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Modelling and Assessment of Sustainability in Transport Policies

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Chapter 1

Introduction

1.1 Background

Transport has always been an essential factor in the socio-economic relationships allowing for moving goods and people. Historically, the introduction of the steam engine first and the internal combustion engine later radically changed the technological framework in which people and products move. It improved the speed of connection and changed the landscape. Nevertheless, this new system changed the energy needs shifting the demand from animal power to fossil fuels, such as coal for railroad trains and boats, to an increasing penetration of oil products in the entire transport sector.

The growing popularity of those means of transportation arose at the same time as the second and third industrial revolutions that, as a matter of fact, saw the automotive industry as one of the leading players. This situation eventually gave rise to a significant diffusion of cars and trucks mostly in the OECD Countries (North America, Europe, and Far East Asia). Better speed and capillarity of connections (with the construction of infrastructure such roads, railways, seaports, and, later on, airports) brought an overall lifestyle improvement during the past century.

The amount of energy demanded by transportation increased as well, leading to a strong dependence on petroleum resources. This dependence partially contributed to the late 1970s oil crisis, deeply affecting both North America and Western European energy (and economic) systems. Among the ensuing initiatives, there was the institution of the International Energy Agency (IEA) and the first instalment of the Corporate Average Fuel Economy (CAFE) standard in the USA. While the purpose of the latter was (and still is) the regulation of overall efficiency of new cars, the first measure provided the management of the emergency oil reserves and the monitoring of the energy needs for all the subscribing nations (most of the members of the OECD).

Right now, concerns about the contribution of the transport sector to the global warming (International Energy Agency, 2009) however, also local pollution and road congestion are starting to catch the policy makers' attention given their compelling impact on the welfare of society (Santos et al., 2010a).

1.2 Transportation, Energy, and Climate Change

Energy and sustainability have become the centre of a large debate in the scientific and political communities. In particular, the impact of energy consumption on the global environment urged governments worldwide to take action in reducing the emissions of the so-called GHGs (Greenhouse Gases), responsible for the increasing temperature globally and the resulting climate and environmental change. Threats coming from the uncertain and long-lasting effects of higher temperatures make a response by the policy makers a necessity for maintaining the current lifestyle. A shift to a more sustainable energy system is essential for limiting the effects of the current climate change trend.

Moreover, the dependence on fossil fuels as a primary energy source has exposed economically and politically the western world to a security of supply risks. One of the main strategical reason is the great unbalance between producer regions (Saudi Arabia, Gulf of Mexico, Russia, prominent among a reduced group) and the consumer regions (mostly industrialised countries and China) of fossil fuels. For instance, non-OECD nations were responsible for the global production of almost 78% of oil and 63% of natural gas. These figures are unlikely to change during the next decades given the location of oil reserves and the likely future increase in energy demand. Moreover, the constant growth in the developing economies, largely unaffected by the last economic crisis, will overtake the developed world in its energy needs and consumption. As claimed in the BP Outlook (BP, 2011), this will translate into a growth of the energy consumption of about 46% in the non-OECD nations during the next two decades, compared to just 3% of the OECD ones. The described situation will affect future energy prices (especially oil) that will probably suffer a further increase. Price fluctuations and the lack of control on the production flows makes it harder for governments to plan the impact of energy (and the eventual lack of the usual sources) on the whole economy accurately.

The transport sector has close links with the current energy issues. Transportation is one of the major oil consumers–61.4% of 2008 world oil consumption (International Energy Agency, 2010b) feeded the fuel tanks of vehicles around the World–and a great CO_2 emitter–22.5% of world CO_2 emissions from fuels (International Energy Agency, 2010a) is linked to transportation. These are just two figures that support the need to shift to a more sustainable transport model.

Substantial efforts are still necessary to reduce emissions in this sector.

1.3 The costs and benefits of transportation

The transportation sector is essential in an essential input in the economic value chain for trade, industry, construction, and tourism, just to name few activities highly dependent on transport services. Because of that, the sector is considered crucial in all modern economies, both from the industrial, service, and infrastructure points of view. According to the official statistics for Spain, commerce, transportation, and tourism accounted for more than 20% of the total GDP (INE, 2012), suggesting the importance of the sector in the whole economy.

