--------------------|----------------|--------|
| Ln (variable km cost) | -0.04964 | 0.00741 | 0.0000 |
| Ln (fixed cost for high-income households) | 0.47022 | 0.07757 | 0.0000 |
| Ln (fixed cost for low-income households) | 0.49478 | 0.07380 | 0.0000 |
| Ln (household's income) | 0.49783 | 0.05830 | 0.0000 |
| Dummy elderly household's head | -0.38047 | 0.09887 | 0.0001 |
| Ln (total kilometres travelled of car) | 0.08288 | 0.01966 | 0.0000 |
| Dummy recent car | 0.14897 | 0.06418 | 0.0208 |
| Dummy small car | 0.17876 | 0.07085 | 0.012 |
| Dummy diesel car | 0.15374 | 0.04849 | 0.0016 |
| Dummy other car is family or large car | 0.10232 | 0.04929 | 0.0386 |

6.7.6 Sub-model 3.c: Use of second car

General estimation results (sub-model 3.c)

Table 6.25 presents the general estimation results of the annual number of kilometres travelled by the second car of two-car household. While we have twelve significant variables for the estimation of the single car use and ten variables for the estimation of the first car use, the number of estimated parameters is in this scenario reduced to only eight.

Table 6.25: General estimation results (sub-model 3.b)

| Model | Two-step least squares |
|--------------------------------|--|
| Number of estimated parameters | 8.00 |
| Dependent variable | Ln (annual kilometres travelled by second car) |
| Sample size | 433.00 |
| F ² -value | 0.9962 |

Parameter estimation results (sub-model 3.c)

Table 6.26 presents the variables entering the sub-model, their estimated parameters, their standard error term and the corresponding robust t-test.

Table 6.26: Detailed estimation results (sub-model 3.c)

| Independent variable | Parameter estimate | Standard error | t-test |
|--|--------------------|----------------|--------|
| Ln (variable km cost) | -0.05115 | 0.02249 | 0.0235 |
| Ln (fixed cost for high-income households) | 0.77380 | 0.04829 | 0.0000 |
| Ln (fixed cost for low-income households) | 0.75635 | 0.04873 | 0.0000 |
| Dummy elderly household's head | -0.35387 | 0.13122 | 0.0073 |
| Dummy place of residence is urban | -0.18497 | 0.07661 | 0.0162 |
| Ln (total kilometres travelled of car) | 0.31265 | 0.03189 | 0.0000 |
| Dummy recent car | 0.30720 | 0.11216 | 0.0065 |
| Dummy old car | -0.28819 | 0.06734 | 0.0000 |
| Dummy small car | 0.25885 | 0.05712 | 0.0000 |

As Table 6.26 indicates, we once again distinguish parameters related to the car cost, to the car characteristics and to the socio-economic situation of the household. However, in this sub-model no income parameter appeared to be significant, while a positive parameter for living area entered the demand equation.

Table 6.27 concludes this chapter by summarising the estimated parameters of the car use models:

- The variable km cost variable has the lowest value for single cars. Consequently, an increase in the variable kilometre cost would result in a higher car use reduction for a one-car household car compared to the second and the first car of a two-car household.
- The estimated values for the fixed cost variables are the highest for the second car, followed by the single and first car. This implies that an increase in the fixed costs will result in a lower increase in the use of the first car compared to the use of the second car.
- The household's income parameter is not significant for the use of the second car. Moreover, a growth of the household income would result in an increase in the use of the first car of a two-car household compared to the car use of a one-car household.
- The value of the dummy variable for households with an elderly household's head is lower for the car use of two-car households compared to the single car use.
- The effect on car use of the total kilometres travelled by the car is the highest for the second car, while this variable has the lowest impact on the use of the first car.
- The value of the dummy variable for recent cars is the highest for single car use.

Table 6.27: Estimated parameters of car use model (summary)

| | Ln (Annual kilometres travelled by single car) | Ln (Annual kilometres travelled by first car) | Ln (Annual kilometres travelled by second car) |
|--|--|---|--|
| Ln (variable km cost) | -0.07947 | -0.04964 | -0.05115 |
| Ln (fixed cost for high-income households) | 0.55260 | 0.47022 | 0.77380 |
| Ln (fixed cost for low-income households) | 0.56128 | 0.49478 | 0.75635 |
| Ln (household's income) | 0.24353 | 0.49783 | |
| Dummy elderly household's head | -0.24501 | -0.38047 | -0.35387 |
| Dummy young household's head | 0.17939 | | |
| Dummy place of residence is urban | | | -0.18497 |
| Dummy household's size >2 members | 0.08332 | | |
| Ln (total kilometres travelled by the car) | 0.25869 | 0.08288 | 0.31265 |
| Dummy recent car | 0.40029 | 0.14897 | 0.30720 |
| Dummy old car | -0.17368 | | -0.28819 |
| Dummy small car | | 0.17876 | 0.25885 |
| Dummy diesel car | 0.12080 | 0.15374 | |
| Dummy family or large car | -0.10556 | | |
| Dummy other car is family or large car | | 0.10232 | |

CHAPTER 7 Simulation for Flanders

In this chapter, we describe the aggregation process of our sample to the level of Flanders as a region. Subsequently, we discuss the simulation results of the base case scenario and develop two scenarios, in which we use both fuel taxes and tradable fuel permits as policy instruments.

7.1 *Working method*

In the previous chapter, we first calculated the fixed and variable costs that households were facing in the year 2000. The households' socio-economic data, their car ownership and car use data are based on the results of the HTS for Flanders. Secondly, these data and costs were used as explanatory variables to estimate the utility functions how many and which cars to own. Using Roy's identity, we could use these utility functions to estimate the VKT demand function.

In this chapter, we aggregate our estimation results to the level of Flanders. This results in the base case scenario, which focuses on fuel consumption amongst different household categories. The level of fuel consumption is calculated as the product of the VKT and the fuel efficiency, which are estimated in respectively sub-model 3 and 2. Subsequently, we will describe two scenario's, which both involve a reduction of fuel consumption. This reduction is obtained by fuel taxes or fuel permits. We calculate the tax level by increasing the variable cost (i.e. the fuel component of the variable cost) of the different sub-models, which corresponds to a specific reduction level of fuel consumption. This trial-and-error procedure ends when the aimed reduction level is obtained. The calculation of the permit price is somewhat more complex. First, we calculate the number of permits to be issued. Subsequently, we allocate these permits amongst the different households of our sample. The free allocation of permits results in an increase in households' income, which is an explanatory variable of the different sub-models. However, contrary to the

variable costs, an increase in income results in an increase in fuel consumption¹⁴⁰. We calculate the permit price by increasing the fuel cost parameters, and consequently the income parameter of the different sub-models. This trial-and-error procedure is repeated until we obtain the desired reduction level.

7.2 Aggregation to Flemish population

Since we developed a disaggregate model, results are obtained at household level. However, we are interested in aggregate variables for Flanders. Therefore, an additional modelling phase of aggregation needs to be included. First, we formulate the problems that are related with aggregation. Secondly, we describe how to solve these problems. Finally, we discuss the robustness of our sample.

7.2.1 Problem statement

Generally, samples do not perfectly fit the population. This inconsistency is caused by the fact that corresponding segments of the sample occur in different proportions in the population. This gives biased results when statements about the whole population are made.

Nuyts and Zwerts (2002a) conclude that weighting of the HTS is necessary because of non-response and sampling error. They found that in the sample elderly and singles are underrepresented in relation to their population share. Since we excluded more than forty percent of HTS records, we expect to face similar problems.

¹⁴⁰ Consequently, the permit price level will be higher compared to taxes to obtain the same reduction target.

Table 7.1 and Table 7.2 show that the categories of young, elderly, female, single and large families are underrepresented, while the male and midlife category is overrepresented.

Table 7.1: Sample and population proportion by age of household's head

| Age of Household's head | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
|-------------------------|-----------|-------------|-------------|-------------|-----------|
| Sample proportion | 0.56 | 13.21 | 19.32 | 52.18 | 14.73 |
| Population proportion | 2.20 | 15.56 | 21.25 | 34.34 | 26.64 |

Table 7.2: Sample and population proportion by household's size and sex of household's head

| Number of household members | 1 | 2 | 3 | 4 | >4 | Total |
|-----------------------------|-------|-------|-------|-------|------|-------|
| Male household's head | | | | | | |
| Sample proportion | 9.24 | 33.93 | 17.19 | 16.13 | 6.44 | 82.93 |
| Population proportion | 12.17 | 28.12 | 15.14 | 14.22 | 6.76 | 76.41 |
| Female household's head | | | | | | |
| Sample proportion | 11.09 | 3.42 | 2.02 | 0.50 | 0.06 | 17.09 |
| Population proportion | 15.09 | 4.89 | 2.30 | 0.89 | 0.41 | 23.58 |

7.2.2 Problem solution

Samples are weighted by using probability weights¹⁴¹. They represent the probabilities that specific households of the population are selected into the sample. These weights can be calculated by taking the inverse of the sampling fraction. However, most samples consider several classes of decision-maker's characteristics, which are also known on population level¹⁴².

In the literature, two weighting methods are described, namely complete and incomplete post-stratification.

¹⁴¹ Next to probability weights, frequency weights, importance weights and analytic weights are distinguished in the literature. Standard versions of statistical software packages such as SPSS and SAS are only designed for calculating frequency weights.

¹⁴² For instance, in our sample, we know for three socio-economic parameters their corresponding population marginals.

In ideal circumstances, when cell values across all weighting classes are known in the sample and in the population, we can use complete post-stratification¹⁴³. However, cell values of the population across all weighting classes are mostly unknown. Therefore, we only take population marginals into account¹⁴⁴ by using incomplete post-stratification. Basically, this process, which is termed *sample-balancing* or *raking*, starts to weight the marginal of one sample class according to its population share. Then the adjusted weights are used for the second class until all shares in the sample equal the corresponding population shares.

To perform the post-stratification of our sample, we use a SAS macro called *Weights*¹⁴⁵, which was developed by the Center for Survey Methodology and the Institute for Social and Political Opinion Research at the Catholic University Leuven (ISPO (2003)). As presented in Table 7.3, we define three weighting classes in our sample: the number of household members, age and sex of household's head¹⁴⁶. Furthermore, this table shows that the underrepresented categories (i.e. the largest households and the youngest and oldest age category) are positively weighted, while the overrepresented category 45-64 years has a weighting factor below one. In our car use model, estimates of aggregate values of the dependent variable (i.e. car kilometres travelled) are obtained by inserting aggregate values of the explanatory variables. However, since our car ownership models are based on the logit distribution, which is not linear in the explanatory variables, simply inserting aggregate values for these variables would result in biased estimates¹⁴⁷. Train (1986) described different aggregation techniques¹⁴⁸ how to obtain aggregate estimates from qualitative

¹⁴³ This technique includes weights equal cell values of the population dividing by their corresponding sample values.

¹⁴⁴ For more details about post-stratification, we refer to Deville et al. (1993).

¹⁴⁵ *Weights* is an upgraded version of *Weight 2.1*, developed which was developed by Hajnal (1995) and used by Nuyts and Zwerts (2002a).

¹⁴⁶ Their corresponding population marginals were provided by NIS (2002).

¹⁴⁷ This phenomenon is visualised in Train (1986) pp.99

¹⁴⁸ More specifically, he discussed sample enumeration of choice probabilities, sample enumeration of randomly generated choices and segmentation.

choice models. We use sample enumeration of choice probabilities. Train (1986, 99) explained this approach as

"the choice probabilities of each decision-maker in a sample are summed or averaged over decision-makers".

Table 7.3: Probability weighting factors

| | | Age of male household's head | | | | |
|-----------------------------|--|--------------------------------|-------------|-------------|-------------|-----------|
| Number of Household members | | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
| 1 | | 4.36186 | 1.59361 | 1.48429 | 0.84666 | 2.70618 |
| 2 | | 2.36880 | 0.86544 | 0.80608 | 0.45980 | 1.46965 |
| 3 | | 1.00000 | 1.07972 | 1.00566 | 0.57364 | 1.83353 |
| 4 | | 1.00000 | 1.07320 | 0.99958 | 0.57017 | 1.82244 |
| >4 | | 1.00000 | 1.38478 | 1.28978 | 0.73571 | 2.35155 |
| | | Age of female household's head | | | | |
| Number of Household members | | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
| 1 | | 5.14418 | 1.87943 | 1.75050 | 0.99851 | 3.19154 |
| 2 | | 4.53247 | 1.65594 | 1.54235 | 0.87978 | 2.81202 |
| 3 | | 1.00000 | 1.36609 | 1.27238 | 0.72579 | 2.31982 |
| 4 | | 1.00000 | 1.96389 | 1.82917 | 1.04339 | 3.33496 |
| >4 | | 1.00000 | 7.27410 | 1.00000 | 1.00000 | 1.00000 |

7.2.3 Robustness

The use of the weighting factors results in a more representative sample of the total population. However, there remains a problem of robustness of data.

In Table 7.4, we observe low numbers of observations for classes of young households heads and for large families headed by a female. This implies that results for these classes are based on only few observations. Since there are no remedial measures to deal with robustness¹⁴⁹, we need to accept some biases. However, since these thin classes represent only 3.5 % of the total population, only minor biases are expected.

Table 7.4: Cell values of our total sample

| | Age of male household's head | | | | |
|-------------------------------|--------------------------------|-------------|-------------|-------------|-----------|
| Number of household's members | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
| 1 | 4 | 21 | 14 | 105 | 21 |
| 2 | 3 | 65 | 34 | 326 | 178 |
| 3 | 0 | 61 | 77 | 145 | 24 |
| 4 | 0 | 50 | 136 | 97 | 5 |
| >4 | 0 | 8 | 53 | 53 | 1 |
| | Age of female household's head | | | | |
| Number of Household's members | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
| 1 | 2 | 12 | 15 | 150 | 19 |
| 2 | 1 | 7 | 5 | 37 | 11 |
| 3 | 0 | 9 | 8 | 16 | 3 |
| 4 | 0 | 2 | 3 | 3 | 1 |
| >4 | 0 | 1 | 0 | 0 | 0 |

¹⁴⁹ Robustness concerns need to be taken into account in the survey design, more specifically in the sample selection.

Table 7.5 shows that especially the data sample of two-cars households is vulnerable to the problem of robustness: we only have one observation of households of the lowest income and lowest age category. Furthermore, we have only 2 observations of single households owning two cars. Consequently, results of these categories are based on only one or two observations. Therefore, we will exclude the simulation results of these three categories for two-car households in the next sections.

Table 7.5: Cell values of samples of households owning one car and two cars

| | One-car household | Two-cars household |
|---------------|-------------------|--------------------|
| Income 1 | 31 | 1 |
| Income 2 | 619 | 52 |
| Income 3 | 380 | 243 |
| Income 4 | 36 | 118 |
| Income 5 | 6 | 19 |
| <25 years | 9 | 1 |
| 25-34 years | 152 | 84 |
| 35-44 years | 217 | 128 |
| 45-64 years | 453 | 198 |
| ≥65 years | 241 | 22 |
| One-member | 185 | 2 |
| Two-members | 488 | 100 |
| Three-members | 191 | 138 |
| Four-members | 155 | 134 |
| > Four-member | 53 | 59 |

7.3 *Simulation base case scenario*

In the literature, policy instruments are generally analysed by simulating the demand by the car ownership-and-use model at least twice. Firstly, we use the observed values for explanatory values to simulate the base case scenario. Secondly, one or more of these explanatory variables are changed to represent a policy change or changes in the socio-economic situation. The differences between the results of these two simulations give us a detailed view of the effect of the modelled changes.

We simulated the base case scenario based on data of 2000. In this section, we discuss the following simulation results:

- General simulation results of the base case scenario;
- Simulation results of the base case scenario by income category;
- Simulation results of the base case scenario by age of household's head;
- Simulation results of the base case scenario by household's size.

In our discussion, we consider car ownership, fuel efficiency, annual number of kilometres driven and the total fuel consumption by households.

7.3.1 General simulation results of base case scenario

Firstly, Figure 7.1 depicts the distribution of households by car ownership. Almost eighty percent of the households owns at least one car. A quarter of them owns at least two cars. If we apply these shares to the total number of households in 2000, we obtain estimated numbers as given by Table 7.6. The estimated number of 2,441,903 cars is a slight overestimation (4.46 percent) of the 2,337,617 of private cars registered on August 2000 in Flanders¹⁵⁰. An explanation is that we excluded households, which own one or more cars for

¹⁵⁰ Source: NIS (2001).

mixed use¹⁵¹. Consequently, when our model simulates that households own one or more cars, in some cases the households replaced their private car by a car for mixed use.

Figure 7.1: Relative share of car ownership (base case)

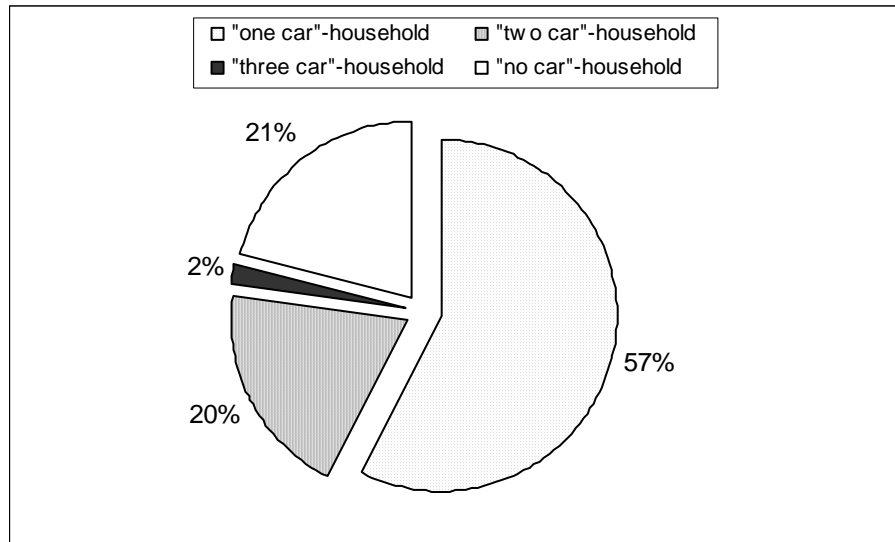


Table 7.6: Total numbers of car by household type (base case)

| Type of household | Number of cars |
|----------------------|----------------|
| One-car household | 1,373,357 |
| Two-cars household | 944,624 |
| Three-cars household | 123,921 |
| Total | 2,441,902 |

Secondly, our estimated average fuel consumption amounts to 7.85 litres per 100 km in the case of a single car. When households own two cars, the average fuel consumption is 7.53 litres per 100 km for each car. This higher fuel efficiency arises because the second car is typically a smaller car with a higher fuel efficiency.

¹⁵¹ Examples of cars for mixed use include Citroën Jumper or Peugeot Boxer. NIS (2001) reports 394,497 registered mixed cars in 2000.

Our estimation is consistent with the literature: Vito (2003) estimated the fuel efficiency of cars in Flanders for 2000. They obtained a fuel efficiency of 6.7 and 8.7 litres per 100 km for respectively diesel and gasoline cars.

Thirdly, next to the number and type of cars owned by household, we also estimated the total number of annual kilometres travelled by households. These numbers are given in Table 7.7.

Table 7.7: Annual kilometres travelled by household type (base case)

| Type of household | Annual kilometres travelled |
|----------------------|-----------------------------|
| One-car household | 13,504.88 |
| Two-cars household | 30,581.88 |
| Three-cars household | 40,775.88 |

While one-car households travel annually 13,500 kilometres, this number is more than doubled when households own two cars. Recall that we did not estimate the annual kilometres travelled by the third car. Instead, we used the average kilometres travelled by the third car as was observed in the HTS (i.e. 10,194 km). If we apply these numbers on the total population of Flanders, we obtain an estimate of almost 35 billion kilometres travelled by households in 2000.

Finally, as is given in Table 7.8, we calculate the total amount of fuel consumption in Flanders. We estimate that Flemish households in 2000 consumed almost three billion litres of fuel for the use of their private cars. This is less than one-third of the total amount of fuel that was sold in Belgium for road transport in 2000.

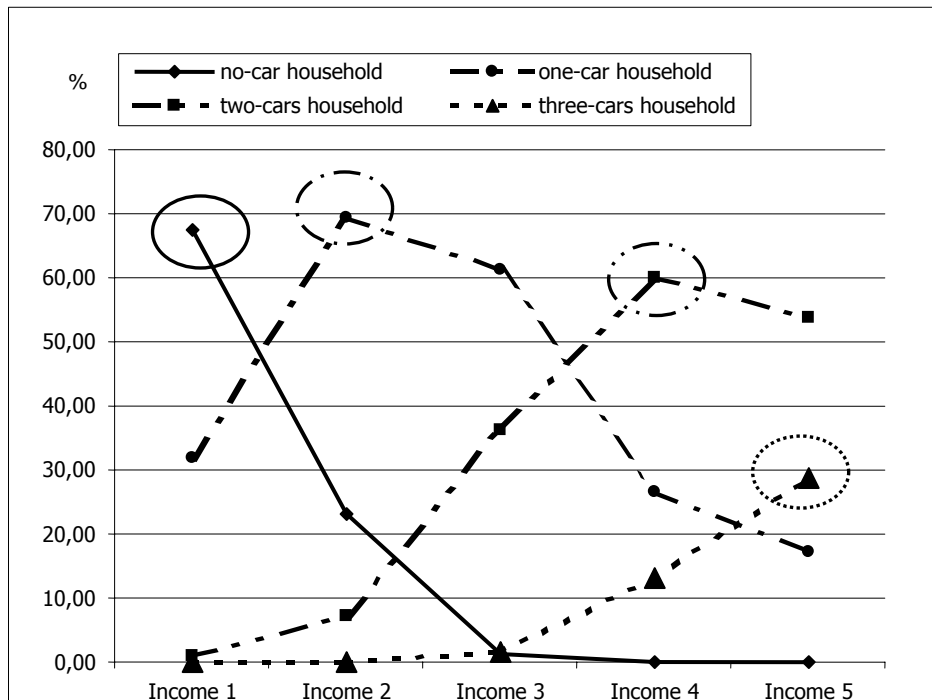
Table 7.8: Total fuel consumption by household type (base case)

| Type of household | Fuel consumption (in litres) |
|----------------------|------------------------------|
| One-car household | 1,455,999,770 |
| Two-cars household | 1,119,848,331 |
| Three-cars household | 130,585,981 |
| Total | 2,706,434,082 |

7.3.2 Simulation results of base case scenario by income category

Figure 7.2 depicts car ownership in relation to income category. This shows the clear positive relation between car ownership and the level of income.

Figure 7.2: Car ownership by income category (base case)



We observe that the different peaks of the number of cars owned, which are encircled in the figure, shift towards growing income. While the highest level of households owning no car is situated at the lowest income level, the maximum share of households owning two and three cars can be find at the highest income groups.

Table 7.9 shows the clear relation between fuel efficiency and income category: the higher the income, the more fuel-consuming cars are owned.

Table 7.9: Household's fuel efficiency (in l/100km) by income category (base case)

| | Income 1 | Income 2 | Income 3 | Income 4 | Income 5 |
|--------------------|----------|----------|----------|----------|----------|
| One-car household | 7.75 | 7.81 | 7.93 | 7.97 | 8.02 |
| Two-cars household | | 7.76 | 7.76 | 7.76 | 7.79 |

A similar positive relation can be found in Table 7.10, which shows the annual kilometres travelled in relation to the income category. The higher the income, the more kilometres are driven: a one-car household of the lowest income category drives less than 10,000 km while a one-car household of the highest income category drives more than 20,000 km.