The necessity to deal with such a diverse sector is not an easy task since it is affected by a really diverse demand (variety of trip purposes, mobility and freight) and supply (many transport modes for the same routes and logistic solutions) making the assessment of transport both complex and compelling. In Europe, for instance, the creation of a common space for travel and market is not just linked to the "free movement" principle for people and goods, but also to the promotion, development, and maintenance of all the infrastructures and services that encourage the free circulation (European Commission, 2011c). However, which is the flip side in transportation?

The sector has attracted the attention of public and politic opinion not just for the energy problems but also for some other issues that affect the population. Regarding urban areas, tail-pipe pollution, noise, and traffic jams cause daily huge costs on the whole society that has to bear with the increasing penetration of private transportation. Together with the issues above related to GHG emissions and security of supply, these consequences of transport demand are considered negative externalities of the transport sector.

[1]

So, when designing policies for sustainable transport, all these aspects must be taken into account. Even if the aim of the thesis proposed here is not to assess the effect of measures on the external costs of transport, considerations will be made on these issues throughout the analysis of the policies, given their significant impact on society.[2]

[1]For a review of the magnitude of the costs associated with externalities in automobiles, see Van Dender (2009). It is worth noticing that in many of the results considered the cost of the impact on climate change does not reach 5% of the external cost generated, while congestion surpasses 50% in many of the cases.

[2]As claimed in a literature survey by Van Dender (2009), the local external costs of transport account for (at least) 62% of the total externalities generated by road transportation. This figure can reach 99% of the total costs depending on the estimation method used.

1.4 The role of technology and technological improvements

The role of improvements in existing and developing technology has received increasing attention in the current debate. Improvements in efficiency, new energy sources, fuel flexibility are among the hot topics which drew attention from institutions, industry, and academia in trying to deal with sustainability and energy concerns.

For instance, the technological advances in battery capacity and costs brought the electric power to private vehicles since the early 2000s. According to IEA's projection on future CO_2 emissions from transportation (International Energy Agency, 2009), the increasing penetration of electricity on private vehicles is an essential ingredient in reaching the objective of reducing global GHGs emissions. IEA claims that while in business as usual scenario energy use from transport sector could double by 2050 (from 2005 levels), a massive introduction of new technologies such as electric and hybrid vehicles (called BLUE scenario) could lead to an overall reduction of 10% in the same timeframe.

However, how does technology intervene in the market for transport services?

In its thorough assessment of current and future technology opportunities, Schäfer et al. (2009) claim that acting on prices of fuels or transport use can have a small impact on GHG reduction (for the low price elasticity), while advances in vehicle efficiency and alternative fuels can effectively lead to a substantial reduction in energy consumption and emissions. In doing so, the authors evaluate the most popular modes of transport in the US setting and, after discussing the historical trends, they assess some of the plausible advances that could be available in the market during the next years, the following limitations, and, most importantly, their impact on sustainability.

Energy efficiency in both private and public vehicles seems to have a large potential, but the increased fuel economy could lead to a higher usage of the vehicle itself, as before. Moreover, research and development in vehicle technology do depend mostly on manufacturers' decisions and investments. In the automotive case, as described by Schäfer et al. bringing examples from Weiss et al. (2000); Weiss (2003), the existing fuel economy potential from (traditional) gasoline private vehicles could be at around 25% to 50% by 2030 (compared to current values). This result relies on the assumption that every gain from improving vehicle performance is eventually transferred just to efficiency improvements and not to comfort, acceleration, safety, or size. Given the characteristics of the demand for new vehicles, this assumption seems to be too conservative. (e.g. Schipper et al., 2002).

On the other hand, from the sustainability perspective, other opportunities are worth considering. Alternative fuels could be used without significant changes in the current fleet composition (Schäfer et al., 2009). Biodiesel, ethanol and compressed natural gas (CNG) are just some of the options that are at the centre of the debate. As for the latter, CNG consumption in Spanish transport is so small it does not appear in the Spanish energy official data report for consumption (MITYC, 2010). Given some limitations in speed of refill (and the capillarity of the associated network) and on-vehicle storage, CNG is not popular in private vehicles, even though it starts to spread in urban buses and taxis (Rabl, 2002). Compared with traditional oil-derived fuels, natural gas provides some advantages over the cost-per-km (given the current prices) and on well-to-wheel GHG emissions. So, even though there are some technical limits in its success, the literature suggests that within the next years it could take a more prominent role in the market for transport energy (Turton, 2006).

Biofuels in general and biodiesel, in particular, started to catch more interest from policy makers, given their potential in reducing the overall GHG emissions (International Energy Agency, 2004). In Spain, in 2010 biofuels reached almost 4% of the total energy consumed in transportation according to MITYC. The potential of biofuels is large in shifting from an almost entirely oil-dependent transportation. This fact provides the significant substitutability between bio- and traditional oil-derived fuels and almost null needs in adapting current car stocks. Concerns about the life-cycle impacts of biodiesel crops and on the price of food (Bureau et al., 2010) are attracting the attention of scientific researchers in determining the correct potential contribution of these fuels towards sustainability. In this case, the concern regards the agricultural product prices and how they can be affected by land use between biofuel and food crops, with the added problems coming from the intesity of the land use and the use of fertilizers (Sastre et al., 2015; Linares and Pérez-Arriaga, 2013).

In a nutshell, even with the current technology, the potential for reducing GHG emissions in the short term is not to be disregarded. However, as the literature suggests, the actual impact of these alternatives has to be evaluated in a system-wide context. Governments have to take into account the marketability, availability and feasibility, the necessary infrastructure (for CNG distribution network), and alternative uses of the resource (food vs. non-food crops) as well as the technology adaptation of current and future vehicle stock.

Nevertheless, most of the attention of policy makers, industry and academia is attracted by the increasing advances in electric-powered vehicles and the resulting penetration (mostly) in the automotive market.

One of the main drivers is the progress in electricity storage. As a matter of fact, the cost, performance, and weight of batteries are considered the main barriers to the spreading of this technology. Vehicles that use electricity as an energy source are hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles

(PHEVs), and full electric vehicles (EVs). The firsts and the seconds, HEVs and PHEVs, have a motor that propels or helps to propel the wheels and a downsized internal combustion engine that can either generate electricity or can connect to the power train. The main differences between the first and the second are that the battery in PHEVs can be recharged using an external plug, while in the HEVs the electricity can come just from the engine (which acts as a generator) or the regenerative brakes. Both of them have the usual (or better) performances of similar gasoline vehicles, but the additional weight and cost of current batteries still represent a barrier to the market penetration.

On the contrary, fully electric vehicles do not rely on any energy source outside the electricity stored in the batteries, thus reducing weight and size, since most of the components needed for the internal combustion engine are not in the vehicle. The downside of this is the limited vehicle range in daily use and for long trips because of the energy density of batteries and the slow recharge. Although current research is continuously pushing these limits, it is complicated to predict how a future technological breakthrough will affect the market for electric vehicles. As battery energy density grows with research development (and cost lowers), fleet electrification can achieve increasing and significative shares.

Moreover, the infrastructure needed to supply the recharge of these vehicle need both resources for the deployment of the new network and consensus among the involved agents. The agents involved are the local governments, where the installment of recharge points take place, the electric car manufacturers for the specification of the recharge methods, and the electricity distributors and network managers, who are in charge of supplying the electricity.

1.5 Policies in transportation sector, and sustainability

A government intervention is, of course, crucial in dealing with the issues presented before. Under a sustainability perspective, efforts in controlling and reducing CO_2 emissions will require governments to take measures that will affect how people and goods move. However, which are the actions a government can take? What are the effects on sustainability? What are the costs of those measures?

These are the main questions that will be addressed by the model proposed here. In the first place, it is important to identify and define the different possible measures that a government (at a local, national or regional level) might take. Although the literature proposes different definitions, we will follow the ones proposed in Santos et al. (2010a) and Santos et al. (2010b). While the first reviews the policy measures specifically aimed at reducing inefficiencies in road transport, the second focuses on those policies designed for improving its sustainability.

Among the main policy measures governments can adopt to reduce externalities, the main distinction is between the ones restricting behaviour for both consumers and producers and the ones providing monetary incentives to certain behaviours.[3] The mainstream literature on regulation and policy define them as Command-And-Control (CAC) and Incentive-Based (IB), respectively.

1.5.1 Command-and-Control Policies

Ordinary Command-and-Control policies are government-defined standards for products like fuels and vehicles but also traffic or parking restrictions for certain vehicle classes (the most polluting ones, for instance). Vehicle standards consist of making each manufacturer keep the average efficiency of cars and light trucks sold below a certain limit without (directly) interfering with the production process and final prices.