Table 7.10: Household's annual kilometres travelled by income category (base case)

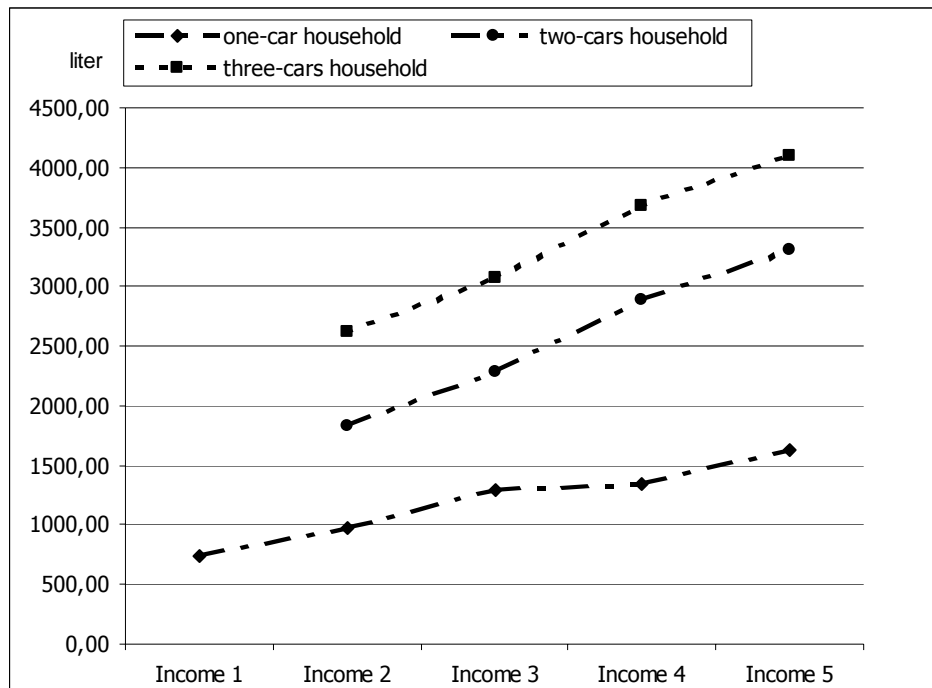
| | Income 1 | Income 2 | Income 3 | Income 4 | Income 5 |
|----------------------|-----------|-----------|-----------|-----------|-----------|
| One-car household | 9,469.586 | 12,481.11 | 16,314.84 | 16,842.95 | 20,332.45 |
| Two-cars household | | 23,553.99 | 29,332.06 | 37,218.78 | 42,428.23 |
| Three-cars household | | 33,747.99 | 39,526.06 | 47,412.78 | 52,622.23 |

Based on the household's fuel efficiency and the annual number of kilometres travelled, we calculate the annual fuel consumption of households. These results are given in Figure 7.3. Again, we observe a clear positive relation between income and fuel consumption. This positive relationship is even more explicit if we take into account the households that do not own a car. These aggregated results for Flanders are given in Table 7.11. We observe that fuel consumption and total kilometres travelled are almost twelve times higher for the highest income category compared to the lowest income category.

Table 7.11: Total kilometres travelled and fuel consumption by income category (base case)

| | Income 1 | Income 2 | Income 3 | Income 4 | Income 5 |
|-------------------------------|----------|-----------|-----------|-----------|-----------|
| Total kilometres travelled | 3,177.90 | 10,421.49 | 21,195.69 | 33,117.11 | 41,538.50 |
| Total fuel consumption (in l) | 245.58 | 813.09 | 1,661.99 | 2,579.41 | 3,245.40 |

Figure 7.3: Annual fuel consumption of households by income category (base case)



7.3.3 Simulation results of base case scenario by age category

Figure 7.4 shows that households with no or only one car are mainly young and elderly households. This can be seen by the U-shape of these curves. Furthermore, owning two cars is mainly observed at households of middle-aged heads.

Figure 7.4: Car ownership by age of household's head (base case)

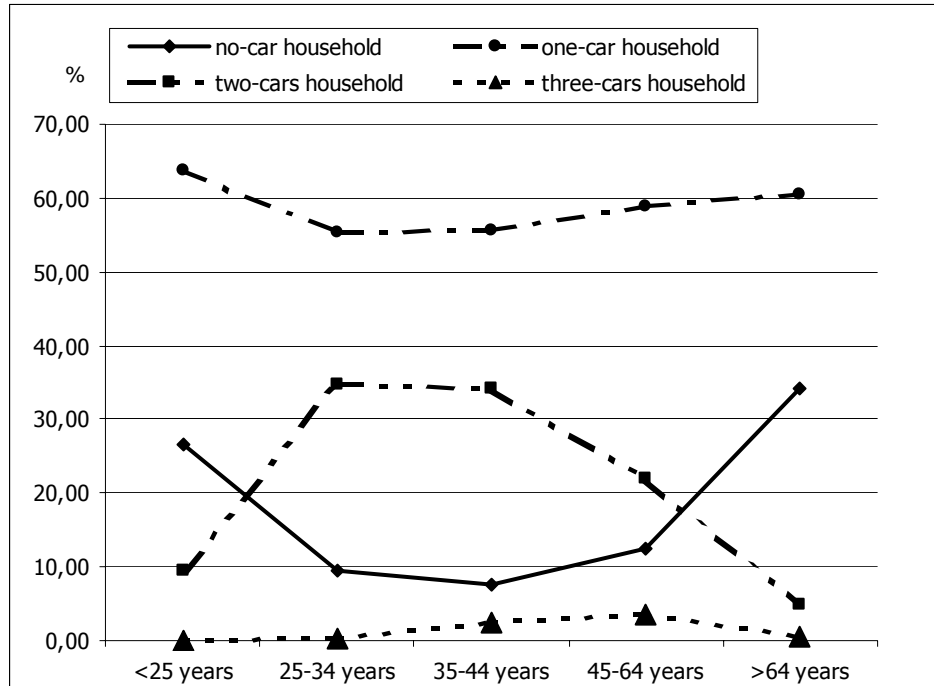


Table 7.12 gives the fuel efficiency in relation to the age of the household's head. There appears to be no clear relation. However, there is one eye-catching value: the fuel inefficiency of households that own one car is very high when household's head is an elderly person: 8.09 l/100 km versus 7.69 to 7.84 for the other age categories.

Table 7.12: Household's fuel efficiency (in l/100 km) by age category (base case)

| | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
|--------------------|-----------|-------------|-------------|-------------|-----------|
| One-car household | 7.72 | 7.69 | 7.76 | 7.84 | 8.09 |
| Two-cars household | | 7.71 | 7.72 | 7.81 | 7.81 |

Figure 7.5 and Table 7.13 give respectively the household's annual fuel consumption and kilometres travelled in relation to the age of the household's head. We observe two different trends: while there is a negative relation for one-car households between car use and age of the household's head, we observe a positive relation for households owning more cars. However, when

the household's head is an elderly the use of more than one car decreases substantially.

Figure 7.5: Annual fuel consumption of households by age of household's head (base case)

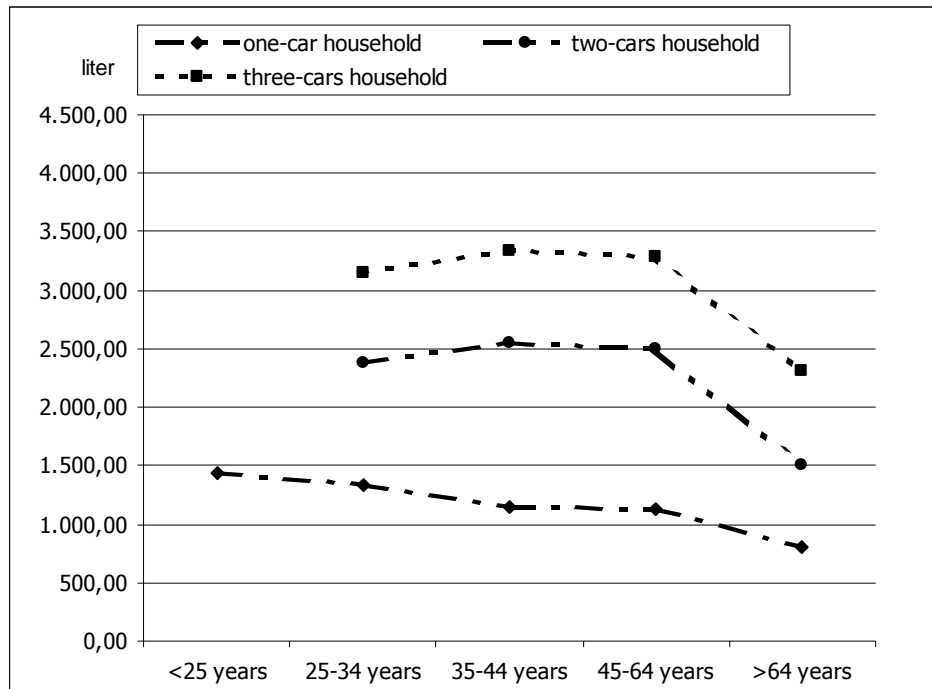


Table 7.13: Household's annual kilometres travelled by age category (base case)

| | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
|----------------------|-----------|-------------|-------------|-------------|-----------|
| One-car household | 18,655.21 | 17,415.15 | 14,869.36 | 14,345.72 | 9,987.91 |
| Two-cars household | | 30,755.11 | 32,943.91 | 31,927.02 | 19,350.60 |
| Three-cars household | | 40,949.11 | 43,137.91 | 42,121.02 | 29,544.60 |

Finally, the aggregated total annual kilometres travelled and fuel consumption in relation to the household's head age is given in Table 7.14. We observe that households with elderly heads have the lowest car use while the households with middle-aged heads consume the most: their fuel consumption is respectively 575 litres and almost 1,595 litres.

Table 7.14: Average annual kilometres travelled and fuel consumption by age category (base case)

| | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
|-------------------------------|-----------|-------------|-------------|-------------|-----------|
| Total kilometres travelled | 14,049.95 | 20,486.00 | 20,622.79 | 17,399.90 | 7,152.62 |
| Total fuel consumption (in l) | 1,086.31 | 1,577.17 | 1,595.49 | 1,361.34 | 575.40 |

7.3.4 Simulation results of base case scenario by household's size

The shares of car ownership in relation to the household's size are presented in Figure 7.6. We observe that half of the single households own no car. Singles that do own a car, own only one car. Furthermore, only ten percent of the duo households have no car, while seventy percent of them own one car. Half of the households with more than two members own one car, the other half typically two.

Figure 7.6: Car ownership by household's size (base case)

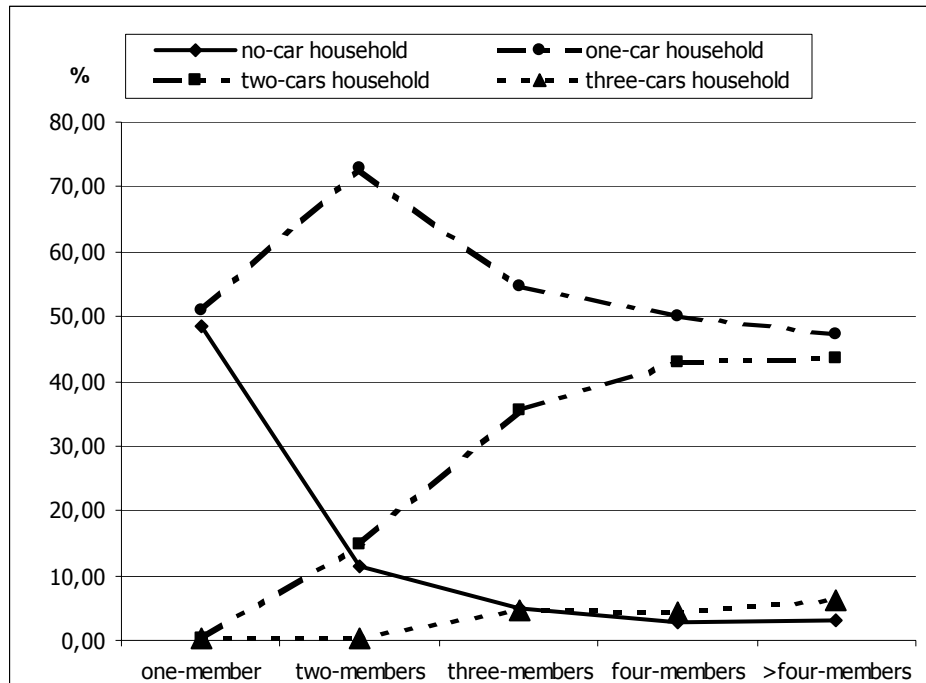


Table 7.15 presents the fuel efficiency by household's size. We observe that the fuel-efficiency is similar across the different household's size categories.

Table 7.15: Fuel efficiency (in l/100 km) by household's size (base case)

| | One-member | Two-members | Three-members | Four-members | >Four-members |
|--------------------|------------|-------------|---------------|--------------|---------------|
| One-car household | 7.81 | 7.84 | 7.90 | 7.91 | 7.90 |
| Two-cars household | | 7.79 | 7.77 | 7.74 | 7.75 |

Figure 7.7 and Table 7.16 present the household's annual fuel consumption and kilometres travelled in relation to the household's size. As expected, there exists a positive relationship between car use and the household's size: a single travels annually 12,765 km while a household with more than four members travels 15,079 km.

Figure 7.7: Annual fuel consumption of households by household's size (base case)

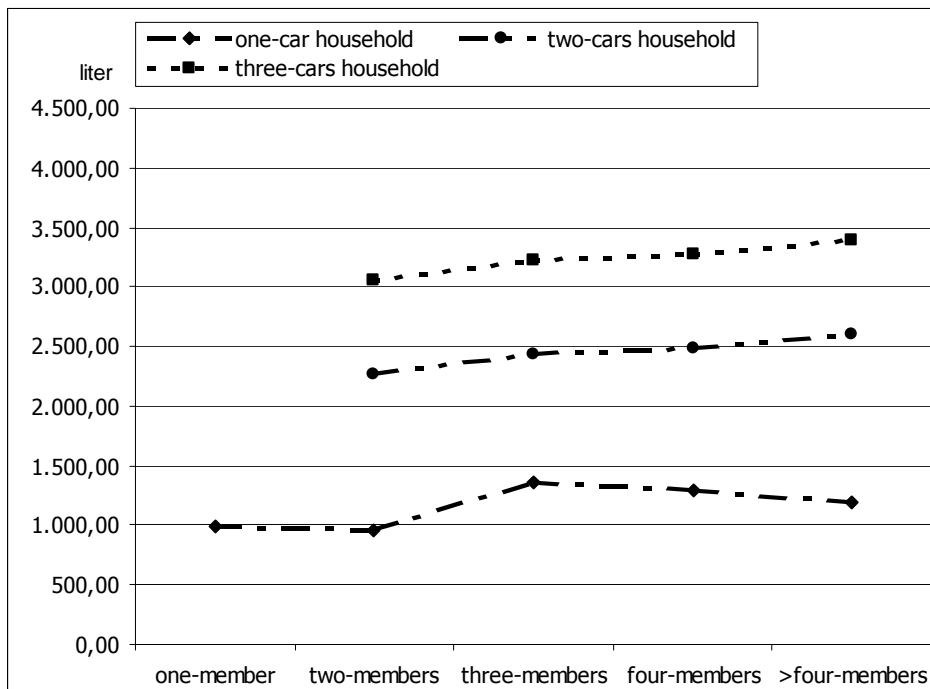


Table 7.16: Household's annual kilometres travelled by household's size (base case)

| | One-member | Two-members | Three-members | Four-members | >Four-members |
|----------------------|------------|-------------|---------------|--------------|---------------|
| One-car household | 12,765.17 | 12,239.85 | 17,123.42 | 16,406.25 | 15,079.29 |
| Two-cars household | | 29,096.75 | 31,267.19 | 32,158.63 | 33,536.54 |
| Three-cars household | | 38,636.96 | 40,807.4 | 41,698.84 | 43,076.75 |

This positive relationship is again confirmed if we take into account the households that do not own a car. These aggregated values of total kilometres travelled and fuel consumption for Flanders are given in Table 7.17.

Table 7.17: Average annual kilometres travelled and fuel consumption by household's size (base case)

| | One-member | Two-members | Three-members | Four-members | >Four-members |
|----------------------------|------------|-------------|---------------|--------------|---------------|
| Total kilometres travelled | 6,725.66 | 14,024.17 | 23,139.32 | 24,567.48 | 25,118.39 |
| Total fuel consumption | 524.74 | 1,096.79 | 1,809.33 | 1,912.97 | 1,956.36 |

7.4 *Simulation results of scenario 1*

7.4.1 Policy goal: Reduction to level of 1990

Several studies estimating the tax effect on environmental pollution use a reduction target of 10% in fuel consumption. Horowitz (1982) used a 14 % quantity reduction of fuel consumption. We hypothesize that the policy goal is to reduce fuel consumption to the level of 1990. As Table 7.18 shows, this corresponds to a reduction level of 14.6 %.

Table 7.18: Total fuel consumption in Belgium

| | Total fuel consumption (x 1,000,000 l) | Absolute reduction level (x 1,000,000 l) | Relative reduction level (in %) |
|--------------|---|---|------------------------------------|
| 2000 | 9,251 | | |
| 1990 | 7,897 | 1,354 | 14.6 |
| Kyoto target | 7,265 | 1,986 | 21.3 |

Source: Ministerie van Economische Zaken - Bestuur Energie (2004)

7.4.2 Use of taxes (scenario 1)

First, we use our model to define the tax level, which is required to reach the policy goal. Consequently, we discuss the simulation results in a similar way as in the base case scenario: next to the general simulation results, we also present the effects of such a tax on different household categories.

Tax level

A common instrument to reduce the consumption of a good is a tax. We simulate that the level of the additional tax should be equal to 0.598 euro per litre of fuel if we want to obtain a 14.6%-reduction of the fuel level in our base case scenario. This tax increase corresponds to a 55 % and 74 % increase of respectively the gasoline and diesel price. Furthermore, the variable costs for gasoline and diesel cars increase with respectively 43 and 49 %.

General simulation results (scenario 1)

Table 7.19 summarizes the relative change (in percentage) of the number of cars owned, the fuel efficiency, average and total annual kilometres travelled by household and the total fuel consumption.

Table 7.19: Relative change (in percent) of car ownership-and-use (tax = 0.598)

| | Car ownership | Fuel efficiency | Household Kilometres travelled | Total kilometres travelled | Total fuel consumption |
|----------------------|---------------|-----------------|--------------------------------|----------------------------|------------------------|
| One-car household | 6.83 | -1.27 | -5.67 | 0.78 | -0.51 |
| Two-cars household | -21.35 | -0.59 | -7.96 | -27.61 | -28.04 |
| Three-cars household | -52.32 | | --7.96 | -56.12 | -56.38 |
| No-car household | 5.67 | | | | |
| Total | -7.07 | | -7.60 | -13.81 | -14.60 |

Firstly, we observe a sharp decline of more than fifty percent of households owning three cars. However, the number of households owning one car grows with more than five percent. Secondly, two-car households are more sensitive to change their annual kilometres travelled than their fuel efficiency compared

to the one-car households. There are various explanations for this: two-cars households can switch towards their more fuel-efficient car and they more easily reduce their amount of travelling by carpooling or abandoning unnecessary trips. As a result, households owning three or two cars reduce their fuel consumption (respectively by 28.04 en 56.38 percent).

Finally, we estimate the fuel price elasticity of fuel consumption¹⁵². We use the elasticity concept to measure the price responsiveness of fuel consumption to changes in fuel prices. In general, an elasticity gives the impact of a change in an independent (or stimulus) variable on a dependent (or response) variable, both measured in percentage changes. We use the following formula:

$$\text{Fuel price elasticity} = \frac{\frac{\Delta p}{p}}{\frac{\Delta q}{q}} = \frac{\frac{p_i - p_t}{p_i}}{\frac{q_i - q'}{q_i}}$$

Whereby p_i and q_i are respectively the initial price and consumption level and p_t and q' are respectively the price and consumption level after the introduction of a tax increase in 0.598 euro per litre. Based on our simulation results, we obtain an estimated elasticity is -0.26 . This means that a 10 percent increase in fuel price is expected to lead to a 2.6 percent fall in fuel consumption. If we want to compare our results with the literature, we need to be very careful since different studies result in considerable variation in estimates of fuel consumption. This variation can be explained by model differences¹⁵³, time range¹⁵⁴ and geographical characteristics¹⁵⁵. Therefore, we compare our

¹⁵² Different types of elasticities can be defined. For a literature overview of different road transport elasticities, we refer to TRACE Consortium (1998), de Jong and Gunn (2001), Hanly et al. (2002), Graham and Glaister (2004), Victoria Transport Policy Institute (2005) and BTE (2005). For an overview of fuel elasticities, we refer to Goodwin (1992) and Graham and Glaister (2002).

¹⁵³ Practically all elasticities are estimated by using models. TRACE (1998) categorised these models by modeled choice and by type of data used.

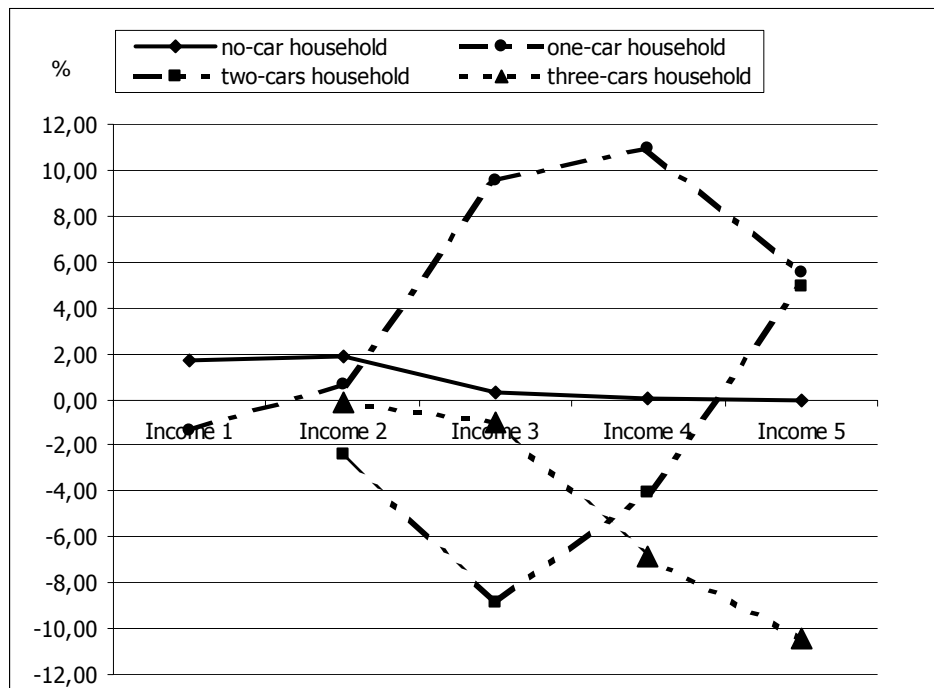
¹⁵⁴ In the literature, short term effects are defined as effects that occur almost immediately (within a year), while long term effects are associated with the turnover of the vehicle fleet and

estimates with studies that are also based on cross-section data. In the survey of Goodwin et al. (2002), the elasticity of fuel consumption with respect to fuel price was found to range between -0.23 and -1.12, with a mean elasticity of -0.55. We observe that our value of -0.26 is situated in the lower part of this range¹⁵⁶. This can be explained by the fact that we use a log linear functional form. Consequently, since our price increase is very high, the elasticity has a lower value compared to those of more modest price increases.

Simulation results by income category (scenario 1)

Figure 7.8 presents the relative change of car ownership.

Figure 7.8: Relative change of car ownership by income category (tax = 0.598 euro)



relocation and redistribution of activities and land uses to decrease trip length (average 5 years). However, since we use a (partial) equilibrium model, our estimates are static.