In Europe, there is no such policy on efficiency for new car production, but there is one for CO_2, as published on the European DG for Climate Action web page citepEuropeanComission2017ReducingAction. In the framework of GHG reductions, European automakers since 1995 self-committed to keeping CO_2 levels below some level, although the European Commission planned to make these limits (progressively) mandatory by 2007. Clearly, since CO_2 emissions and fuel consumption are closely linked one with the other, the limitation will affect both, thus reducing GHG emissions and oil dependence. Among the actions, it is worth mentioning the EU labelling initiave, aiming to the transparency in the new vehicle choice regarding, making mandatory and uniform the information displayed about the new vehicle emission and efficiency (European Parliament, 2000).The target for 2021 of the European regulation is to obtain an average CO_2 emission per (new) car of 95 gCO_2/vkm from the actual 120 gCO_2/vkm, as published in the Directive (European Parliament, 2014).

1.5.2 Incentive Based Policies

As opposed to CAC policies, incentive-based policies do not impose any restriction on agents' behaviour. Nonetheless, they provide monetary incentives which may influence their choices. Among the most common, there are purchase and ownership taxes (and rebates), tolls and charges, and cap and trade (or quantity control) programs. While the first two appears in transport policies, cap-and-trade programs have been applied in very seldom instances to the sector (e.g. in Santiago

[3]Incentives policies can be both positive (as rebates) and negative (as charges).

de Chile). Although a market for CO_2 permits is already functioning in Europe (EU-ETS), the transport sector is not part of this market.[4]

Tolls and charges are instruments intended for pricing the usage of public spaces (like parking) and roads (toll roads) and recently, supported by new technologies, have been used for charging the entrance to a few major cities, mostly moved by congestion issues.[5] In most cases, tolls and charges are not directly aimed to fuel consumptions and GHG emissions but are effective measures for internalising some externalities such as congestion and local pollution and for funding the infrastructure costs.

Excises and rebates are without any doubt the most widely used policy tools in transportation. As for vehicles, government intervention in vehicle purchases helped the renewal of the car and truck fleets. Well calibrated scrappage and feebate schemes[6] (or discriminated taxation) can help removing the most inefficient and polluting cars while encouraging the purchase of more efficient vehicles (MITyC, 2010).

Among the traditional fiscal instruments, fuel taxes are, without any doubt, the most widely used, although not necessarily to reduce emissions or fuel use. Given their easiness to collect and the relatively low elasticity on changes in price (price elasticity of fuel) they represent an indispensable source of revenues for governments. The tax rate represents almost half of the retail price in most of the European countries (EU27), reaching 60% in United Kingdom (European Commission, 2011a).

Apart from the revenue collecting purposes, fuel taxes may be able to internalise different external costs, especially the ones directly related to fuel consumption such as GHG emissions and oil dependence. Nevertheless, these are not the right instruments for dealing with other externalities such as congestion and accidents: vehicle mileage (directly related to the local external costs produced) strictly depends on vehicle efficiency, and so a fuel tax is not an efficient instrument. Taxing kilometres should overcome this problem, yet the number of full implementation for mileage taxation is limited: one example is heavy trucks in Switzerland (Suter and Walter, 2001), which have to carry a distance meter with the only purpose of recording travel distance and tax the driver accordingly.

Incentive Based instruments are usually more economically efficient respect to

[4]According to European Union (2008), the only transport sector taking part to EU-ETS is aviation.

[5]A well-known example is the London Congestion Charging Scheme that achieved in just three years (from 2002 to 2005) a 35% reduction in the circulating cars and, within the same period, a 36% increment in the circulating buses (European Energy Agency, 2008).

[6]Feebate schemes are those charging the inefficient vehicles while giving premia (rebates) to the efficient ones. This scheme is supposed to be neutral from a fiscal point of view, incentivizing the purchase of efficient car, with reduced cost for the government.

CAC, and allow the governments to receive some revenues, but the debate on which one is the best practice to improve the sustainability of transport efficiently is still open.

1.5.3 Other policies for sustainability in transportation

Along with the fiscal measures presented above, other measures can be adopted by governments for achieving a more sustainable transport sector. These measures include improving the infrastructure, promoting other modes such as the public transport, better planning of land use, or simply supporting more efficient driving behaviour through educational campaigns or financing the research and development of more efficient technologies.