¹⁵⁵ For more information about the sources of variation in elasticity estimates, we refer to Oum et al (1992) and Goodwin et al.(2004).

¹⁵⁶ Note that the elasticity values are expressed in absolute values.

We observe a clear trend towards owning fewer cars. More than ten percent of the highest income level category abandons their third car, while approximately five percent of this category reduces their car ownership from two to one. The middle-income groups also abandon their third or second car, which gives an eight percent rise in single car ownership. The only movement towards no-car households occurs at the lowest income level: two percent of them abandon their single car.

The changes in fuel efficiency of the different households across income categories are given in Table 7.20. There appears to be no huge differences across income categories.

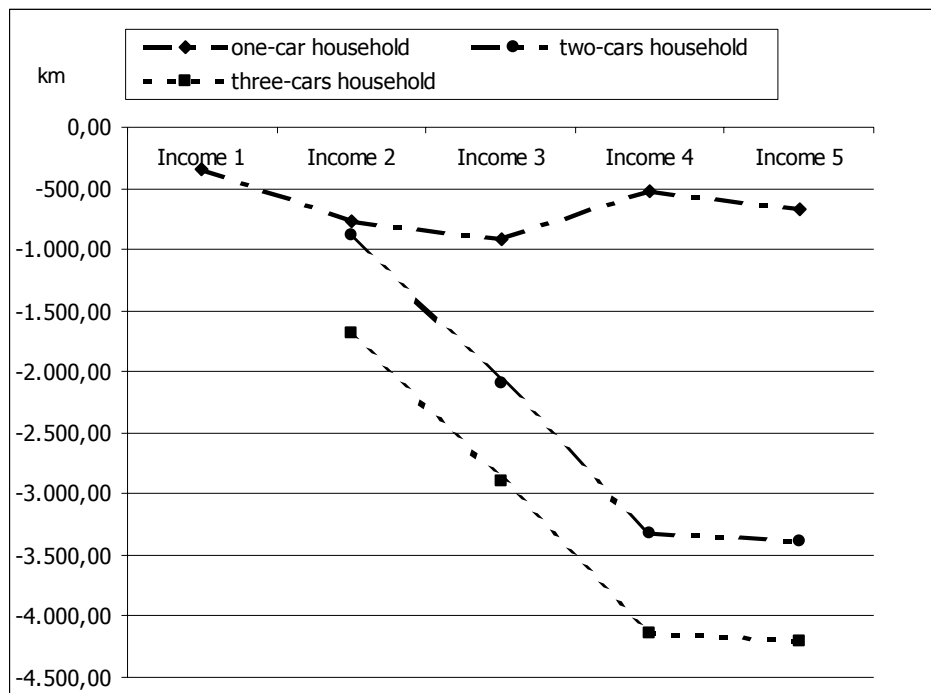
Table 7.20: Relative change (in %) of fuel efficiency by income category (tax=0.598 euro)

| | Income 1 | Income 2 | Income 3 | Income 4 | Income 5 |
|--------------------|----------|----------|----------|----------|----------|
| One-car household | -0.96 | -1.00 | -1.02 | -1.01 | -0.98 |
| Two-cars household | | -0.47 | -0.46 | -0.45 | -0.46 |

Figure 7.9 depicts the absolute change in fuel consumption of households across income categories.

We observe that variations for one-car households are rather modest. However, when households own two or more cars, there is a clear positive relation between the reduction of fuel consumption and income level.

Figure 7.9: Absolute change (in l) of household's annual fuel consumption by income category (tax=0.598 euro)



Simulation results by age category (scenario 1)

Figure 7.10 visualizes the relative changes of car ownership across age categories. We observe that seven percent middle-aged households abandon their second car, while two percent of the households with young and elderly head abandon their only car.

Figure 7.10: Relative change (in %) of car ownership by age of household's head (tax=0.598 euro)

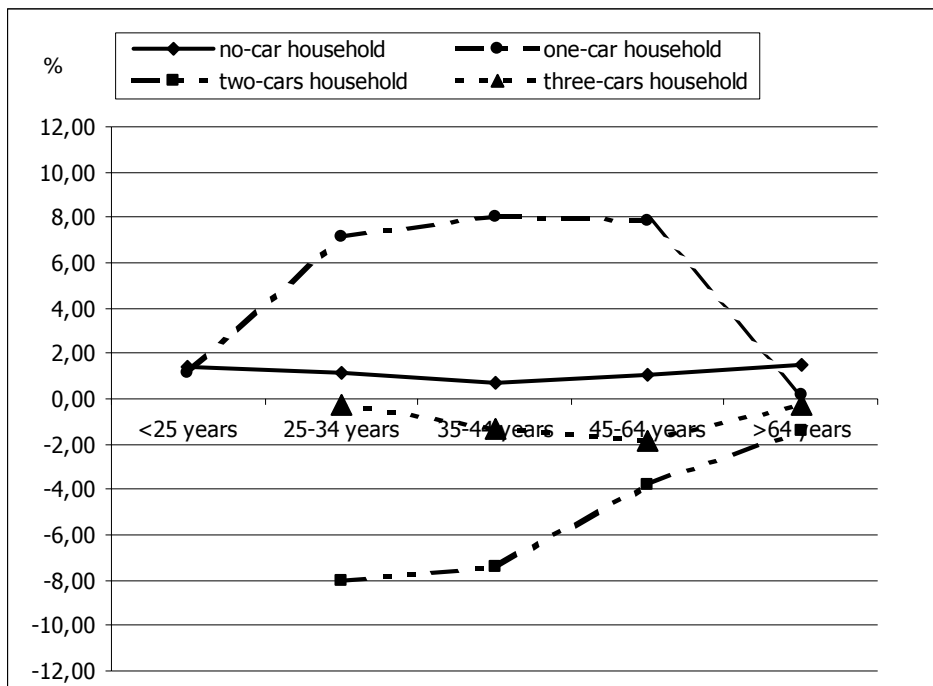


Table 7.21 shows the improvement of fuel efficiency across age categories.

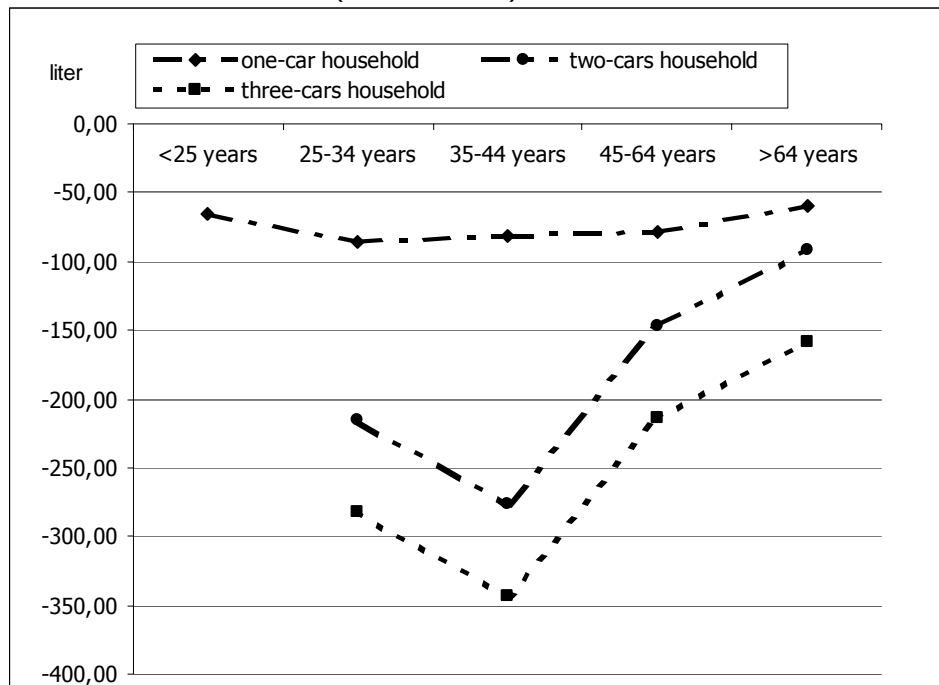
Table 7.21: Relative change (in %) of fuel efficiency by age of household's head (tax=0.598 euro)

| | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
|---------------------|-----------|-------------|-------------|-------------|-----------|
| One-car households | -0.97 | -0.96 | -0.99 | -1.01 | -1.03 |
| Two-cars households | | -0.45 | -0.45 | -0.47 | -0.46 |

We observe for the one-car households a slightly positive relationship between fuel efficiency and age of household's head: the older the household's head, the higher the improvement. An explanation is that the initial fuel efficiency of older households was lower, which implies a higher potential for improvement.

Figure 7.11 illustrates the changes in fuel consumption of the different households according to age category. We observe that the reduction level is the highest for middle-aged households. Recall that these households have the highest level of fuel consumption in our base case scenario.

Figure 7.11: Absolute change (in l) of household's annual fuel consumption by age of household's head (tax=0.598 euro)



Simulation results by household's size (scenario 1)

The relative changes of car ownership across household's size are depicted in Figure 7.12. We observe that an increase in households owning no car is the highest (i.e. two percent) for singles. Three to ten percent of the other households abandon their second car.

Figure 7.12: Relative change (in %) of car ownership by household's size (tax=0.598 euro)

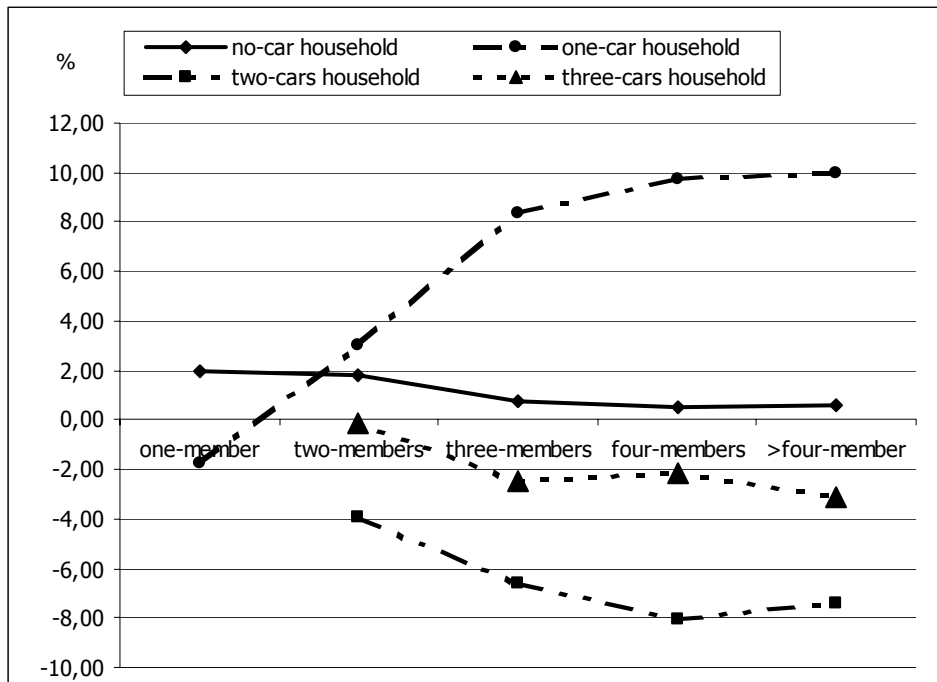


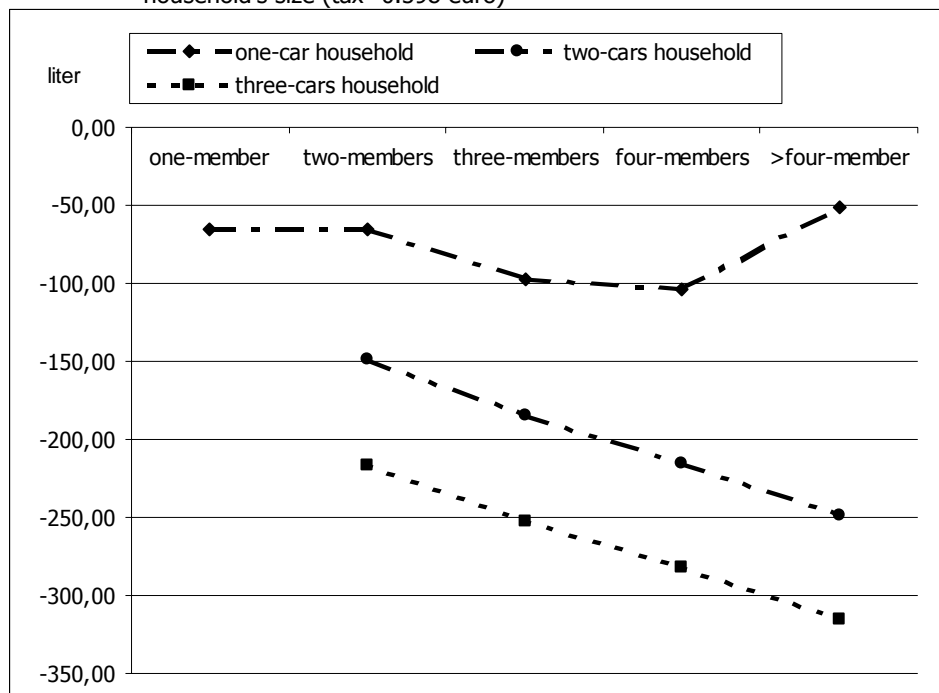
Table 7.22 shows the improvement of fuel efficiency across household's size. There appears to be no differences across these categories.

Table 7.22: Relative change (in %) of fuel efficiency by household's size (tax=0.598 euro)

| | one-member | two-members | three-members | four-members | >four-members |
|---------------------|------------|-------------|---------------|--------------|---------------|
| One-car households | -0.99 | -1.00 | -1.02 | -1.02 | -1.02 |
| Two-cars households | | -0.46 | -0.46 | -0.46 | -0.45 |

Figure 7.13 illustrates the changes in fuel consumption of the different households according to their size. We observe that the reduction level for the one-car households is quite equal. However, when households own two or more cars, the absolute reduction level increases with the household's size.

Figure 7.13: Absolute change of household's annual fuel consumption (in l) by household's size (tax=0.598 euro)



7.4.3 Use of tradable fuel permits (scenario 1)

Initial allocation of permits (scenario 1)

As chapter 2 described, different allocation schemes of initial permits might be considered. However, our choice is constrained by the variables, which are included in the HTS¹⁵⁷. We apply the following allocation rule: every household member receives a same amount of permits, except if the household's head is

¹⁵⁷ For instance, for each household, the number of children aged below six years is known. However, we have no information on the number of children older than six years.

older than 65 years¹⁵⁸. In that case, the household's head and his partner receive only 50 % of this amount. Other members of these households receive the full amount¹⁵⁹ of permits. To meet our policy goal of a 14.6%-reduction of the fuel level in our base case scenario, the initial number of permits distributed amounts to 439 permits, which correspond to 439 litres of fuel per person¹⁶⁰. Based on our simulation, we obtain a permit price of 0.798 euro.

General simulation results of permits (scenario 1)

Table 7.23 summarizes the relative changes of the number of cars owned, the fuel efficiency, average and total annual kilometres travelled by households and the total fuel consumption. We observe a sharp decline of more than 57 percent in the number of households owning three cars. However, the number of households owning one car grows by more than eight percent. Consequently, we observe a minor increase in total kilometres travelled by one-car households.

Table 7.23: Relative changes (in %) of car ownership-and-use (permit level = 439)

| | Car ownership | Fuel efficiency | Household Kilometres travelled | Total kilometres travelled | Total fuel consumption |
|----------------------|---------------|-----------------|--------------------------------|----------------------------|------------------------|
| One-car household | 8.30 | -1.61 | -5.67 | 2.16 | 0.52 |
| Two-cars household | -22.48 | -0.76 | -7.53 | -28.32 | -28.87 |
| Three-cars household | -57.25 | -0.76 | -7.53 | -60.47 | -60.77 |
| No-car household | 3.14 | | | | |
| Total | -6.93 | | -7.24 | -13.58 | -14.60 |

¹⁵⁸ In car use policies, it is common practice to define age as a characteristic to distinguish different categories of people. Examples include the driving age and the calculation of the insurance premium, which is based on age categories.

¹⁵⁹ We assume that a male elderly head of a household with more than one member, has a partner of the same age category. Other household members are considered as younger.

¹⁶⁰ An average household will have 1,008 permits at his disposal.

When we split up these values according to income category, age of household's head and household's size, we observe similar trends as we discussed in the case of the introduction of a 0.598 euro tax.

Furthermore, we now introduce a new elasticity of fuel consumption: the fuel permit price elasticity of fuel consumption¹⁶¹.

We use the following equation:

$$\text{Fuel permit price elasticity} = \frac{\frac{\Delta p}{p}}{\frac{\Delta q}{q}} = \frac{\frac{p_i - p_p}{p_i}}{\frac{q_i - q'}{q_i}} \quad (7.1)$$

Whereby p_i and q_i are respectively the initial price and consumption level and p_p and q' are respectively the price and consumption level after the introduction of a permit level of 439 permits, which corresponds to a quantitative cap of 14.6 %. Based on our simulation results, we obtain an estimated fuel permit price elasticity is -0.19 .

As expected, this value is lower than the fuel price elasticity. This can be explained by the income generating effect of the initial allocation of permits.

7.4.4 Discussion of taxes versus permits in scenario 1

In this section, we compare the effectiveness and welfare effects of the implementation of fuel taxes versus tradable fuel permits. Since both instruments result in the same policy outcome (i.e. a reduction of fuel consumption by 14.6 percent), we also consider their effect on the car fleet, fuel efficiency and the total annually kilometres travelled by households. Next to the effectiveness, we use the consumer surplus (or loss) as a measure of welfare change. Furthermore, we discuss this consumer surplus according to

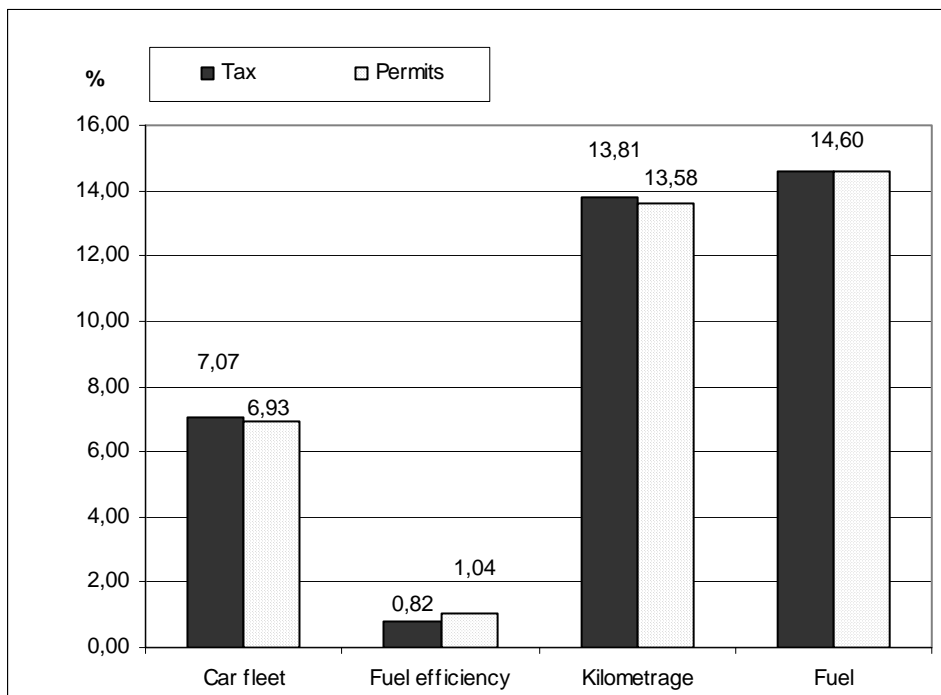
¹⁶¹ Note that the convention in economics is that the name of the independent variable comes first (before the word 'elasticity') and the dependent variable follows after the words 'elasticity of'.

different household categories: income, age of household's head and household's size.

Effectiveness (scenario 1)

As Figure 7.14 shows, both the levying of an additional fuel tax of 0.598 euro as the distribution of 439 permits amongst all individuals results in a reduction of the fuel consumption by 14.6 percent. On the one hand, the use of taxes leads to a higher reduction in the car fleet compared to permits (7.07 versus 6.93 percent). On the other hand, permits give households a higher incentive towards using fuel-efficient cars than taxes (1.04 percent improvement of fuel efficiency versus 0.82 percent). Consequently, the use of permits results into a lower reduction of annual kilometres travelled (13.81 versus 13.58 percent).

Figure 7.14: Relative reduction levels (in %) of scenario 1



When we apply these differences to the situation of Flanders in 2000, we obtain the following numbers:

- The introduction of permits results in a reduction of 169,308 cars while taxes decrease the car fleet by 172,707 cars.
- When taxes are introduced, the average fuel efficiency improves to 7.75 l/100 km for one-car households and 7.71 l/100 km for two-cars households. In the case of permits, the average fuel efficiency is coming to 7.72 l/100 km for one-car households and 7.69 l/100 km for two-cars households.
- The introduction of permits results in a reduction of 4,708,371,312 kilometres annually travelled by households while taxes decrease the total kilometres travelled by 4,789,730,172 km. In other words, the introduction of taxes results in an additional reduction of more than 81 million kilometres annually travelled compared to permits.

Welfare effect (scenario 1)

As we discussed in chapter two, we estimate the welfare effect of taxes by calculating the change in consumer surplus C_t using equation 2.1:

$$C_t = \{(p_t - p_i) q_t\} + 0.5\{(p_t - p_i) (q_i - q_t)\}$$

As we discussed in chapter four, the consumer surplus calculation for fuel permits C_p is more complex. We use equation (4.1):

$$C_p = (p_p - p_t) q_p - 0.5(p_t - p_i)(q_i - q_p) - (p_p - p_i) (q_p - q_c)$$

Figure 7.15 depicts the consumer losses (or surpluses) caused by the introduction of taxes and permits according to the household's income level. We find a positive relation between the level of income and the consumer losses for both policy instruments. However, permits generate consumer surpluses for the lowest income categories. Furthermore, we observe that consumer losses for taxes are higher than permits for all income categories: While tradable permits generate a consumer surplus of 216 euro for the lowest income category, they face a consumer loss of 137 euro with taxes. Even the highest income group is better off with permits compared to taxes: the consumer losses are 719 euro and 1,728 euro for respectively permits and taxes.