In an extensive review, Santos et al. (2010b) point out that these policies can help the sustainability of the transport sector substantially. For instance, improving the access and the availability of public transport and, at the same time, implementing smart land use planning can reduce the usage (and, in the longer term, the ownership) of private cars. Integrating the road freight logistic with both seaports (or even inland waterways) and railway can help increasing the use of these more efficient and sustainable modes. Eco-driving and car-pooling programs as well have a great potential in reducing the fuel usage by improving the vehicle usage (in passenger per vehicles) and the car efficiency without the need of introducing new technologies.

A particularly relevant place to look at is metropolitan areas, where many different transport options are possible, and also where most of the population lives. According to the World Bank, the population living in urban areas account for 80% of the total, with almost 34% in the metropolitan areas that exceed 1 Million inhabitants. There much of the economic activity takes place, (e.g. representing 80% of global GDP), but also accounts for 65% of all energy consumption and 70% of all carbon emissions, therefore presenting a challenge between preserving the environment while keeping welfare levels unaffected. Besides, not all metropolitan areas are the same regarding alternative transport modes or demand for mobility: sustainability policies affecting the transport sector in these different cities may, therefore, have different outcomes.

Moreover, studying policy effects on mobility in the metropolitan areas may disclose interesting insights on the relevance of pooled transport modes, such as public buses or metropolitan train, and their possible contribution to lowering the greenhouse gas emissions. The impact of policy in these contexts has to come accompanied by an assessment of the policy implications for welfare, thus taking into account not only changes in prices but effects also on the external costs.

1.6 The need for a formal model

As extensively reported in the European Commission's White Paper (European Commission, 2011c), and repeated above, the necessity to enhance the competitiveness and the integration of the transport system has also to deal with the tighter requirements of sustainability. Especially regarding global warming, the figures provided here have shown how substantial the contribution of the sector is to the emission of GHGs. The latter applies in particular to Spain, which experienced a fast yet chaotic growth during the past two decades resulting in a highly energy intensive transport sector and economy in general (Schipper et al., 2010; Del Río and Mendiluce, 2010; Mendiluce, 2010). So strong policies are needed to kerb the environmental impact and energy use of transport while keeping the benefits it provides for the economy. However, the complexity of this sector requires that these policies carefully evaluated in their consequences. So, reasons for a model are many and diverse.

First, because the efforts so far and the potential ones need a thorough assessment: the whole energy system needs to be adapted to reduce its reported high impact on the global environment and the transport sector will be a crucial part of that process, given its weight in this system. Moreover, the complexity of the interactions between the agents involved such as consumers and industry, energy providers and vehicle manufacturers, but also governments and society, in general, is the reason why a complete and detailed insight of the processes is needed. Disclosing the mechanisms underneath the economy of transport is indeed critical in the task of evaluating the effects and interaction of those policies. Finally, a thorough assessment should go through an estimation of the social costs of those various policies to assess their impact on society.

Hence, the objective of the thesis is to develop tools able to handle the complexity of the transport sector and so provide an instrument capable of quantitatively assessing the current and potential policies, price settings and technological framework, studying the effects in the long term while taking into account the associated costs.

Nevertheless, the intervention on fuel demand through fiscal policy should be done carefully, since tax changes might affect consumers' behaviour and utility[7]. Moreover, as Santos et al. (2010b) and Santos et al. (2010a) suggest, any change in the tax burden is usually subject to high pressure from public opinion since it affects largely the competitiveness of a nation and, even if needed, it must rely on a wide political and public consensus.

Cross elasticities, hidden costs and rebound effects are just some examples of how difficult it is to design or modify a policy on energy and transport. Under this

[7]For a study on the redistributive effects of fuel taxes, see Asensio et al. (2003)

perspective, the need for both the data and the scientific instruments, or models, to interpret them is crucial for refining predictions and estimates of policy effects. Many of them involve econometric techniques, investigating how changes in prices and income (among other aspects) affect changes in consumers' behaviour in the transport sector.

The objective of the thesis is thus to provide a clear assessment of the sustainability of some transport policies, in particular regarding the emissions of greenhouse gases and the economics effects, both internal, as costs for transport services, and external, as local pollution. To do this we develop the tools and collect information and data to carry on some experiments of how a fiscal reform could affect these results.