Figure 7.15: Consumer losses by income category (scenario 1)

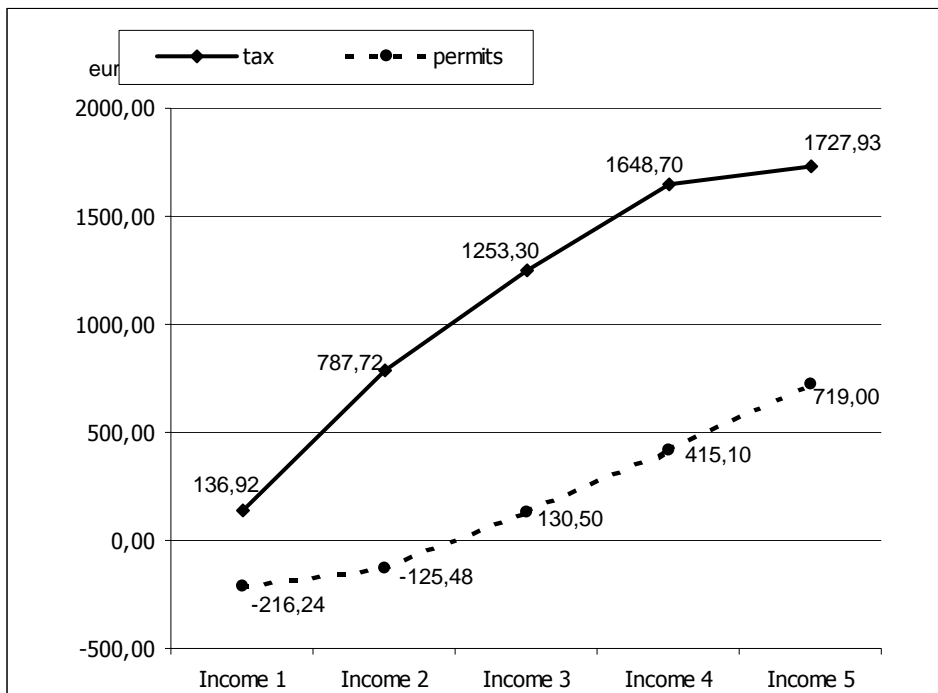
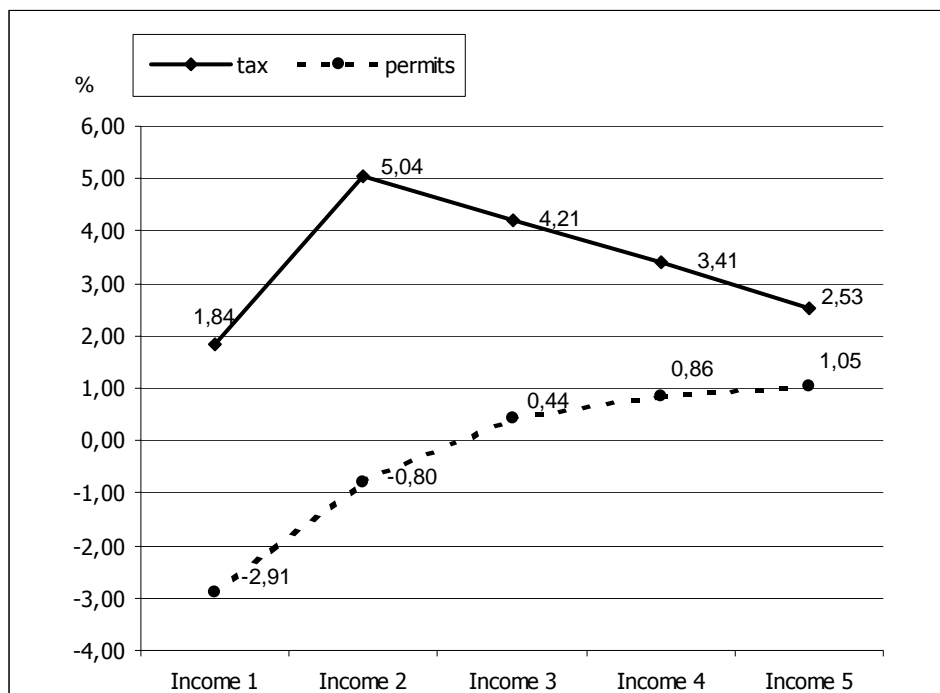


Figure 7.16 presents the consumer losses across different income categories relative to the household's income. On the one hand, the relative consumer losses of taxes decrease with income, starting from the second income category (i.e. 5.04 percent for the second income category and 2.53 percent for the highest income category). Consequently, we consider taxes¹⁶² as regressive. The small loss (1.84 percent) for the lowest income category is a result of the low car ownership and hence car use of this category. On the other hand, we observe that permits are progressive: The lowest income category gains a relative consumer surplus of 2.91 percent, while the share of consumer losses for the highest income categories values 1.05 percent.

Figure 7.16: Relative consumer losses (in %) of scenario 1 by income category



¹⁶² This conclusion is in line with the literature. Asensio et al. (2002) used a petrol expenditure function for Spain to evaluate the redistributive effects of petrol taxation. They found that for taxes are progressive for the lowest income deciles, but after a certain income level the tax becomes regressive.

West (2004) obtained a similar pattern by using a disaggregate demand model for the United States.

Consequently, all categories are better off with permits compared to taxes. This conclusion is in line with the literature.¹⁶³

¹⁶³ Archibald and Gillingham (1981) used a disaggregate demand model for the United States to estimate the distributional impact of gasoline conservation policies. They concluded that rationing schemes are more progressive. To make taxes more regressive, revenues need to be spent in a progressive way. However, they do not favour a broad-based redistribution scheme since the relative burden does not fall monotonically with rises in the income level. The importance of the purposes for which tax revenues are used was already recognised by Kendrick (1931). This discussion is still nowadays subject to widespread research activities (e.g. REVENUE (2005)). Dahl (1984) found similar result for the United States by using an aggregate demand model. Moreover, she concluded that total societal losses of rationing schemes would be higher because of higher administrative costs.

Figure 7.17 compares consumer losses of taxes and permits according to the household's head age.

In the case of taxes, we observe that the consumer losses increase with age until the age category of 35-44 years and values 1,315 euro, while older households face the lowest consumer losses with 603 euro.

In the case of permits, we find that consumer losses have lower values and less variation compared to taxes. While the values of consumer losses for permits lie between 81 and 221 euro, we find values between 603 and 1,315 euro for taxes. Furthermore, we find that for households with an elderly head, the difference in consumer losses between taxes and permits is the smallest: the consumer losses in the case of taxes and permits are respectively 603 compared to 221 euro for permits. Clearly, this is a result of our initial allocation of permits.

Figure 7.17: Consumer losses (in euro) of scenario 1 by age of household's head

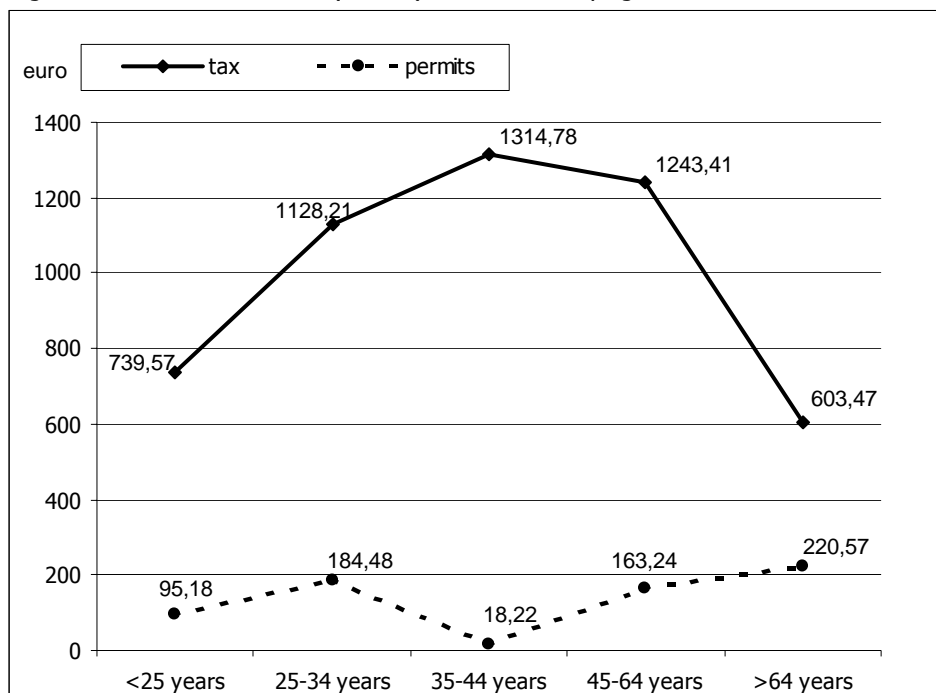
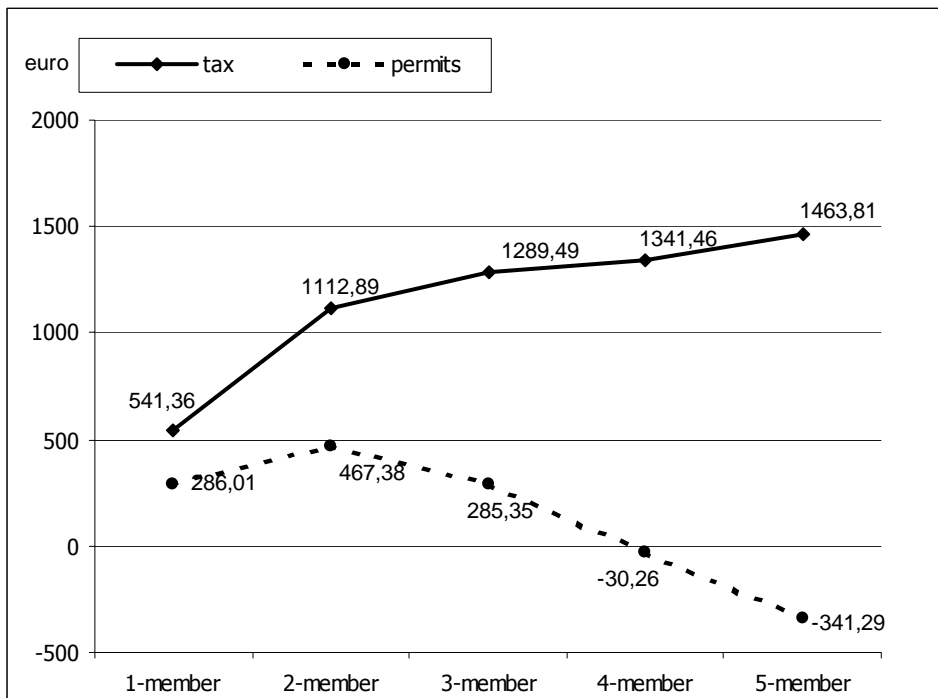


Figure 7.18 depicts the consumer losses (or surpluses) according to the household's size. We observe two dispersing curves: consumer loss of taxes increases with increasing household's size while consumer loss of permits decreases. While the differences in consumer losses for singles are rather small (541 euro in the case of taxes versus 286 euro in the case of permits), there is a large difference between both consumer losses in the case of large households (1,464 euro for taxes versus a surplus of 341 euro for permits). There are two explanations for this. Firstly, our initial allocation ratio is based on the number of household's members, resulting in a higher amount of allocated permits. Secondly, larger households consume more fuel and hence pay in absolute terms more fuel taxes compared to smaller households.

Figure 7.18: Consumer losses (in euro) of scenario 1 by household's size.



Financial effect (scenario 1)

Besides the welfare effects, we also estimate the financial impact on different household types of taxes and permits. These financial effects can be considered as out-of-pocket costs for households, which arise from the introduction of taxes and permits. We first discuss the calculation method for taxes. Recall Figure 2.3, which showed the welfare change after the introduction of taxes. Two financial effects can now be considered. At the one hand, we have the additional tax costs at a consumption level q_t . At the other hand, there are savings that resulted from a reduction of consumption. Consequently, we can use the following equation to calculate the financial effect F_t :

$$F_t = (p_t - p_i) q_t - p_i (q_i - q_t) \quad (7.2)$$

Secondly, we discuss the calculation method for tradable permits. Recall figure 4.4, which depicted the change in consumer surplus of tradable permits. Besides the same financial effects as with taxes, tradable permits generate a third financial effect. More specifically, we need to include the additional income through the initial allocation of permits. Consequently, we can use the following equation to calculate the financial effect F_p :

$$F_p = (p_p - p_i) q_p - p_i (q_i - q_p) - (p_p - p_i) q_c \quad (7.3)$$

Or,

$$F_p = (p_p - p_i) (q_p - q_c) - p_i (q_i - q_p) \quad (7.4)$$

Figure 7.19 depicts the financial losses (or surpluses) caused by the introduction of taxes or permits according to the household's income level. Similar to the welfare losses, we find a positive relation between the level of income and the financial losses of both taxes and permits: while the financial loss of the lowest income household is 125 euro in the case of taxes, the financial loss amounts to 1,592 euro for the highest income group. However, we observe that financial losses for permits are for all income categories much lower than taxes. Moreover, households in the lowest income category have a financial gain of 180 euro when permits are introduced. Even the highest income group is better off with permits compared to taxes: the financial losses are respectively 1,592 euro and 1,143 euro.

Figure 7.19: Financial losses by income category (scenario 1)

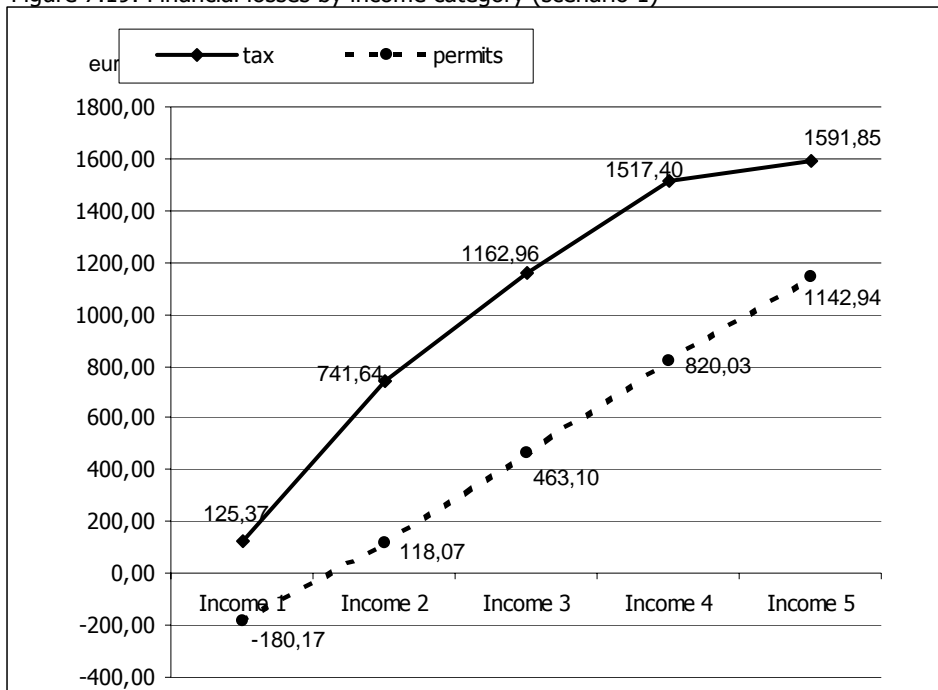


Figure 7.20 presents the financial losses across income category relative to the household's income. We found similar observations as with welfare losses: On the one hand, taxes are regressive starting from the second income category (i.e. 4.75 percent for the second income category and 2.33 percent for the highest income category). On the other hand, we observe that permits are progressive: While the lowest income category gains a relative financial surplus of 2.42 percent, the share of financial losses for the higher income categories range from 0.76 to 1.67 percent. Consequently, all categories are financially better off with permits compared to taxes, especially the lowest and middle-income categories.

Figure 7.20: Relative financial losses (in %) of scenario 1 by income category

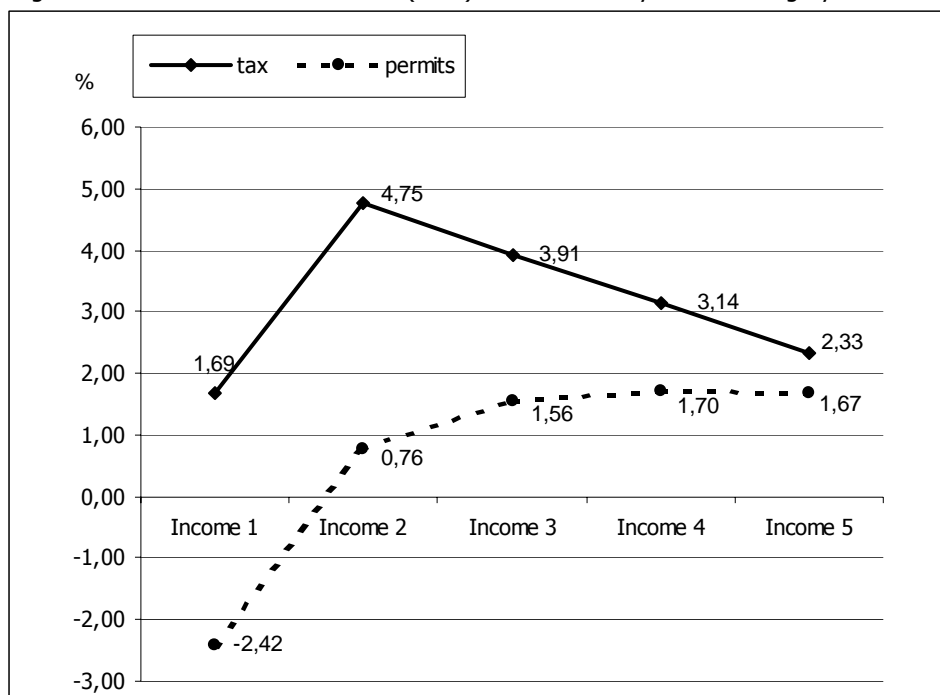


Figure 7.21 compares the financial losses of taxes and permits according to the household's head age. In the case of permits, we find that financial losses have lower values and less variation compared to the losses when taxes are used: While the values of financial losses for permits lie between 309 and 507 euro, we find values between 563 and 1,202 euro for taxes. Furthermore, we find that for households with an elderly head, the difference in financial losses between taxes and permits is the smallest: the financial loss in the case of taxes is 563 euro compared to 375 euro for permits. Clearly, this is a result of our initial allocation of permits.

Figure 7.21: Financial losses (in euro) of scenario 1 by age of household's head

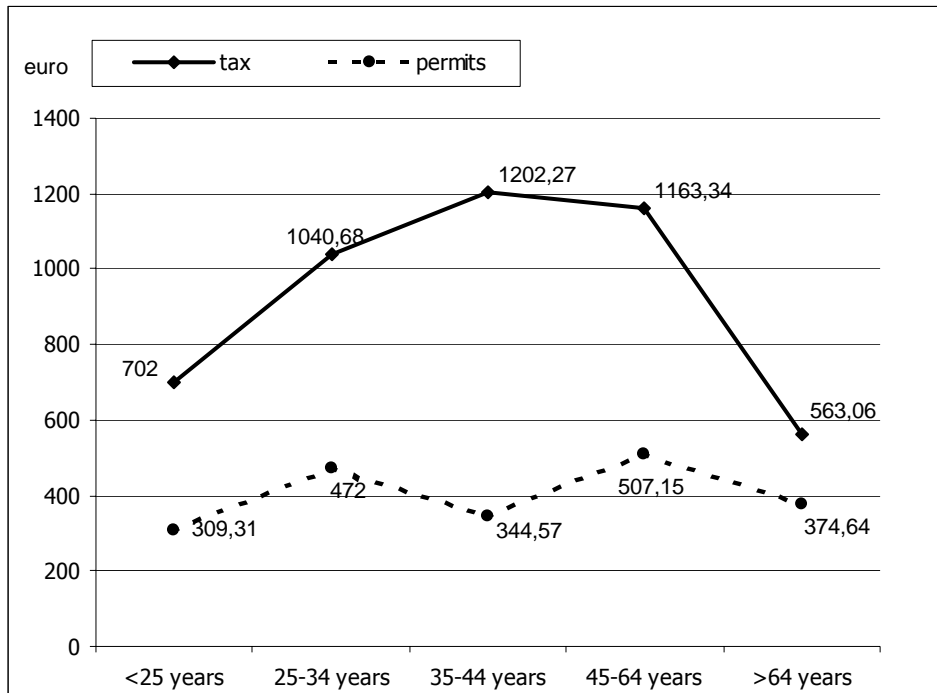
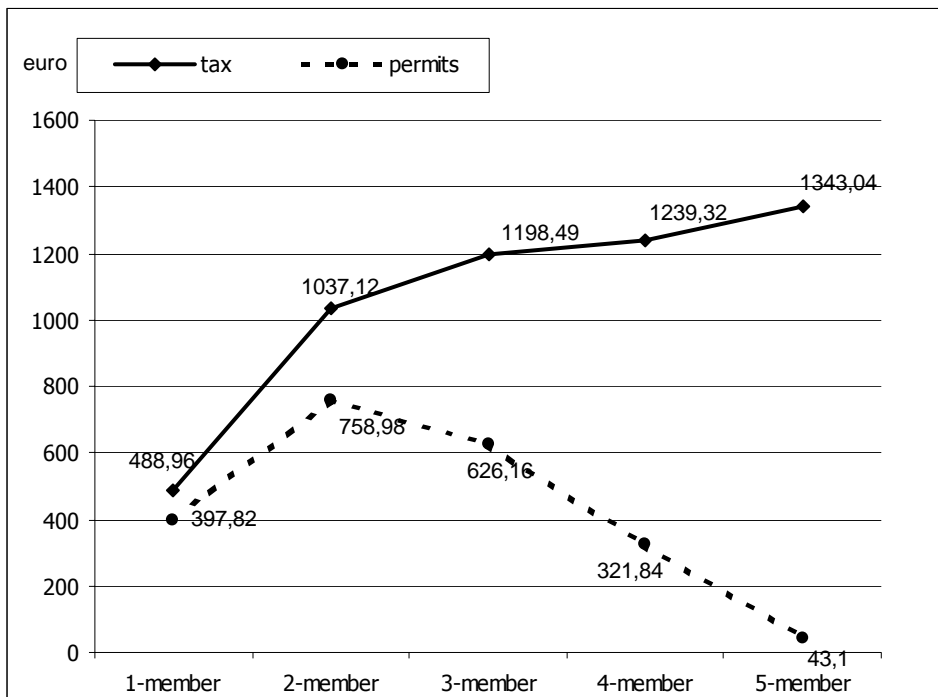


Figure 7.22 depicts the financial losses (or surpluses) caused by the introduction of taxes or permits according to the household's size. We observe two dispersing curves: financial loss of taxes increases with increasing household's size while financial loss of permits decreases. While financial loss for singles are quite similar (489 euro in the case of taxes versus 398 euro in the case of permits), there is a large difference between both financial losses in the case of large households (1,343 euro for taxes versus 43 euro for permits). There are two explanations for this. Firstly, our initial allocation ratio is based on the number of household's members, resulting in a higher amount of allocated permits. Secondly, larger households consume more fuel and hence pay in absolute terms more fuel taxes compared to smaller households.

Figure 7.22: Financial losses (in euro) of scenario 1 by household's size.



7.5 *Simulation Scenario 2*

7.5.1 Policy goal: Reduction to meet Kyoto target

In this scenario, our policy goal is set to reduce fuel consumption by 21.3 percent. As Table 7.18 showed, this reduction level corresponds to the Kyoto target for Belgium.

7.5.2 Use of taxes (scenario 2)

Tax level (scenario 2)

To meet our policy goal of a 21.3%-reduction in fuel consumption, the level of the additional tax should be equal to 1.206 euro per litre of fuel. This tax increase corresponds to a 111 % and 149 % increase of respectively the gasoline and diesel price. Furthermore, the variable costs for gasoline and diesel cars increase with respectively 87 and 100 %.

Simulation results of taxes (scenario 2)

Table 7.24 summarizes the relative changes of the number of cars owned, the fuel efficiency, average and total annual kilometres travelled by household and the total fuel consumption.

Table 7.24: Relative changes (in %) of car ownership-and-use (tax= 1.206 euro)

| | Car ownership | Fuel efficiency | Household Kilometres travelled | Total kilometres travelled | Total fuel consumption |
|----------------------|---------------|-----------------|--------------------------------|----------------------------|------------------------|
| One-car household | 10,80 | -2,48 | -7,94 | 2,00 | -0,54 |
| Two-cars household | -34,98 | -1,17 | -9,53 | -41,18 | -41,87 |
| Three-cars household | -73,55 | | -9,53 | -76,07 | -76,35 |
| No-car household | 9,38 | | | | |
| Total | -11,19 | | -9,28 | -19,78 | -21,30 |

Our outcomes of the first scenario are still valid, although more pronounced. In this scenario, the total numbers of cars decreases by eleven percent. While the number of households owning three cars decreases by more than seventy percent, the number of households that own no or one car increases with respectively nine and eleven percent. The total kilometres travelled are mainly reduced in the categories of households owning three or two cars (respectively by 41 en 76 percent).

7.5.3 Use of tradable fuel permits (scenario 2)

In this section, we discuss the following simulation results for tradable permits:

- Allocation of permits and permit price.
- General simulation results.
- Simulation results by income category.
- Simulation results by age of household's head.
- Simulation results by household's size.

Allocation of permits and permit price (scenario 2)

To meet our policy goal of a 21.3 %-reduction of the gasoline level in our base case scenario, the initial allocated level of permits amounts to 404 permits, which correspond to 404 litres of fuel per person¹⁶⁴. Based on our simulation, we obtain a permit price of 1.809 euro. Consequently, the initial allocated permits represent a monetary value of 730.84 euro.

General estimation result (scenario 2)

Table 7.25 summarizes the relative changes of the number of cars owned, the fuel efficiency, average and total annual kilometres travelled by household and the total fuel consumption. In this scenario, the total number of cars decreases by 10.63 percent. We observe a reduction of the number of households owning three cars by 79.24 percent. However, the number of households owning one

¹⁶⁴ An average household will have 891 permits at his disposal.

car grows by 13.59 percent. Consequently, we observe an increase in total kilometres travelled by one-car households. The total kilometres travelled are mainly reduced in the categories of households owning two or three cars (respectively by 42.26 and 81.02 percent).

Table 7.25: Relative changes (in %) of car ownership-and-use (permit level=404)

| | Car ownership | Fuel efficiency | Household Kilometres travelled | Total kilometres travelled | Total fuel consumption |
|----------------------|---------------|-----------------|--------------------------------|----------------------------|------------------------|
| One-car household | 13,59 | -3,45 | -7,95 | 4,57 | 0,96 |
| Two-cars household | -36,84 | -1,68 | -8,59 | -42,26 | -43,23 |
| Three-cars household | -79,24 | | -8,59 | -81,02 | -81,34 |
| No-car household | 3,98 | | | | |
| Total | -10,63 | | -8,48 | -19,10 | -21,30 |

Simulation results by income category (scenario 2)

The relative change of car ownership across income categories is visualized in Figure 7.23. We observe a clear trend towards owning less cars; the share of households owning three cars in the high-income group decreases by nineteen percent. The middle-income groups also abandon their third or second car, which gives a raise of single car ownership of fifteen to twenty percent. The only movement towards no-car households occurs at the lowest income levels: one percent of them abandon their single car.

Figure 7.23: Relative change (in %) of car ownership by income category (permit level=404)

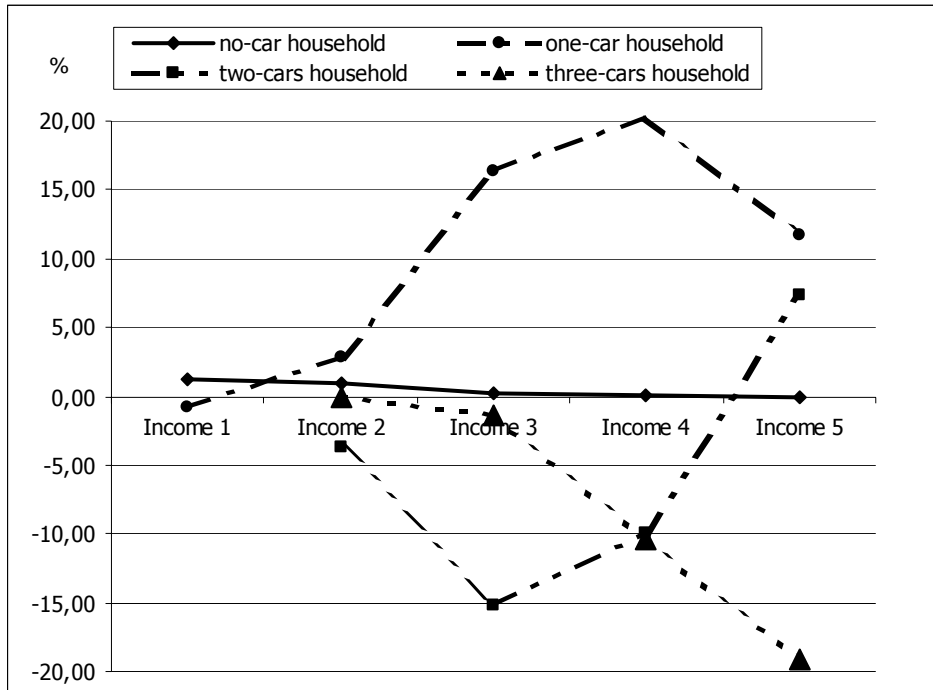


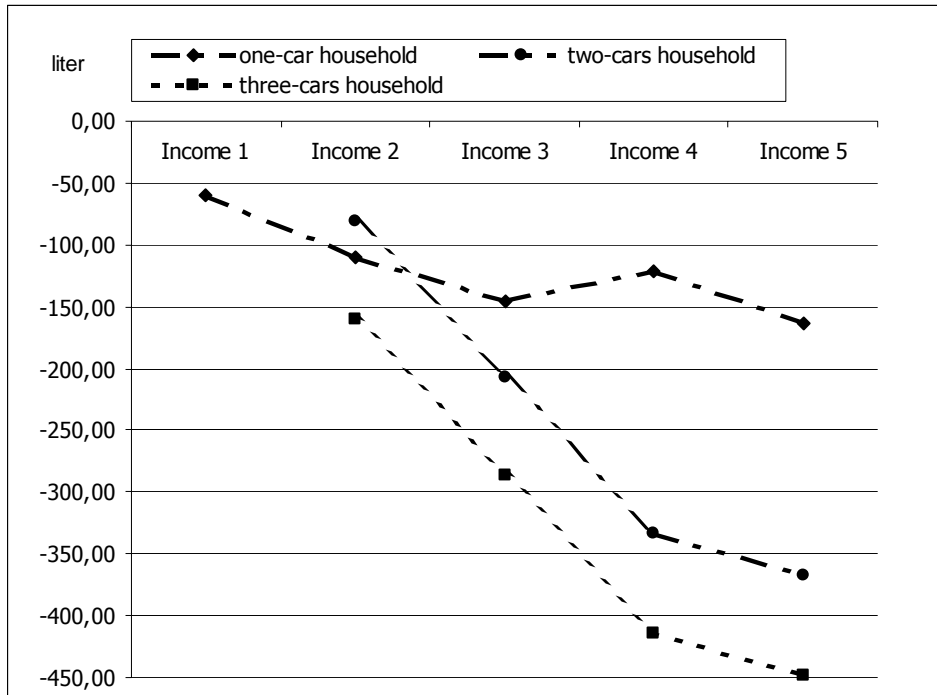
Table 7.26 shows the improvement of fuel efficiency across income categories. In this scenario, we observe a positive relation between fuel efficiency and income level for the one-car households: for the lowest income category, the improvement amounts to 2.55 percent while the fuel efficiency of the highest income category improves by 2.80 percent.

Table 7.26: Relative change of fuel efficiency by income category (permit level=404)

| | Income 1 | Income 2 | Income 3 | Income 4 | Income 5 |
|--------------------|----------|----------|----------|----------|----------|
| One-car household | -2.55 | -2.68 | -2.77 | -2.82 | -2.80 |
| Two-cars household | | -1.33 | -1.31 | -1.30 | -1.33 |

Figure 7.24 depicts the absolute changes in fuel consumption of households across income categories. While we observed in the first scenario only a positive relation between the reduction of fuel and income level when households own two or more cars, this relationship now occurs as well for households owning one car.

Figure 7.24: Change in annual fuel consumption of household by income category (permit level = 404)



Simulation results by age of household's head (scenario 2)

Figure 7.25 presents the relative changes of car ownership across age categories. Similar, but more pronounced observations compared to the first scenario can be made: middle-aged households abandon their second car (i.e. a reduction of more than ten percent), while young and elderly household's head abandon their only car (i.e. less than five percent).

Figure 7.25: Relative change (in %) of car ownership by age of household's head (permit level = 404)

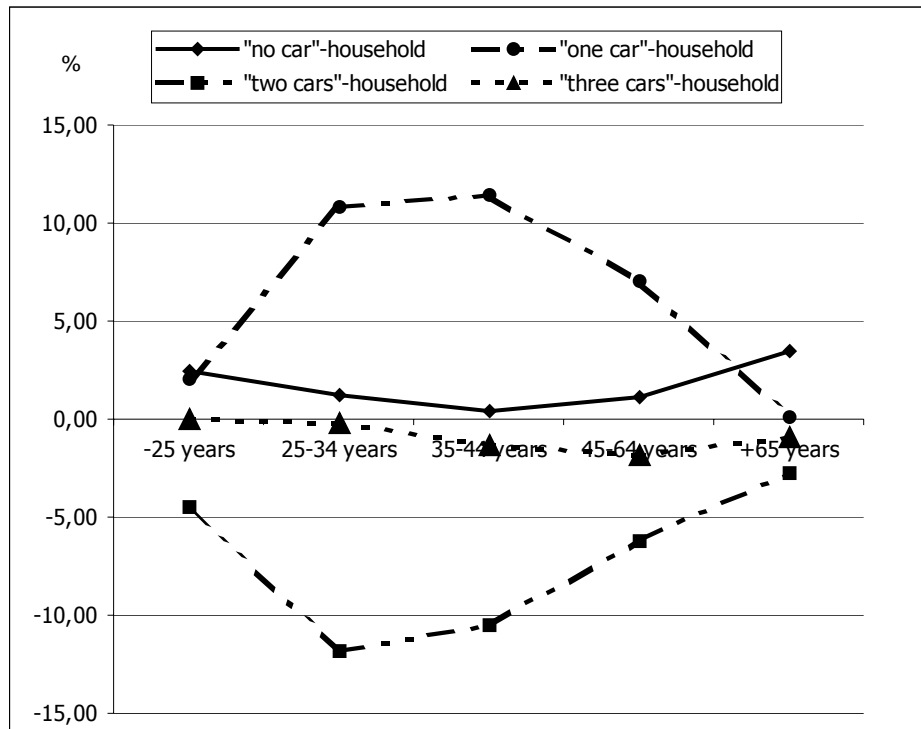


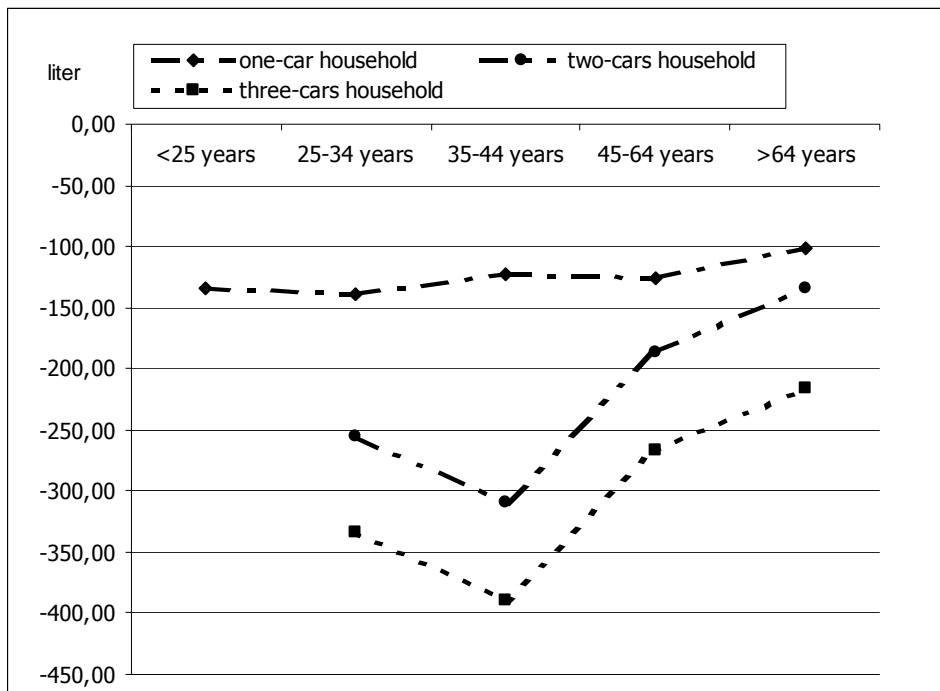
Table 7.27 shows an improvement of fuel efficiency across age categories. We observe a positive relationship between fuel efficiency and age of household's head.

Table 7.27: Relative changes of fuel efficiency by age of household's head (permit level = 404)

| | <25 years | 25-34 years | 35-44 years | 45-64 years | ≥65 years |
|---------------------|-----------|-------------|-------------|-------------|-----------|
| One-car households | -2,62 | -2,59 | -2,67 | -2,73 | -2,79 |
| Two-cars households | | -1,28 | -1,26 | -1,34 | -1,35 |

Figure 7.26 illustrates the changes in fuel consumption of the different households according to age category. As discussed in the first scenario, we observe that the absolute reduction level is the highest for middle-aged households.

Figure 7.26: Change in annual fuel consumption of household by age of household's head (permit level = 404)



Simulation results by household's size (scenario 2)

Figure 7.27 depicts the relative changes of car ownership across household's size. The same observation as in the first scenario can be made: an increase in households owning no car is the highest for singles while the other households abandon their second car.

Figure 7.27: Relative change (in %) car ownership by household's size (permit level=404)

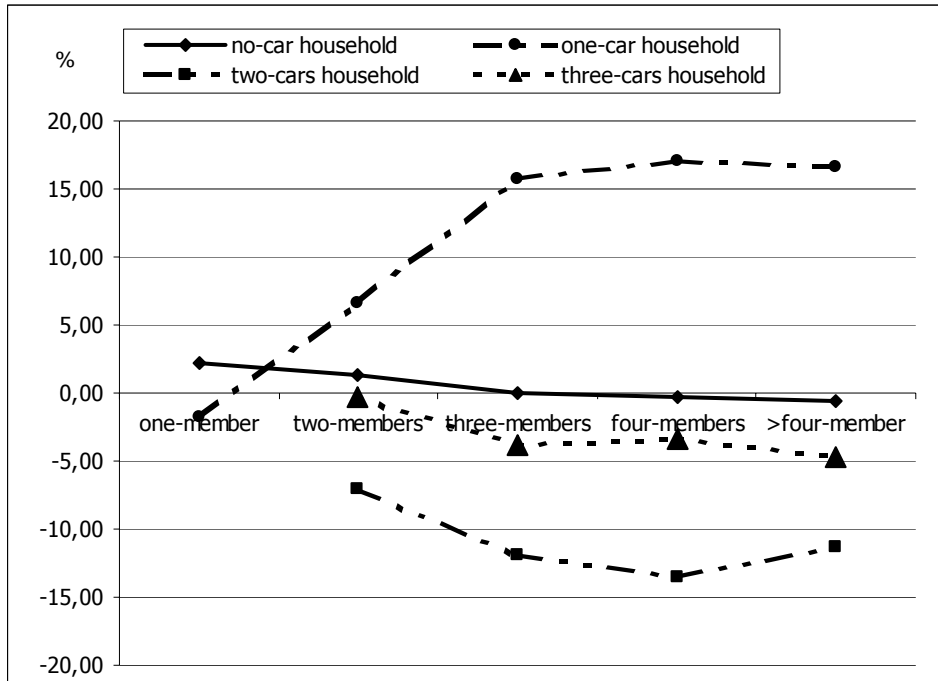


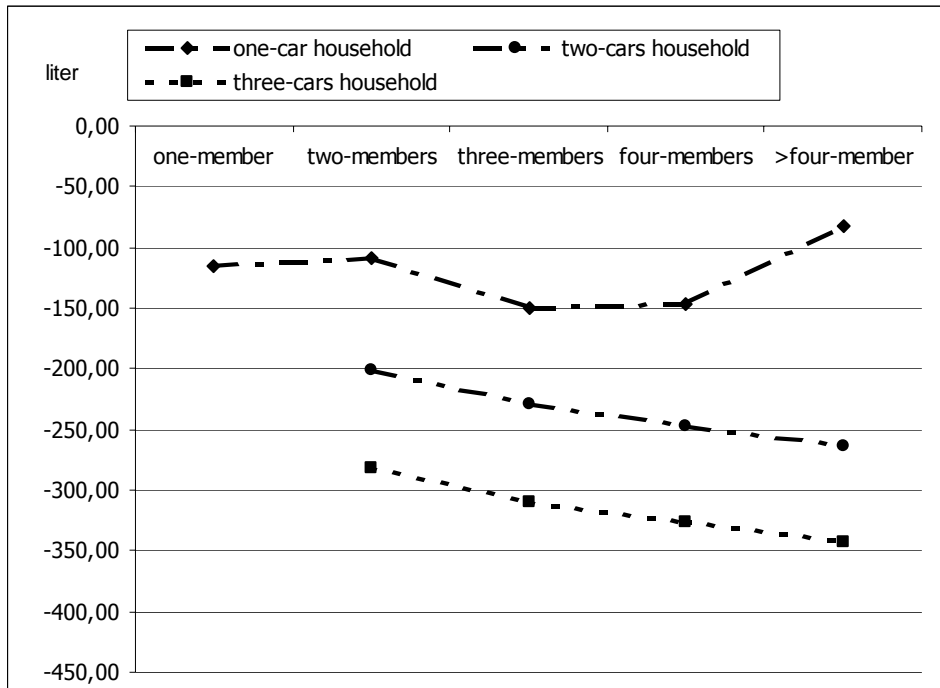
Table 7.28 shows the improvement of fuel efficiency across household's size categories. While there was no clear relation in the first scenario between fuel efficiency and household's size, we now observe a positive relationship between fuel efficiency and household's size: the more members, the lower the gain in fuel efficiency.

Table 7.28: Relative changes of fuel efficiency by household's size (permit level=404)

| | one-member | two-members | three-members | four-members | >four-members |
|---------------------|------------|-------------|---------------|--------------|---------------|
| One-car households | -2,73 | -2,71 | -2,73 | -2,69 | -2,64 |
| Two-cars households | | -1,33 | -1,32 | -1,29 | -1,27 |

Figure 7.28 shows the changes in fuel consumption of the different households according to their size. There is a similar relation as in the first scenario: the reduction level for the one-car households shows little variation, while the absolute reduction level increases with the household's size when households own two or more cars.

Figure 7.28: Change in annual fuel consumption of household by household's size (permit level = 404)



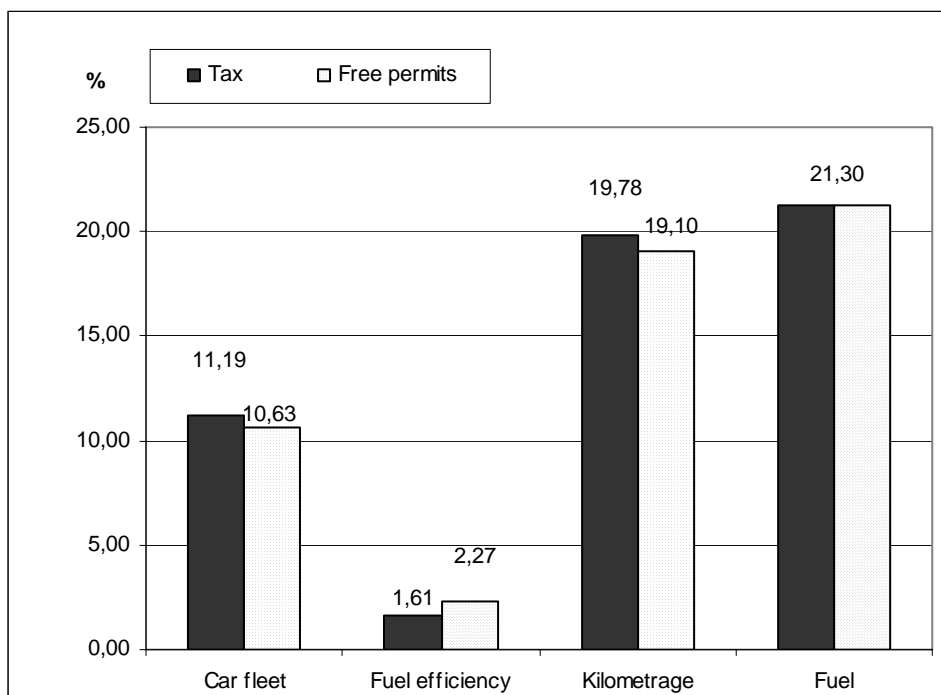
7.5.4 Discussion of scenario 2

Similarly to scenario 1, we now compare the effectiveness, welfare and financial effect of taxes versus permits. Moreover, we also include an estimation of the transaction costs.

Effectiveness (scenario 2)

Figure 7.29 shows that both the implementation of an additional tax of 1.206 euro and the distribution of 404 permits results in a reduction of fuel consumption by 21.3 percent. However, the reduction levels for car ownership, fuel efficiency and total kilometres travelled are not equal. On the one hand, the introduction of taxes leads to a higher reduction in the car fleet compared to permits (11.19 versus 10.63 percent). On the other hand, permits give households a higher incentive towards using fuel-efficient cars (2.27 percent versus 1.61 percent). Consequently, the use of permits results into a lower reduction of annual kilometres travelled.

Figure 7.29: Relative reduction levels of scenario 2



Welfare effect (scenario 2)

Figure 7.30 depicts the consumer losses (or surpluses) resulting from the introduction of taxes and permits according to the household's income level. Similar to the first scenario, the upward slopes depict the positive relation between the level of income and the consumer losses of taxes and permits. However, consumer losses for taxes are always higher compared to permits for all income categories: While permits generate a consumer surplus of 465 euro for the lowest income category, they face a consumer loss of 262 euro with taxes.

Figure 7.30: Consumer loss by income category (scenario 2)

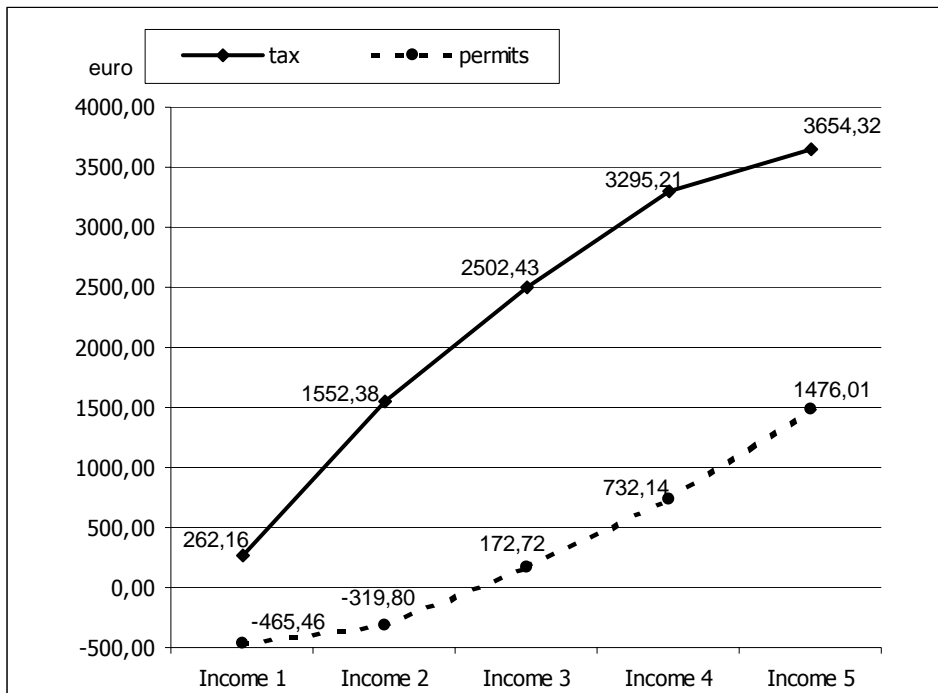


Figure 7.31 presents the consumer losses relative to the household's income across different income categories. We observe similar patterns as in the first scenario: fuel taxes are regressive starting from the second income category, while fuel permits are progressive. The households of the second income category have a consumer loss of almost 10 percent relative to their income with taxes, while with permits they have a surplus of 2 percent. The highest-income households have a relative loss of more than 5 percent with taxes and more than 2 percent with permits.

Figure 7.31: Relative consumer loss (in percent) by income category (scenario 2)

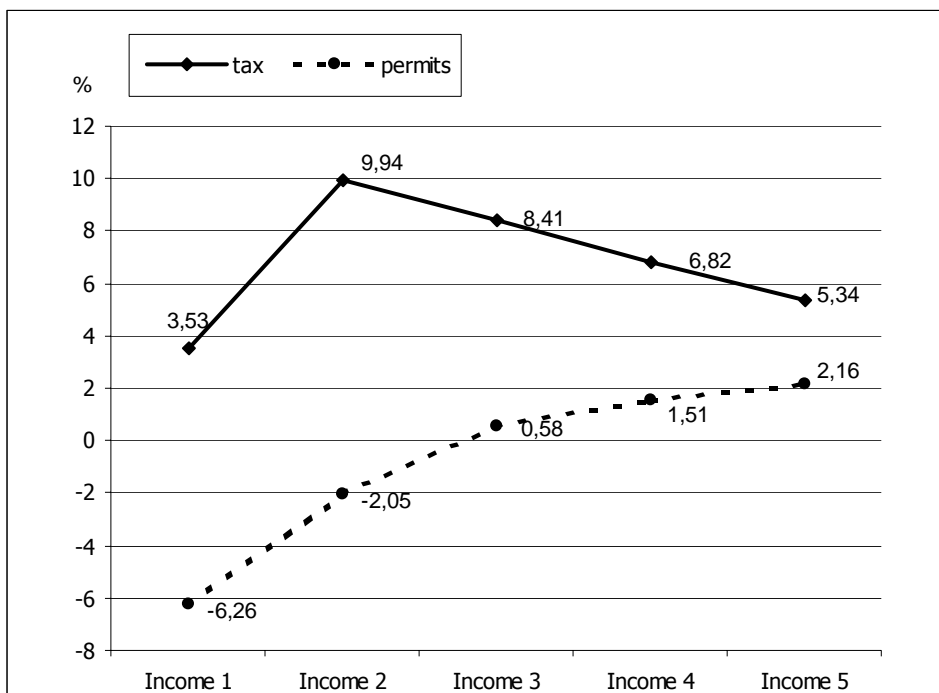


Figure 7.32 compares consumer losses of taxes and permits according to the household's head age. Similar to the first scenario, we observe that permits generate lower consumer losses compared to taxes. Again, this difference is the smallest for households with an elderly head: Their consumer losses value 1,188 euro in the case of taxes compared to 400 euro with permits.

Figure 7.32: Consumer loss by age of household's head (scenario 2).

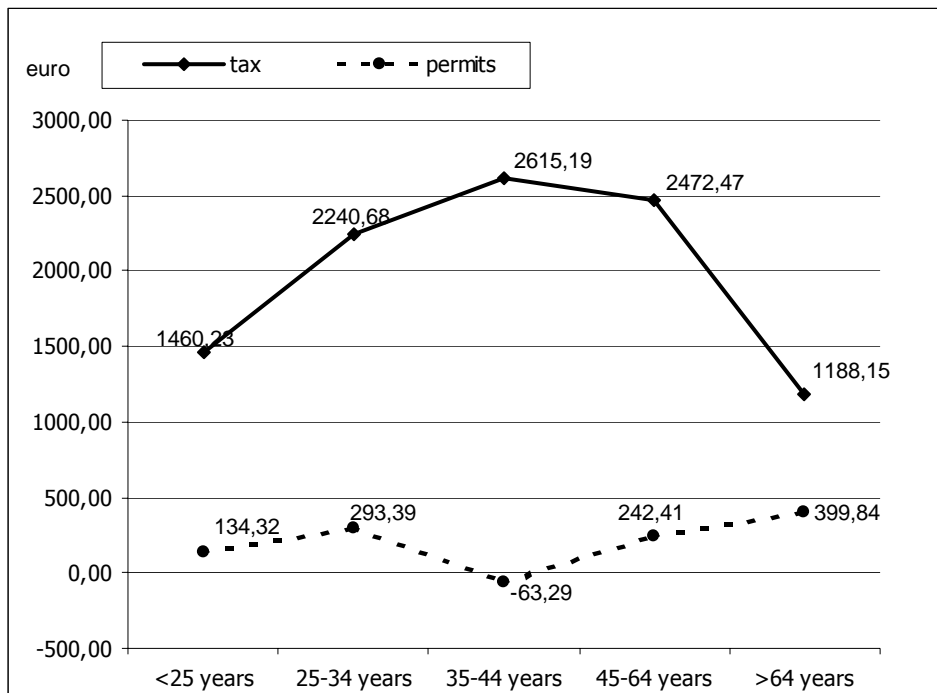
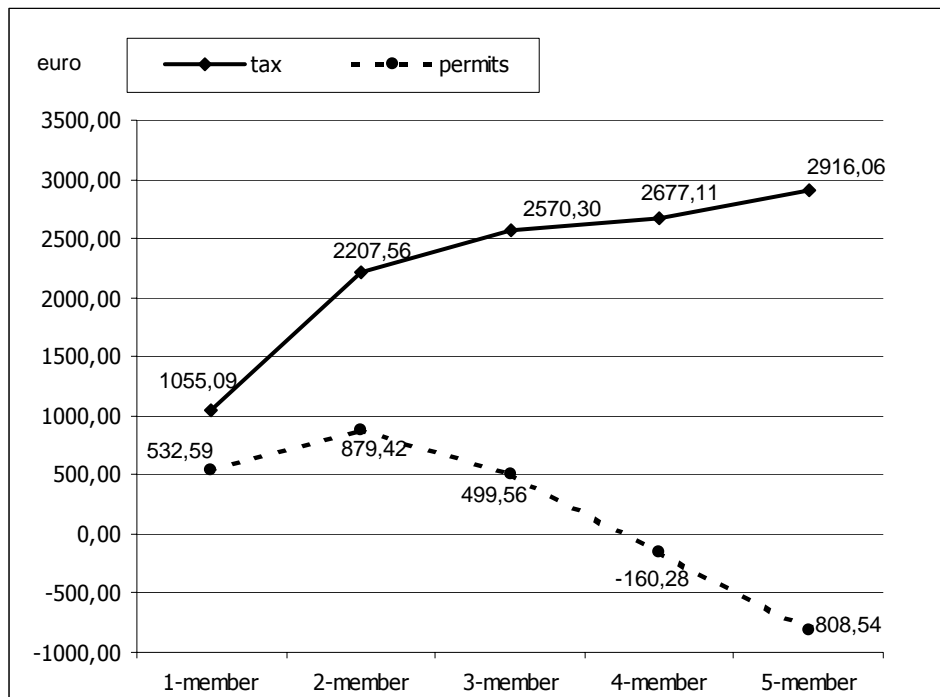


Figure 7.33 depicts the consumer losses (or surpluses) caused by the introduction of taxes and permits according to the household's size. Similar to the first scenario, we observe two dispersing curves: consumer losses of taxes increase with increasing household's size while consumer losses of permits decrease.

Figure 7.33: Consumer loss by household's size (scenario 2)



Financial effect (scenario 2)

Similar to scenario 1, we use equation 7.2 and 7.4 to calculate the financial effects on households of respectively taxes and tradable permits.

Figure 7.34 depicts the financial losses (or surpluses) resulting from the introduction of taxes or permits according to the household's income level. Similar to the first scenario, there is a positive relation between the level of income and the financial losses of both taxes and permits. Furthermore, we observe that financial losses for taxes are higher than permits for all income categories: while for the lowest income category permits generate a financial surplus of 351 euro, they face a financial loss of 240 euro with taxes. However, in this scenario, the financial losses in the highest income category are of similar magnitude (i.e. 3,352 euro for taxes versus 2,935 euro for permits).

Figure 7.34: Financial loss by income category (scenario 2)

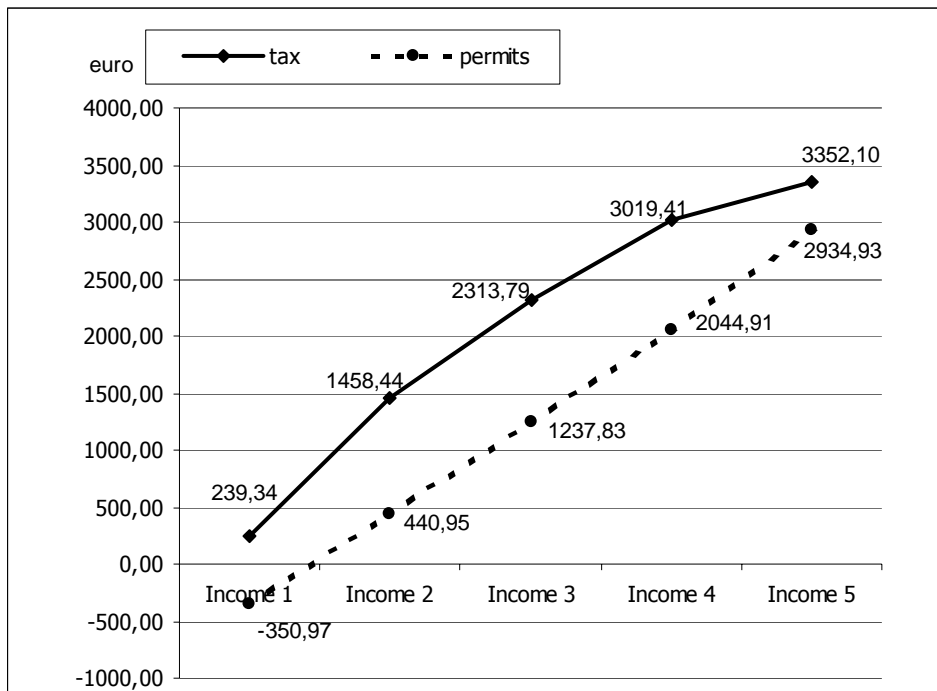


Figure 7.35 presents the financial losses relative to the household's income across different income categories. We observe similar patterns as in the first scenario: fuel taxes are regressive starting from the second income category, while fuel permits are progressive.

Figure 7.35: Relative financial loss (in %) by income category (scenario 2)

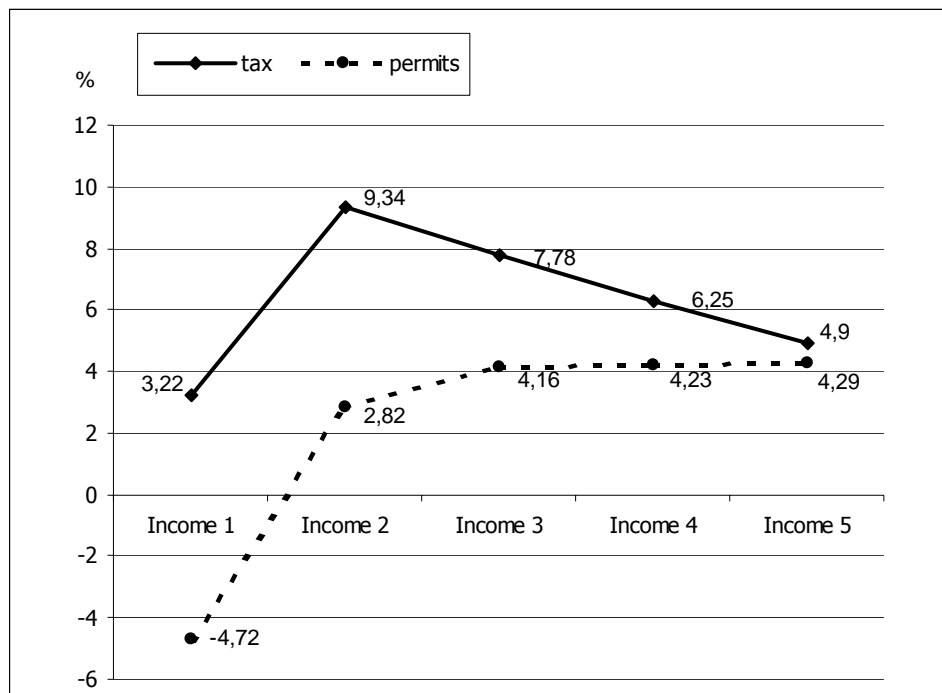


Figure 7.36 compares financial losses of taxes and permits according to the household's head age. Similar to the first scenario, we observe that permits generate lower financial losses compared to taxes. This difference is the smallest for households with an elderly head: their financial loss is 1,105 euro in the case of taxes compared to 888 euro with permits. Moreover, differences between categories are less pronounced with permits: while the range for permits varies between 803 and 1,334 euro, the financial loss with taxes varies between 1,105 and 2,380 euro.

Figure 7.36: Financial loss by age of household's head (scenario 2).

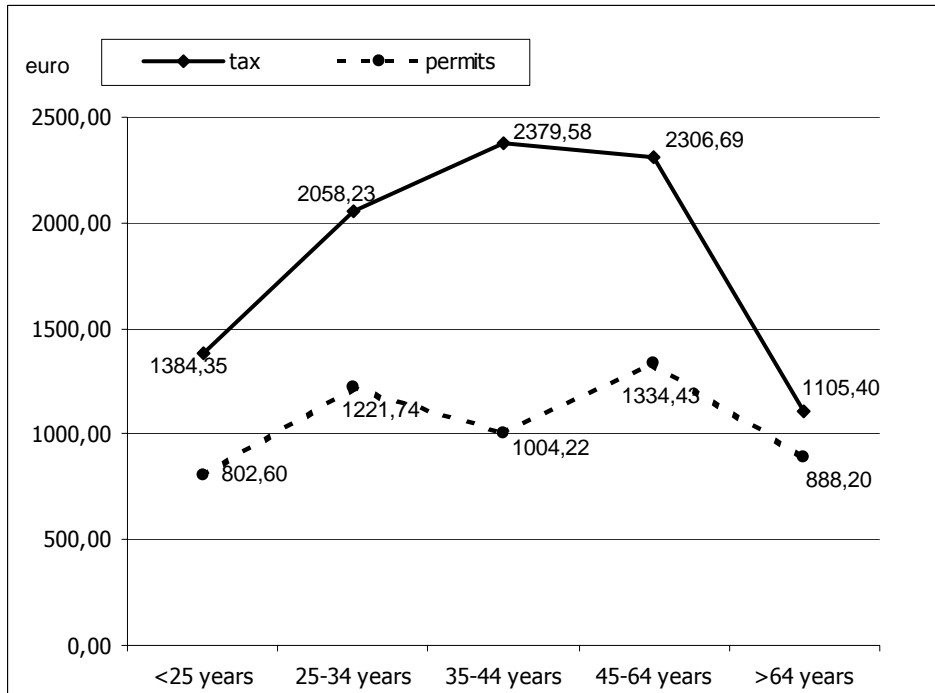
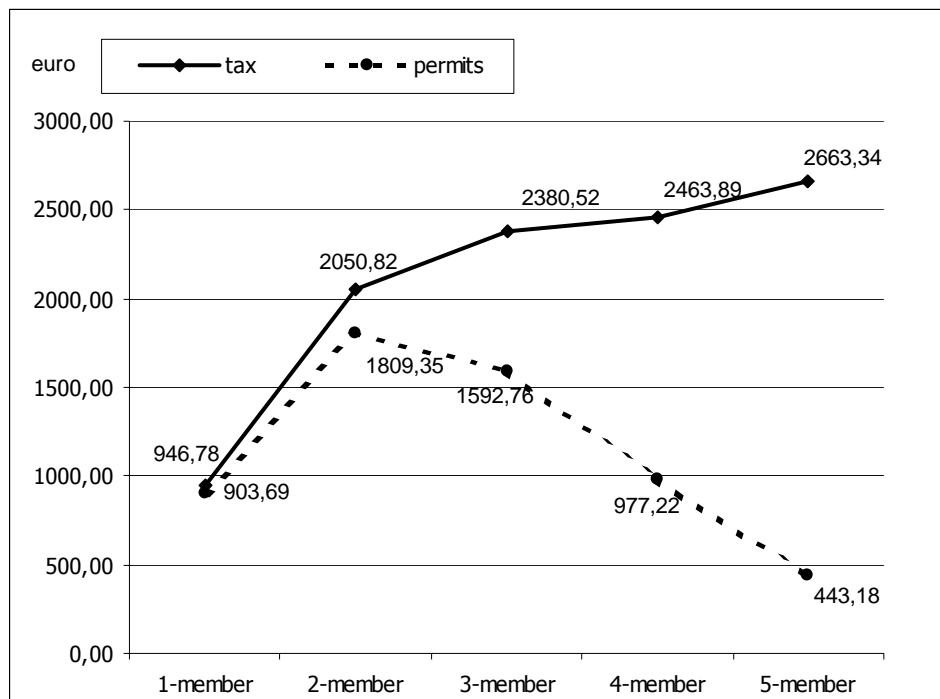


Figure 7.37 depicts the financial losses (or surpluses) caused by the introduction of taxes or permits according to the household's size. Similar to the first scenario, we observe two dispersing curves: financial loss of taxes increases with increasing household's size while financial loss of permits decreases. However, while in the first scenario financial losses have similar values for singles, this now also occurs for duos (2,051 euro for taxes versus 1,809 euro for permits).

Figure 7.37: Financial loss by household's size (scenario 2)



Transaction costs

The introduction of a tradable fuel permit scheme within the existing tax structure generates additional transaction costs. We estimate the following transaction costs¹⁶⁵:

- Administrative costs including the initial distribution of permits, the depreciation costs when refuelling and the costs of keeping a permit account;
- Monitoring, enforcement and compliance costs, which include that fuel producers keep a permit record of their fuel sold;
- Negotiation and contracting costs, which result from the establishment of a permit market.

Our calculation¹⁶⁶ is based on previous or on-going experiences with smart-cards. Firstly, all Flemish households receive a smart card, uploaded with a number of permits. At present, a similar distribution of smart-cards is on-going in Belgium: all citizens receive an electronic identity (e-ID) card. The Federal Government (2004) calculated that issuing and distributing this e-ID-card costs 10 euro. Since the permit card needs to have less functions as is required by an e-ID card, we consider 10 euro per card as a good estimation of the initial distribution costs. Based on the total number of households in Flanders in 2000¹⁶⁷, and assuming that each household receive only one card, we obtain a distribution cost of almost 24 million euro.

Secondly, this permit card should be depreciated at fuel stations. Fapetro (2001) reports that on January 1st, 2001, there were in Flanders 2,693 fuel

¹⁶⁵ Consequently, the legislative and information and planning costs are not included in our estimation. For reasons of simplicity, we assume that these costs are similar for a tax increase in this magnitude (+1.206 euro/l).

¹⁶⁶ In our estimation of transaction costs, we use current prices (i.e. for the year 2005). Note that, the cost calculations of car ownership-and-use, which we made earlier are based on prices of 2000.

¹⁶⁷ In 2000, there were 2,391,694 households in Flanders (NIS (2001)).

stations¹⁶⁸, mostly equipped with electronic payment infrastructure¹⁶⁹. A private company (BANKSYS) operates this infrastructure. Most of the banks have a connection to this system, which enable their customers to pay their fuel purchases electronically¹⁷⁰. Depreciating fuel permits can be seen as an additional transaction of the actually functioning electronic refuelling system. Therefore, we only take into consideration the marginal costs of one electronic transaction, which at present values 6.17 eurocent¹⁷¹. Furthermore, if we assume an average fill up of 50 litres of fuel¹⁷² and consider an average annual household fuel consumption of 1,132 litres¹⁷³, the depreciation costs at the fuel station represent an annual cost of 1.42 euro for each household, or 3.4 million euro for Flanders as a whole.

A final administrative cost component is keeping the fuel permit accounts. Since we opted for an exchange market whereby financial institutions act as intermediaries, we expect that they keep the fuel permit accounts of all households. Consequently, we compare this fuel permit account with an ordinary bank account. Since 2003, the cost of keeping a basic bank account¹⁷⁴ is set at a fixed maximum price¹⁷⁵: 12 euro¹⁷⁶. If we assume that all Flemish

¹⁶⁸ In 2003, there were only 2,317 fuel stations in Flanders (Fapetro (2003)).

¹⁶⁹ Belgische Petroleumfederatie (2002) reported that 84 percent of the Belgian fuel stations were equipped with electronic payment infrastructure. In 2004, this number increased to more than 90 percent (Belgische Petroleumfederatie (2005)).

¹⁷⁰ Customers are only able to refuel after the system checks and approves their liquidity at their bank.

¹⁷¹ BANKSYS, personal communication.

¹⁷² This assumption was also used in Meulepas et al. (1999).

¹⁷³ This is the annual consumption of an average household in our base case scenario.

¹⁷⁴ This bank service includes a limited number of manual actions and an unlimited number of electronic direct debit instructions, transfer of money, deposition and collection of money. Moreover, administration costs and a two-weekly extract of the bank account are also included.

¹⁷⁵ There is a large price variation for bank accounts in Belgium. Some banks provide a free bank account, others have different prices according to the age of the bank account holder.

¹⁷⁶ Wet van 24 maart 2003 tot instelling van een basis-bankdienst

households keep one fuel permit account, the annual total costs of keeping fuel permit accounts is estimated at 29 million euro.

Subsequently, we estimate the monitoring, enforcement and compliance costs. Since the introduction of fuel permits does not imply that the tax system and their corresponding monitoring efforts are abandoned, no additional monitoring and enforcement costs are needed. However, as we discussed in chapter 3, the fuel producers and importers have to present a proportional amount of TFPs for the fuel sold. This implies that they also need to keep a fuel permit account. Since this task can easily be integrated within the current accounting system of the fuel producers, we expect that the additional costs are limited to employ one additional bookkeeper at the account department of the different fuel suppliers. We assume the annual cost of employing one bookkeeper at 96,800 euro¹⁷⁷. Fapetro (2001) reported that in 2000, there were 9 large and 30 small fuel companies in Belgium. If we assume that only 60 percent of the small companies were operational in Flanders, we take into account 27 fuel companies, which need to keep a permit account.

Finally, we estimate the negotiation and contracting costs. Clearly, the estimation of the costs related to the exchange of permits between sellers and buyers is the most difficult task. We estimate the broker's commission for the tradable fuel permit scheme, which we discussed in chapter 3. There are 20.5 percent of the households that do not own a car¹⁷⁸. Consequently, we assume they exchange their surplus of permits¹⁷⁹. Furthermore, we assume an equal amount of buying and selling transactions. The initial allocation amount to 929

¹⁷⁷ Based on the wage scale of an administrative staff member (KVIV (2005)).

¹⁷⁸ This is the share of no-car households in our base case scenario.

¹⁷⁹ Obviously, it is possible that also households, that own one or more cars are selling permits. However, we assume that this underestimation is compensated by the fact that most households that do not own a car (singles and duo's), have a smaller amount of initially allocated permits, compared to the average household. In other words, we assume that 20.5 percent of the total volume of permits is sold on the exchange market.

permits for an average household and each permit values 2.19 euro¹⁸⁰. Since sellers of permits are typically low-income households, we expect that they have only limited access to electronic resources. To this end, we use a differentiated broker's fee: We apply an average broker's fee of one percent for selling permits and of 0.5 percent for buying permits¹⁸¹. Finally, we obtain an annual cost of exchange of 15 million euro. Table 7.29 summarizes the estimated transaction costs.

Table 7.29: Estimation of the transaction costs of the TFP scheme

| Cost category | Description | Costs for an average household (in euro) | Total costs (in million euro) |
|--------------------------------------|--|--|-------------------------------|
| Administrative | Distribution of fuel permit cards (non-recurrent cost) | 10.0 | 23.9 |
| | Depreciation when refuelling | 1.4 | 3.4 |
| | Keeping fuel permit account | 12.0 | 28.7 |
| Monitoring, enforcement & compliance | Permit record of fuel suppliers | 0.0 | 2.6 |
| Negotiating & contracting | Permit exchange | 6.3 | 15.0 |
| Total | | 29.7 | 73.6 |

We estimate that the total transaction costs during the first year of implementation amounts to 71 million euro for Flanders as a whole. For an average household, this corresponds to a value of 29.7 euro. If we take into account this additional cost, the conclusions we earlier made in our financial analysis can be maintained. More specifically, the different households categories are better off with tradable permits compared to taxes. The lowest-

¹⁸⁰ This is the amount of initially allocated permits for a household and the permit price as we calculated in this scenario.

¹⁸¹ When a stock market exchange transaction is done electronically, the brokerage is 0.5 percent. Otherwise, the costs are one percent of the transaction's value (ING (2005)).

income category is even better off with tradable permits compared to the status-quo option.

CHAPTER 8 Conclusions, limitations and topics for further research

8.1 Conclusions

8.1.1 Prioritisation of policy goals

In this dissertation, we have studied and assessed the economic feasibility of using tradable permits in private road transport. As we portrayed in the introduction, many benefits originate from our current road transport, which is mainly car-based. However, there is a drawback to our ever-increasing car use: negative externalities such as pollution, global warming, reduced human health, congestion, road fatalities and an over-dimensioned car-related public space. Many of these externalities, especially those related to the environment and human health, originate from the dependency of fossil fuels as energy source. Until now, the availability of fossil fuels has always been considered as abundant. However, experts alert that the peak of oil production is getting closer: within seven to forty years, oil supplies will no longer meet the steadily growing worldwide need of fossil fuels. Modern history teaches us that this trend is inherent to any kind of energy source (i.e. wood and coal). The consequences of a limited availability of oil are incalculable for our society. However, for our private road transport this would essentially lead to a decrease of car use. On the one hand, this would lead to a decrease of the negative externalities, but unfortunately, on the other hand, all benefits related to car use would be reduced as well. At present, policy goals are mainly defined to cure our transport system from these negative size-effects, rather than decreasing the oil dependency. In our research, the reduction of fuel consumption is considered the major policy goal.

8.1.2 Policy instruments

The actual set of policy instruments to reduce fuel consumption is currently limited to fuel taxes and fuel economy standards. Little attention has been paid to the feasibility of limiting demand or setting a quantitative cap, for example by introducing tradable fuel permits. The tradable fuel permit system creates a cash transfer program whereby the transferred amount varies with the household's fuel consumption: if the consumption is lower than the level of the cap, we have a positive cash transfer; in the opposite case, we have a negative cash transfer. Furthermore, the greater the difference between consumption and the level of cap, the greater is the cash transfer in absolute terms.

As we described in chapter four, in the wake of the oil crisis of the seventies, a lot of research has been done in the United States to ration gasoline by coupons. Since the nineties there is a revival of using tradable permits in many areas. Unfortunately, research into using tradable permits in road transport has been mainly a rhetorical discussion.

8.1.3 Model to evaluate policy instruments

This dissertation goes beyond the recent noncommittal statements and researches the economic impact of the introduction of tradable fuel permits in Flanders.

Consequently, this objectivity requires an intense modelling approach of car ownership-and-use, which was until this research non-existing in Flanders. The Household Travel Survey 2000, which comprises 3,000 observations, provides us with actual data on car ownership-and-use in Flanders. Based on these data, we calculate the fixed and variable car costs that households are facing. In our sample, we observe a clear difference between fixed and variable costs according to different car characteristics such as car size, vintage and fuel type and purchase condition.

Next to these fixed and car costs, we are able to include car specific and socio-economic characteristics as independent variables in our model. The choice of these variables is based both on theoretical considerations and on practical

availability and statistical tests. By using these disaggregate data, our study estimates more accurately the behavioural effects across households with respect to car ownership-and-use in Flanders. Since we explain the causal relationships between these variables and car ownership-and-use, the model can be used to forecast the effect of future changes in any of these variables.

The basic framework of our model is derived from a model in Dubin and McFadden (1984), where they conduct a two-step approach: first, they applied a logit model to estimate the discrete choice, and then conditional on the chosen choice, they estimated a continuous demand. The observed values for the explanatory variables of the base year 2000 are used to simulate the base case scenario.

The simulation results of the base case scenario demonstrate that car and fuel needs are positively correlated with the income level. The economic hypotheses behind this observation are twofold. Firstly, the income growth raises the value of time and consequently, shifts transport demand from slow and cheaper modes to faster and more expensive modes such as the car. Secondly, the income growth increases the household's means to spend money on fuel and cars.

Moreover, we observe that car ownership-and-use is correlated to other household's characteristics such as household's size and the age of the household's head.

8.1.4 Evaluation of fuel taxes and permits

Simulation of two scenario's

Next to the base case scenario we simulated two other scenarios. In the first scenario, the policy goal is set to reduce the fuel consumption to the level of 1990, while the second scenario aimed to meet the Kyoto target. To simulate these policy goals, we changed the fuel price (i.e. the variable cost variable) of our base case scenario.

Discrete-continuous choice models of car ownership-and-use are typically used to simulate the effect of an increase in the fuel price (typically by taxes). Our methodology was slightly different: we set a fixed reduction level and calculate the corresponding tax level and permit price. This approach required a trial-and-error method to calculate the tax and permit level to reach a specific reduction level. For the first scenario, which comprised a reduction level of 14.6 percent of the level of 2000, the level of the additional tax should be equal to 0.598 euro per litre of fuel. When the reduction level is set on 21.3 percent (scenario 2), an additional tax of 1.206 euro should be levied.

The initial allocation of fuel permits is based on the number and the age of the household's members: every household member receives a same amount of permits. However, persons older than 65 years receive only 50 percent of this amount. In the first scenario, the initial allocated level of permits amounts to 439 permits, which correspond to 439 litres of fuel per person. In this case, the calculated permit price amounts to 0.798 euro. In the second scenario, the distribution of 404 permits results in a reduction of the fuel consumption by 21.3 percent. The corresponding permit price equals 1.809 euro.

In both scenario's, we observe a significant higher permit price compared to the tax level. The evident rationale of this observation is that the initial allocation of permits results in an additional income and, consequently, more money to spend on car ownership-and-use.

Effectiveness

We evaluate both instruments as effective to reach the policy goal of reducing fuel consumption. However, our results demonstrate that taxes and permits have a different path towards the fuel reduction target: the reduction levels for car ownership, fuel efficiency and total kilometres travelled are different. On the one hand, the introduction of taxes leads to a higher reduction in the car fleet compared to permits. On the other hand, permits give households a higher incentive towards using fuel-efficient cars. Consequently, the use of permits results into a lower reduction of annual kilometres travelled. We conclude that

permits are less effective to reduce the number of cars and the annual kilometres travelled while taxes are less effective to promote fuel-efficient cars.

Welfare

The disaggregate data enabled us to examine more systematic differences across households in the expected welfare impact from the introduction of taxes or permits. Since most households rely at least partially on cars as a mean of transportation, the policy goal to reduce fuel use would inevitably result in welfare losses. We distinguish two sources of welfare losses. On the one hand, households would not fully substitute away from driving cars after a tax increase or introduction of permits. Consequently, they incur higher expenditures on fuel purchase, which results in a reduction of real income. On the other hand, households that switch to other modes incur a loss of well-being since they would have preferred to use their car in the absence of the policy change.

The simulation results demonstrate a positive relation between the level of income and the absolute consumer losses of both taxes and permits. Furthermore, the consumer losses for taxes are higher than permits for all income categories in both scenarios. When we compare consumer losses of taxes and permits according to the household's head age, we observe that in the case of both instruments, consumer losses increase with an increasing age until the age category of 35-44 years, while older households face the lowest consumer losses. Finally, we observe that consumer losses of taxes and permits increase with increasing household's size.

We conclude that welfare losses of taxes for households are always higher compared to permits, not taken into account the effects of any redistribution scheme of tax revenues.

Financial effect

Besides the welfare effect on different household categories, we also distinguish the financial impact of taxes and permits.

The simulation results demonstrate a positive relation between the level of income and the absolute financial losses of both taxes and permits. Furthermore, the financial losses for taxes are higher than permits for all income categories in both scenarios. When we consider the financial losses relative to the household's income across different income categories, we conclude that taxes are regressive starting from the second income category, while permits are progressive. When we compare financial losses of taxes and permits according to the household's head age, we observe that in the case of taxes, financial losses increase with an increasing age until the age category of 35-44 years, while older households face the lowest financial losses. In the case of permits, we find that financial losses have lower values and are less variable compared to taxes. However, as a result of our initial allocation rule, this difference is smaller for households with an elderly head.

Finally, we observe that financial loss of taxes increases with increasing household's size while financial loss of permits decreases.

We conclude that, even if we include the transaction costs of 29.7 euro, all household categories have in both scenarios higher financial losses with taxes compared to permits. Of course, this conclusion assumes that no redistribution scheme accompanies the taxes. To design such a neutral tax policy, it is essential to take into account the potential welfare and financial losses that taxes impose on different households categories.

8.1.5 Relevance for policy makers

There is a general misunderstanding that fundamental research has little relevance for policy makers. This dissertation, which contributes to the fundamental research in the field of tradable fuel permits, intends to be evidence to the contrary. We distinguish a wide range of relevant policy issues:

- This dissertation increases the awareness that taxes and standards are not the only policy instruments to deal with private road transport externalities. We discussed several possible designs of tradable permits.

More specifically, we focused on tradable fuel permits and compared them with fuel taxes.

- The fixed and variable cost structure of the households in the household travel survey teaches us that some households due to their limited car use face very high travel cost per kilometre. An increased availability of taxis and car-sharing initiatives could provide them a better alternative than owning their rarely used car.
- Moreover, we observe that households owning company cars have a significant higher car use. The explanation for this is that the cost structure of households owning company cars consists of only fixed costs. The parameter estimates of our sub-models of car use show that an increase in fixed costs generates a higher car use. This implies that there is at present no incentive to drive less with the company car.
- With a more comprehensive understanding of relative tax burdens and welfare effects across different household's categories, policymakers are able to effectively design a neutral tax scheme or redistribution scheme when increasing fuel taxes.
- Our car ownership-and-use model is able to simulate the impact of future socio-economic trends such as a further decrease of household's size and a rise in the ageing population on car ownership and use. Since car related taxes are an important source of public revenues, an efficient estimation of car use and demand is a crucial step in drawing up the Public Budget.
- The model can simulate the effect of price instruments on car ownership-and-use and impact on different household 's categories. An actual policy question in this field is the variabilisation of fixed costs.
- Finally, our simulation results can be used as input data for other modelling activities (emission-related and travel demand models)

8.2 *Limitations*

8.2.1 **Related to the model**

In this section, we describe the limitations that are related to our model design.

The following topics are covered:

- Partial equilibrium model
- Medium term model
- Discrete choice modelling of car ownership
- Data availability
- Definition of fuel consumption

Partial equilibrium approach

Although a general equilibrium model would provide more evidence on the overall incidence of tradable fuel permits and taxes, we use a partial equilibrium model, holding fuel and car producers' behaviour fixed. Moreover, we do not consider fuel taxes and permits within the global tax framework nor accompanying instruments to ensure that government revenues are preserved. In our model setting, we assume that policy makers value goal attainment above revenue neutrality.

Medium term

We define fuel consumption by car kilometres divided by the car's fuel economy, summed over the number of car owned by a household.

Consequently, derivation of the demand for fuel requires the modelling of three household decisions: (1) number of cars owned, (2) car type and (3) number of kilometres travelled. However, these are short and medium term decisions. Long term-decisions such as location of residence and workplace are not taken into account.

Discrete choice of car ownership

We used the discrete choice modelling technique to estimate the number and type of cars owned by households. However, this imposes some limitations. In the case of two-car households, the choice alternatives are different pairs of cars.

Moreover, due to the limited observations of three-car households, we included them into our sub-model of the two-car households.

Limited data availability

In the household travel survey, the income parameter was a categorical variable, comprising five different income levels. However, due to importance of the income variable in the household's behaviour of car use and ownership we transformed them into a continuous variable with five possible values. Consequently, a lot of variation of the income variable could not be captured.

Definition of fuel consumption

In our model, we only include the fuel consumption of end-users. Consequently, the energy consumption needed during the manufacture of the different car components, the assembling of the car and the fuel production are not taken into account. However, Albrecht (2001) calculated that CO₂-emissions during car use are 25 times higher than during car production.

8.2.2 Related to permit scheme

In this section, we describe the limitations that are related to the economics of the permit scheme. The following topics are covered:

- Relative welfare change
- Transaction costs
- Auctioning of permits

Relative welfare change

Since our research interest was mainly focused on a comparison between taxes

and permits, we did not calculate the total welfare effects of both instruments. We compared only the direct income effects of taxes and permits, rather than the real income effect, which is used in total welfare estimations.

Transaction costs

This dissertation includes only a calculation of the most important transaction costs related to the introduction of permits. We assume that the other transaction costs of the introduction of permits and the adjustment of the fuel tax are negligibly small.

Auctioning of permits

This dissertation does not include a study of the optimal design of auctioning fuel permits, nor the properties of different auction formats and their welfare implications, the strategic interactions between auction participants and the optimal bidding strategies they would use to compete effectively. Moreover, we do not estimate the private and public information, inherent to each bidder, that influences his expectations of market demand and his valuation of the permits and formulate his bidding strategy accordingly.

8.3 Further research

Since this dissertation aims to contribute to the fundamental research of tradable fuel permits, many issues to further research can be defined. In this section, we distinguish further modelling activities and economic research towards a better understanding of tradable fuel permits¹⁸².

8.3.1 Modelling activities

Model structure

¹⁸² Open research questions in the field of tradable permit schemes in general and in other transport applications are not taken into consideration.

As we discussed in chapter 5.1.3 and 5.5 we used stringent assumptions by using the MNL-model. By using other models these assumptions can be eased. We especially consider the use of cross-nested and mixed multinomial logit as further research areas.

Extensions to the model

The model of car ownership-and-use for Flanders, which we developed in this dissertation could be further extended:

- The number of kilometres travelled could be further classified according to travel purpose. Train (1986) used this modelling approach. This would provide a more detailed estimate of the impact on peak travel;
- Instead of using the model for the entire region of Flanders, it can be applied to a limited geographical area such as the provincial or urban level;
- The choice of car type can be refined to make a model choice. Moreover, emission rates can be applied to measure the impact on pollution.

Full equilibrium model

Our model is a partial-equilibrium model, which implies that we only take into account the demand curve and assume a fixed supply curve. However, as we discussed in chapter four, car and fuel industry change their behaviour when policy changes are introduced. Goldberg (1998) developed a full-equilibrium model.

Stated preference

In this dissertation, we assume that household's behaviour is similar for price and quantity instruments. However, there are likely to be other factors (e.g. the endowment effect as described in chapter four) that influence demand for car ownership and use with permits. Another research question is whether low-income financials would spend their additional permit-based revenues on

luxuries or use them for their travel needs. Only a richer dataset than the one we used can reveal these preferences. A stated preference survey can be elaborated to better understand the expected household behaviour towards using, buying, selling and auctioning permits. At present, no stated-preference surveys in the field of tradable fuel permits have been conducted or were described in the literature.

Travel demand survey

The results of the Flemish household travel surveys were until now hardly used as data for modelling activities. Our explanation of the lack of interest is that the manipulation of the disaggregate data is a time-consuming activity. However, these surveys provide a rich source of information. The household's travel survey, which we used was part of an individual travel survey with more than 6,700 household members. The results of these data could be used to design a travel demand model based on the framework developed by Domencich and McFadden (1975).

8.3.2 Economic analysis of permit system

Total welfare change and inequality analysis

As we described in chapter 7, taxes and permits generate different reduction levels of car ownership-and-use. Consequently, an analysis of the total welfare change after the introduction of taxes or permits could provide more details of the welfare effects of both instruments. A social welfare approach implies that we calculate the real income changes of the different household's categories. This real income change is the net income equivalent of all the changes that result from the policy, which includes the extra expenditure, time gains, lower environmental damage, reduction in other taxes.

Moreover, Atkinson (1970) provided a theorem to relate the social welfare function and the Lorenz curve, which plots the cumulative proportion of the population against the cumulative proportion of total income received by the

income units. This Lorenz curve is useful to measure the redistributive effects of a policy change by calculating the Gini index or the Reynolds-Smolensky index. Lambert (2001) provided a useful guide to conduct this research.

Transaction costs

A detailed transaction cost study of tradable fuel permits could provide further evidence towards the feasibility of introducing such scheme. Crals and Vereeck (2005) provided a detailed overview of possible sources of transaction costs.

Auctioning of permits

In the literature, there exists a wide range of auction schemes for price determination. Klemperer (1999), who gives an extensive literature overview of the auction theory, serves an excellent guide towards the analysis of an optimal auction design.

Bibliography

- Adelman, M. and Lynch, M. (1997) Fixed View Of Resource Limits Creates Undue Pessimism. *Oil & Gas Journal* 4/7/97.
- Agren, C. (1999) Getting more for less: An alternative assessment of the NEC directive. European Environmental Bureau (EEB), The Swedish NGO Secretariat on Acid Rain and European Federation for Transport and Environment (T&E) .
- Ahmed, S. and Greene, D. (2003) A Preliminary Economic Analysis of Tradable Credits for Fuel Economy Standards, TRB 2003 Annual Meeting CD-ROM.
- Albrecht, J. (2001) Tradable CO₂ permits for cars and trucks, *Journal of Cleaner Production* 9, pp. 179-189.
- Amann, M., Bertok, I., Cofala, J., Gyarmas, F., Heyes, Ch., Klimont, Z., Makowski, M., Schöpp, W. and Syri, S. (1998) Cost-effective Control of Acidification and Ground-Level Ozone. 5th Interim Report to the European Commission , DG-XI, IIASA, Laxenburg.
- André, M. and Hammarström, U. (2000) Driving speeds in Europe for pollutant emissions estimation. *Transportation research Part D* 5:321-335.
- Archibald, R. and Gillingham, R. (1981) A Decomposition of the Price and Income Elasticities of the Consumer Demand for Gasoline. *Southern Economic Journal* 47:1021-31.
- Archibald, R. and Gillingham, R. (1981) A Decomposition of the Price and Income Elasticities of the Consumer Demand for Gasoline. *Southern Economic Journal* 47: 1021-31.
- Armoogum, J. and Madre, J-L. (1997) Item Sampling, Weighting and Non-Response. International Conference on Transport Survey Quality and Innovation, Grainau, Germany.
- Asensio, J., Matas, A., and Raymond, J.L. (2002) Petrol expenditure and redistributive effects of its taxation in Spain, *Transportation Research A* 37:49-69.
- Atkinson, A. (1970) On the measurement of inequality. *Journl of Economic Theory* 2:244-263.

- Baumol, W.J. and Oates, W.E. (1988) *The Theory of Environmental Policy*. Cambridge University Press, Cambridge.
- Becker, G. (1968) Crime and Punishment: An Economic Approach. *The Journal of Political Economy* 76:169-217.
- Ben-Akiva, M. and S.R. Lerman (1985) *Discrete Choice Analysis: Theory and Application to Travel Demand*. The MIT Press. Cambridge, MA.
- Ben-Akiva, M., Bierlaire, M., 2003. Discrete choice models with applications to departure time and route choice. In: Hall, R.(Ed.), *Handbook of Transportation Science*, second ed. Kluwer.
- Bentley, R. (2002) Global oil & gas depletion:an overview. *Energy Policy* 30(189–205).
- Bentley, R. (2005) Global Oil Depletion – Methodologies and Results. In *Proceedings of the IV international workshop on oil and gas depletion*. Organizing Committee CGE/UE. Evora .
- Bento, A., Cropper, M., Mobarak, M. and Vinha, K. (2003) *The Impact of Urban Spatial Structure on Travel Demand in the United States*. The Bren School of Environmental Science and Management, Working Paper.
- Bhat, C.R., and Sen S. (2005) Household Vehicle Type Holdings and Usage: An Application of the Multiple Discrete-Continuous Extreme Value (MDCEV) Model. *Transportation Research Part B*, Vol. 40, No. 1, pp. 35-53.
- Bierlaire, M. (2003) BIOGEME: a free package for the estimation of discrete choice models. In *Proceedings of the 3rd Swiss Transportation Research Conference*, Ascona, Switzerland.:1-27 .
- Bohm, P. and Russell, C. S. (1985) Comparative analysis of alternative policy instruments. In *Handbook of Natural Resource and Energy Economics* (Eds. Kneese, A. V. Ad Sweeney) North-Holland, Amsterdam.
- Bouwmann M. and Moll H. (2000) Energy use reduction potential of passenger transport in Europe. *Transport Reviews* 20(2):191 - 203.
- Bray W. (1980) Gas rationing: complex, costly, confusing. *ABA banking journal* 72(9): 116-121.
- Buchanan, J. (1969) *External Diseconomies, Corrective Taxes and Market*

- Structure. *American Economic Review* 59:139-147.
- Bunch, D.S. (2000) "Automobile Demand and Type Choice," *Handbook of Transport I: Transport Modeling*, David A. Hensher and Kenneth J. Button, editors, Pergamon (2000), pp. 463-479.
- Burrows, P. (1981) Controlling the Monopolistic Producer: Nihilism or Eclecticism. *Journal of Environmental Economics and Management* 8:372-380.
- Cambridge systematics (1997) Vehicle availability modelling US Federal Highway Administration, Final report
- Campbell, C. (1997) Better understanding urged for rapidly depleting reserves. *The oil and gas journal* april 5-54.
- Carlton, D.W. and Loury, G.C. (1980) The Limitations of Pigouvian Taxes as a Long-run Remedy for Externalities', *Quarterly Journal of Economics* 95(3):559-566.
- Cason, N.T. And Gangadharan, L. (2003) Transactions Costs in Tradable Permit Markets: An Experimental Study of Pollution Market Designs. *Journal of Regulatory Economics* 23(2):145-165
- Choo, S. and Mokhtarian, P.L. (2004) What type of vehicle do people drive? The role of attitude and lifestyle in influencing vehicle type choice. *Transportation Research Part A* 38:201-222 .
- Coase, R. (1960) The Problem of Social Cost. *The Journal of Law and Economics* 3(October):1-44.
- Colby, B.G. (2000) Cap-and-Trade Policy Challenges: A Tale of Three Markets. *Land Economics* 76(4):638-658.
- Crals, E. (2005) Tradable Rights and Transaction Costs: A Comparative Analysis of Alternative Policy Instruments for Emissions, Road Use and Public Deficits. Doctoral Dissertation, University of Erfurt Germany.
- Crals, E. and Vereeck, L. (2005) Taxes, Tradable Rights and Transaction Costs. *European Journal of Law and Economics*, forthcoming.
- Crals, E., Keppens, M. and Vereeck, L. (2003) Tradable Fuel Permits Towards a Sustainable Road Transport System. In: Wulfhorst, J.D. and Haugestad, A.K. *Future as Fairness: Ecological Justice and Global Citizenship*.

- Crocker, T. D. (1966) *The Structuring of Atmospheric Pollution Control Systems. The Economics of Air Pollution*. H. Wolozin. New York, W. W. Norton & Co.:61-86.
- Dahl, C. (1979) Consumer adjustment to a gasoline tax, *Review of Economics and Statistics*, 61:427-432.
- Dahl, C., and Sterner, T. (1991) Analyzing gasoline demand elasticities: a survey. *Energy Economics* 13(3): 203-310.
- Dales, J. H. (1968) *Pollution, Property and Prices*. Toronto, University of Toronto Press.
- De Ceuster G., (2004) Internalisering van externe kosten van wegverkeer in Vlaanderen. Studie uitgevoerd in opdracht van de Vlaamse Milieu-maatschappij, MIRA, MIRA/2004/04. Transport & Mobility, Leuven.
- de Jong, G. and Gunn, H. (2001) Recent Evidence on Car Cost and Time Elasticities of Travel Demand in Europe. *Journal of Transport Economics and Policy* 35(2):137-160.
- De Jong, G.C. (1990) An indirect utility model of car ownership and private car use. *European Economic Review* 34:971-985.
- De Keukeleere, D., Cornu, K., De Vlieger, I. and Van Poppel, M. (2001) Evaluatie reductiepotentieel van mogelijke aanvullende maatregelen rond milieuvriendelijke motorvoertuigen en brandstoffen. Studie uitgevoerd in opdracht van het Ministerie van de Vlaamse gemeenschap. Vito.
- De Serpa, A. (1988) *Microeconomic theory issues and applications*. Allyn and Baco. Boston .
- De Vlieger, I., Berloznik, R., Colles, A., Cornu, K., Duerinck, J., Mensink, C., Van Aerschot, W., Van Poppel, M. And Verbeiren S. (2001) Maatregelen in de transportsector voor de vermindering van CO₂ en troposferische ozon. Studie uitgevoerd in opdracht van de DWTC. VITO.
- Derber M. (1943) Gasoline rationing policy and practice in Canada and the United States. *Journal of Marketing* 8(2):137-144.
- Deville J-C, Särndal C-E, Sautory O. (1993) Generalized raking procedures in survey sampling. *Journal of the American Statistical Association* 88:1013-20.
- Dinan, T. And Rogers, D.L. (2002) *Distributional Effects of Carbon Allowance*

-
- Trading: How Government Decisions Determine Winners and Losers. *National Tax Journal* LV(2): 199-221.
- Dobes, L. (1999) Kyoto: tradable greenhouse emission permits in the transport sector. In *Transport Reviews*, 19, pp. 81-97.
- Domencich, T.A. and McFadden, D. (1975) *Urban Travel Demand, A behavioral analysis*. North-Holland. Amsterdam.
- Dubin, J. and McFadden, D. (1984) An Econometric Analysis of Residential Electric Appliance Holding and Consumption. *Econometrica* 52(2): 345-362.
- Essenhigh, R., Shull, H., Blackadar, T. and McKinstry, H. (1979) Effect of vehicle size and engine displacement on automobile fuel consumption. *Transportation research A* 13:157-177.
- Everall, P. (1968) The effect of road traffic and traffic conditions on fuel consumption. Ministry of Transport RRL Report LR 226, Crowthorne.
- Fahrar B., Unseld C., Vories R. and Crews R. (1980) Public opinion about Energy. *Annual Review of Energy* 5:141-172.
- Faiz, A., Weaver, C. S. and Walsh, M. (1996) *Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions*. World Bank, Washington, DC.
- Fapetro (2001) Verslag van de activiteiten van het fonds voor de analyse van aardolieproducten. Available at www.mineco.fgov.be/fapetro.
- Farrow, S. (1995) The Dual Political Economy of Taxes and Tradable Permits. *Economics Letters* 49(2):217-220.
- Fleming, D. (1997) Tradable quotas: using information technology to cap national carbon emissions. *European environment*, 7:139-148.
- Flugsrud, K., E. Gjerald, G. Haakonsen, H. Høie, Kristin Rypdal, B. Tornsjø and F. Weidemann, (2000) *The Norwegian Emission Inventory. Documentation of methodology and data for estimating emissions of greenhouse gases and long-range transboundary air pollutants*. Reports 2000/1. Statistics Norway. Oslo, Norway.
- Franciosi R., Kujal, P., Michelitsch, R., Smith, V. and Deng, G. (1996) Experimental tests of the endowment effect. *Journal of Economic Behavior & Organisation*. 30:213-226.

- Franciosi, R., P. Kujal, R. Michelitsch, V. Smith and G. Deng (1996) Experimental Tests of the Endowment Effect. *Journal of Economic Behavior and Organization* 30:213-226.
- Fullerton, D. and West, S. () Tax and Subsidy Combinations for the Control of Car Pollution, NBER Working Paper No. 7774, Cambridge, MA, 2000.
- Glaister, S. and Graham, D. (2000) The effect of fuel prices on motorists. The AA Motoring Policy Unit and the United Kingdom Petroleum Industry Asso, London.
- Goddard H. (1997) Using Tradable Permits to Achieve Sustainability in the World's Large Cities. *Environmental and Resource Economics* 10:63-99.
- Goldberg, P. (1995) Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry. *Econometrica* 63(4):891-851.
- Goodin, R. E. (1994) Selling Environmental Indulgences. *Kyklos* 47(4):573-96.
- Goodwin, P., Dargay, J. And Hanly, M. (2004) Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. *Transport Reviews* 24(3): 275–292 .
- Graham, D. J. and Glaister, S. (2004) Road traffic demand elasticity estimates: a review. *Transport Reviews* 24(3):261–274.
- Greene, D. L. (1992) Vehicle use and fuel economy: how big is the 'rebound' effect?, *Energy Journal*, 13: 117–143.
- Greene, W.H. (1997) *Econometric Analysis*, Third Edition. New Jersey: Prentice-Hall.
- Hajnal, I. (1995) Weight 2.1 voor Windows: Een programma voor het herwegen van steekproeven. *ISPO Bulletin* 57.
- Hanly, M., Dargay, J. and Goodwin, P. (2002) Review of Income and Price Elasticities in the Demand for Road Traffic, Report 2002/13. ESRC Transport Studies Unit, University College London.
- Harberger, A. C., 1974. *Taxation and Welfare*. University of Chicago Press, Chicago.
- Harrison, D. (1999) Tradable Permits for Air Pollution Control: The US experience. In *Implementing Domestic Tradable Permits for Environmental*

- Protection. OECD Paris.
- Harrison, D.H. and Radov D.B. (2002) Evaluation of alternative initial allocation mechanisms in a European Union greenhouse gas emissions allowance trading scheme, National Economic Research Associates. Prepared for DG Environment, European Commission.
- Hau, T.D., (1992) Congestion Charging Mechanisms for Roads: an Evaluation of Current Practice, in Policy Research Working Papers, The World Bank, Washington.
- Hausman, J. (1981) Exact consumer's surplus and deadweight loss. *American Economic Review* 71(4): 662– 676.
- Heckman, J. (1976) The common structure of statistical models of truncation, sample selection and limited dependent variables and a simple estimator for such models. *Annals of Economic and Social Measurement* 5 (Fall): 475-492.
- Henderson C. (1978) The inevitability of Petroleum rationing in the United States. Princeton Center for Alternative Futures. Princeton.
- Hicks, J. (1939) *Value and Capital*. 2nd edition, New York: Oxford University Press.
- Hirsch, R.L., Bezdek, R. and Wendling, R. (2005) *Peaking of World Oil Production: Impacts, Mitigation, & Risk Management*. U.S. Department of Energy, National Energy Technology Laboratory.
- Hofman, P., Keppens M. and Lambrechts, K. (2001) *Verhandelbare mobiliteitsrechten, een denkoefening*. De verkeersspecialist.
- Horowitz, J.L. (1982) *Air Quality Analysis for Urban Transportation Planning*. MIT Press, Cambridge, MA.
- Hotelling, H. (1925) General Mathematical Theory of Depreciation. *Journal of the American Statistical Association* 20:340-353.
- International Energy Agency (2001) *Saving Oil and Reducing CO₂ Emissions in Transport, Options and Strategies*. OECD/IEA, Paris.
- International Energy Agency (2005) *Saving Oil in a Hurry: Measures for Rapid Demand Restraint in Transport*. OECD/IEA, Paris.
- Int Panis L., De Nocker L., De Vlioger, I. and Torfs R. (2001) Trends and uncertainty in air pollution impacts and external costs of Belgian passenger car

- traffic. *International Journal of Vehicle Design* 27:183-194.
- ISPO(2003) *Weights: From sample to weighted sample*. ISPO, Leuven.
- IT Transport (2005) *How to Manual: The Valuation of Rural Travel Time Savings in Least Developed Countries*. IT Transport Ltd., Ardington
- Jensen, M. (1999) Passion and heart in transport-a sociological analysis on transport behaviour. *Transport Policy* 6:19–33.
- Kahneman, D. and Tversky, A. (1984) Choices, values, and frames. *American Psychologist* 39:341-350.
- Kahneman, D., Knetsch, J., Thaler, R. (1990) Experimental tests of the endowment effect and the Coase theorem. *Journal of Political Economy* 98:1325–1348.
- Kaplow, L. And Shavell, S. (2002) On the Superiority of Corrective Taxes to Quantity Regulation. *American Law and Economics Review* 4(1):1-17.
- Keay-Bright, S. (2001) A critical analysis of the voluntary fuel economy agreements, established between the automobile industry and the European Commission, with regard for their capacity to protect the environment. Draft paper for ECPR, Joint session, Grenoble 6-11 April 2001.
- Keezer, D. (1943) Observations on Rationing and Price Control in Great Britain. *The American Economic Review* 33(2):264-282.
- Keppens, M. and Vereeck, L. (2003a) The design and effects of a Tradable Fuel Permit system. *Proceedings of the European Transport Conference, Strasbourg, October 8-10*.
- Keppens, M. and Vereeck, L. (2003b) System requirements for the use of Tradable Transport Permits, *Proceedings of the ITS World Congress, Madrid*.
- Klemperer, P. (1999) Auction theory: a guide to the literature. *Journal of Economic Surveys* 13(3):227-286.
- Kling, C. L. and Jinhua Z. (2000) On the Long-run Efficiency of Auctioned vs. FreePermits. *Economics Letters* 69:235–238.
- Knetsch, J. (1989) The endowment effect and evidence of nonreversible indifference curves. *American Economic Review* 79:1277–1284.
- Knetsch, J. and Sinden, J. (1984) Willingness to pay and compensation

- demanded: experimental evidence of an unexpected disparity in measures of value. *Quarterly Journal of Economics* 99(2): 507-521.
- Koh, W. and Lee, D. (1994) The Vehicle Quota System in Singapore: An Assessment. *Transportation Research Part A: Policy and Practice*, 28(1):31-47.
- Koppelman, F. and Sethi, V. (2000) Closed-form Discrete-choice Models. In *Handbook of transport Modelling* edited by Henser D. and Button, K. Pergamon Elsevier.
- Kornhauser A. and Felig M. (2003) Marketable Permits for Peak Hour Congestion in New Jersey's Route 1 corridor. TRB 2003 Annual Meeting, Washington
- KVIV (2005) Voorwaarden betreffende opdrachten van Raadgevend Ingenieurs website:X.
- Laffont, J. and Tirole, J. (1996) Pollution permits and environmental innovation. *Journal of Public economics* 62:127-140.
- Lambert, P. (2001) The distribution and redistribution of income. Manchester University Press, Manchester.
- Loewenstein, G. and Adler, D. (1995) A bias in the prediction of tastes. *The economic Journal* 105:929-937.
- Louviere, JJ., Hensher, D.A., Swait, J.D. (2000) *Stated Choice Methods. Analysis and Application*, Cambridge University Press.
- Luce, R. (1959) *Individual choice behaviour*. John Wiley and Sons, Inc.
- Lynch, M. (2003) Petroleum Resources Pessimism Debunked in Hubbert Model and Hubbert Modelers' Assessment. *Oil and Gas Journal*, July 14, 2003.
- Mackett, L. (2003) Why do people use their cars for short trips? *Transportation* 30:329-349.
- Maddison D, Pearce D, Johansson O, Calthrop E, Litman T, Verhoef E. (1996) *The True Costs of RoadTransport*. Earthscan, London.
- Malueg, D. (1990) Welfare Consequences of Emission Credit Trading Program. *Journal of Environmental Economics and Management* 18:66-77.
- Manski, C.F. and Lerman, S.R.(1977) The estimation of choice probabilities from choice based samples. *Econometrica* 45(8):1977-1988.
- Maxwell, J., Balcom, M. (1946) Gasoline rationing in the United States, I. The

- Quarterly Journal of Economics 60(4):561-587.
- Maxwell, J., Balcom, M. (1946) Gasoline rationing in the United States, II. The Quarterly Journal of Economics 61(1):125-155.
- May, A.D., and Nash, C.A. (1996) Urban congestion: A European Perspective on Theory and Practice. Annual Review of Energy Environment 21:239-60.
- Mayeres, I., Proost, S., Vandercruyssen, D., De Nocker, L., Int Panis, L., Wouters, G. and De Borger, B. (2001) The External Costs of Transportation Final Report. Federal Office for Scientific, Technical and Cultural Affairs, State of Belgium, Prime Minister's Services, Brussels.
- Metcalfe, G. (1999) A Distributional Analysis of Green Tax Reforms. National Tax Journal 52(4): 655-681.
- Meulepas, P., Vercaemst, P. and Dijkmans, R. (1999) Best Beschikbare Technieken voor de benzinetankstations. Vito, Vlaams BBT Kenniscentrum, Academia Press, Mol.
- Montgomery, W. (1972) Markets and Licenses and Efficient Pollution Control Programs. Journal of Economic Theory, 5(4):395-418.
- Morrison, G.C. (1997) Resolving differences in willingness to pay and willingness to accept:comment. American Economic Review 87(1):236-240.
- Mueller, D. C. (1989) Public Choice 2. Londen Cambridge University Press.
- Neary, J.P. and Roberts, K.W.S. (1980) The Theory of Household Behaviour under Rationing. European Economic Review 13:25-42.
- Newbery, D. (1988) Road damage externalities and road user charges. Econometrica 56 n°52:295-316.
- Noland, R. (2001) Relationships Between Highway Capacity and Induced Vehicle Travel. Transportation Research A 35(1):47-72.
- Norregaard, J. And Repellin-Hill, V. (2000) Taxes and Tradable Permits as Instruments for Controlling Pollution Theory and Practice. IMF Working Paper WP/00/13. International Monetary Fund, Fiscal Affairs Department.
- OECD (2001) Domestic Transferable Permits Systems for Environmental Management. Design and Implementation. OECD,.
- Ong, P. (2002) Car ownership and welfare-to-work. Journal of Policy Analysis and Management 21(2):239-252 .

- Orasch, W. and Wirl, F. (1997) Technological efficiency and the demand for energy (road transport). *Energy Policy* 25: 1129–1136.
- Oak Ridge National Laboratory (ORNL), (1999) *Transportation Energy Data Book: Edition 19*.
- Oum, T.H., Waters, I. And Yoong, J. (1992) Concepts of price elasticities of transport demand and recent empirical estimates: an interpretative survey *Journal of Transport Economics and Policy* 26(2):139-154.
- Pargal, S. and Heil, M. (2000) Reducing Air Pollution from Urban Passenger Transport: A Framework for Policy Analysis. *Journal of Environmental Planning and Management*, 43(5): 665-688 .
- Parry, I.W.H. (2004) Are emissions permits regressive? *Journal of Environmental Economics and Management* 47:364-387.
- Peles, Y.C. (1988) On the Depreciation of Automobiles. *International Journal of Transport Economics* 15(1):43-54.
- Pezzey, J. (1992) The Symmetry Between Controlling Pollution by Price and Controlling It By Quantity. *The Canadian Journal of Economics* 25(4):983-991.
- Pezzey, J. C. (2003) Emission Taxes and Tradeable Permits: A Comparison of Views on Long-Run Efficiency *Environmental and Resource Economics* 26:329–342.
- Pieper, R., (2001) *Mobimiles, conscious on the road on behalf of the Dutch Minister of Transport, Public Works and Water Management, Bloemendaal*.
- Pigou, A.C. (1920) *The Economics of Welfare*. MacMillan, London,.
- Pocklington, D., (2000) Progress towards Kyoto targets through an EU environmental agreement on CO₂ emissions from passenger cars. *Environmental Law Management* 12(2):60-70.
- Polterovich, V. (1993) Rationing, Queues and Black Markets *Econometrica* 61(1):1-28.
- Rand Europe (2002) *Audit of Car Ownership Models*. www.rand.org/pubs/monograph_reports/MR1664
- Raux, (2002) The use of transferable permits in the transport sector. In *Implementing Domestic Tradable Permits: Recent Developments and Future Challenges*. OECD .

-
- Raux, C., (2004) The use of transferable permits in transport policy. *Transportation Research Part D* 9:185–197.
- Raux, C. and Marlot, G. (2005) A system of tradable CO₂ permits applied to fuel consumption by motorists. *Transport Policy* 12:255–265.
- Requate, T. (1998) Incentives to Innovate under Emission Taxes and Tradeable Permits. *European Journal of Political Economy* 14(1):139-65.
- Reuter, T. and Enholm, G. (1980) A proposal for gasoline rationing. *Journal of Post Keynesian Economics* 3(2):287-293.
- Richardson, A.J. (2000) Workshop Report on Item Non-Response. In *Transport surveys: Raising the Standard*, Transportation Research E-Circular E-C008, Transportation Research Board.
- Roberts, M.J. and M. Spence (1976) Effluent Charges and Licenses under Uncertainty. *Journal of Public Economics* 5(3-4):193_208.
- Ross, M. (1994) Automobile fuel consumption and emissions: Effects of Vehicle and Driving Characteristics. *Annual Review of Energy Environment* 19:75-112.
- Rothengatter, W. (1994) Do External Benefits Compensate for External Costs of Transport? *Transportation Research A* 28(4):321-328.
- Rouwendal, J. and Pommer, J. (2004) An indirect utility model of multiple car ownership and use. TI 2004-085/3 Tinbergen Institute Discussion Paper. Amsterdam.
- Rubin, D.B. (1987) *Multiple Imputation for Nonresponse in Surveys*. New York" John Wiley & Sons.
- Sah, R. (1987) Queues, Rations, and Market Comparisons of Outcomes for the Poor and Rich. *The American Economic Review* 77:69-76.
- Shahabuddin, S. and Chang, Y. (1978) Consumer attitude towards fuel consumption in the United States. *Urban systems* 3:117-122.
- Sheu, M. (2003) *Driving Away Inequities: Uncovering the Distributional Effects of a Gasoline Tax*.
- Shoup, D. (1997) Evaluating the Effects of Cashing Out Employer-Paid Parking: Eight Case Studies. In *Transport Policy* 4(4):201-216.
- Stavins, R.N. (1995) Transaction Costs and Tradable Permits", *Journal of Environmental Economics and Management* 29:133-148.

- Stavins, R.N. (1998) What Have We Learned from the Grand Policy Experiment: Lessons from SO₂ Allowance Trading. *Journal of Economic Perspectives* 12(3):69-88.
- Syri, S., Amann, M., Capros, P., Mantzos, L., Cofala, J. and Klimont, Z. (2001) Low-CO₂ energy pathways and regional air pollution in Europe. *Energy Policy* 29(11):871-884.
- Thaler, R. (1980) Toward a positive theory of consumer choice. *Journal of Economic Behavior and Organization* 1:39-60.
- Tietenberg, T. (2001) *Emissions Trading Programs*. Aldershot, UK: Ashgate .
- Tietenberg, T. H. (1990) Economic Instruments for Environmental Regulation. *Oxford Review of Economic Policy* 6(1):17-33.
- Tietenberg, T. H. (1998) Ethical Influences on the Evolution of the US Tradeable Permit Approach to Pollution Control. *Ecological Economics* 24(2,3):241-257.
- Tobin, J. (1952) A Survey of the Theory of Rationing. *Econometrica* 20(4):521-553.
- TRACE Consortium(1998) Deliverable 1: Outcomes of Review on Elasticities and Values of Time. TRACE Consortium, The Hague.
- TRACE Consortium(1999) Deliverable 5: Elasticity Handbook. TRACE Consortium, The Hague.
- Train, K. (1986) *Qualitative Choice Analysis: Theory, Econometrics and an Application to Automobile Demand*. The MIT Press, Cambridge.
- Train, K. (2003) *Discrete Choice Methods with Simulation*, Cambridge University Press, Cambridge.
- U.S. Department of Energy (1980) Standby Gasoline rationing Plan 80-1. U.S. Department of Energy, Economic Regulatory Administration, Office of Regulation and Emergency Planning. Washington D.C.
- Van Boven, L., Loewenstein, G. and Dunning, D. (2003) Mispredicting the endowment effect: underestimation of owners' selling prices by buyer's agents. *Journal of Economic Behavior & Organization* 51:351-365.
- van Dijk, E. and van Knippenberg, D. (1996) Buying and selling exchange goods: Loss aversion and the endowment effect. *Journal of Economic Psychology* 17:517-524.

- Van Mierlo, J., Magetto, G., van de Burgwal, E., and Gense, R. (2003) Driving style and traffic measures –influence on vehicle emissions and fuel consumption. *Journal of Automobile Engineering* 218 Part D:1-7.
- Varian H. (1978) *Microeconomic analysis*. Norton and Co. New York.
- Verhoef, E., Nijkamp, P. and Rietveld, P. (1997) Tradeable Permits: Their Potential in the Regulation of Road Transport Externalities. *Environment and planning B: Planning and Design* 24:527-548.
- Victoria Transport Policy Institute(2005) *Transportation Elasticities-How Prices and Other Factors Affect Travel Behavior*. Available from: <http://www.vtpi.org/tdm> [Accessed 05 May 2005].
- Walters, A. (1961) The theory and measurement of private and social cost of highway congestion. *Econometrica* 29(4): 676-699.
- Walton, W.,(1997) The potential scope for the application of pollution permits to reducing car ownership in the UK. *Transport Policy* 4(2):115-122.
- Waters, M. (1992) *Road Vehicle Fuel Economy*. London.
- Weitzman, M. (1977) Is the price system or rationing more effective in getting a commodity to those who need it most? *Bell Journal of Economics* 8(2): 517-525.
- Weitzman, M.L. (1974) Prices vs Quantities. *The Review of Economic Studies* 41(4):477-491.
- West, S. (2003) *Distributional Effects of Alternative Vehicle Pollution Control Policies*. *Journal of Public Economics*.
- WHO (2005) *Health effects of transport-related air pollution*. edited by Krzyzanowski, M., Kuna-Dibbert, B. And Schneider, J. WHO. Copenhagen.
- Willig, R.D. (1976) Consumer's Surplus Without Apology. *The American Economic Review*. 66(4):589-597.
- Willoughby, C. (2001) Singapore's motorization policies 1960-2000. *Transport Policy* 8:125-139.
- Wong, J. (1997) Basic concepts for a system for advance booking for highway use *Transport Policy* 4(2):109-114.
- Wright, C. Egan, J. (2000) De-marketing the car. *Transport Policy* 7:287-294.
- Wrigley, C. (1997) Design criteria for electronic market servers. *International*

Journal of Electronic Markets 7(4):12-16.

Zimowski, M., R. Tourangeau, R. Ghadialy, and S. Pedlow (1997) Non-Response in Household Travel Surveys," prepared for Federal highway Administration

<http://tmip.fhwa.dot.gov/clearinghouse/docs/surveys/nonresponse/glossary.stm>

[Accessed 05 December 2004].

Zmud, J., and C. Arce (2000) Item Nonreponse in Travel Surveys: Causes and Solutions. In Transport Surveys: Raising the Standard. Proceedings of an International Conference on Transport Survey Quality and Innovation, May 24-30, 1997. Grainau, Germany.

Zwerts, E. & Nuyts E. (2002a) Onderzoek Verplaatsingsgedrag Vlaanderen (januari 2000- januari 2001). Deel 1: Methodologische analyse, Provinciale Hogeschool Limburg, Departement Architectuur, Diepenbeek.

Zwerts, E. & Nuyts E. (2002b) Onderzoek Verplaatsingsgedrag Vlaanderen (januari 2000- januari 2001). Deel 3A: Analyse Personenvragenlijst, Provinciale Hogeschool Limburg, Departement Architectuur, Diepenbeek.