In the next section we provide a review of the literature that focuses on the modelling and the assessment of the transport sector.

Then, in chapter 3, we start analyzing the effects of a tax reform on fuel demand in Spain, by means of an econometric study. The chapter assesses fuel demand elasticities and how the dieselization of the fleet could affect the estimation results. This exercise however shows the limitations of an econometric model to identify the particularities of consumers' responses.

Hence, a more accurate model that focuses on just metropolitan areas is designed and developed in chapter 4, including a detailed description of the available information and data sources and the methods to integrate them into the model. Given the relevance of transport sector in metropolitan areas and the peculiarities of mobility in these regions–share of public transportation, commuting and importance of air quality issues connected to mobility–chapter 5 we carry on the experiment for five Spanish metropolitan areas. The assesment focuses on the impact on the economy, fiscality, welfare, energy savings, and CO_2 emissions of the same green fiscal reform proposal.

Finally, in chapter 6.1 we summarise the main conclusions of the previous chapters, providing policy recommendations, and suggesting some future work.

Chapter 2

Literature Review

2.1 Introduction

Modelling transport and mobility (and their interaction with the economy) has been the focus of many academic works. Approaches differ mostly by the scope of the study and the methods used.

In this chapter, we review some of the state-of-the-art in the relevant work regarding the study and the modelling transport and mobility that will help to defy the research question and the tools and methods to answer it.

2.2 Modelling transport, energy, and sustainability

Both the interest and the complexity in studying the evolution of transportation have led to a vast and diverse development of models, especially in Europe and North America. Still, many of the attempts in estimating the long-term evolution of the transport demand started as part of wider energy computational models. Currently, the most known models in this field are MARKAL-TIMES (Loulou and Labriet, 2008), developed and used by IEA (International Energy Agency), PRIMES (E3Mlab, 2008), adopted by the European Commission, NEMS (U.S. Energy Information Agency, 2011), operated by the United States Energy Department, and POLES (Criqui, 1996), for a global perspective of the energy market.

These, which are wide energy models, have dedicated modules for transportation that are more or less developed, depending on the case. Transportation models, which will be reviewed later in this section, can have different purposes than just assessing energy and sustainability, like evaluating transport pricing policies (Van Dender and Proost, 1996) or wider infrastructure policies (Wegener, 2008).

It is worth reminding that all aspects should be taken into account although we will focus on energy and sustainability.

The different approaches used in all these models can be more oriented towards technology or the macroeconomy (often called bottom-up or top-down approaches), providing a more detailed representation of the technology for the first while relying on a more developed and accurate description of how agents and economy interact with the second. Between the former (bottom-up) and the latter (top-down) some models, called hybrid, try to include some aspects of both.[1]

Other differences between those models can arise from the methods (or approaches) used in defining how demand and supply interact with each other. While some use a simulation (sometimes called accounting) approach like POLES, others use optimisation processes like TIMES. The simulation approach tries to capture (often through an econometric estimation) the current behaviour of agents and project it into plausible future socio-economic and technological settings (often called scenarios). The optimisation, on the contrary, assumes a fully rational set of agents and their set of available technologies. After providing defining costs and (more or less sophisticated) utility functions, deriving the equilibrium quantities and prices.

Sterman (1991) assesses both approaches underlying pros and cons for each. In a nutshell, the simulation methods can better represent details of the physical world and the processes dynamics in general while the optimisation can describe more precisely how agents interact with each other and how demand meets supply. Limitations for simulations are precisely the difficulty in describing how prices form and how measures affect the economic system. Moreover, the soft variables, characterised qualitatively, can hardly be represented in such models although they represent critical specifications in decision-making. Regarding optimisation, the lack of dynamics (or the difficulty in representing delays) limits the possibility to represent the time dimension, which is crucial when trying to evaluate decisions about infrastructure construction or vehicle purchase.

One of the state-of-the-art models for assessing the transport sector is TREMOVE (Ceuster et al., 2007). It is a bottom-up simulation approach for determining mobility and freight demand with a highly detailed technology description and constant-elasticity-of-substitution-type (CES) demand and supply. It covers most of the modes and most of the technologies, for all private, public, and freight transport, making it a reference in the transportation literature. The TREMOVE structure has three main (*core*) modules: transport demand, vehicle stock turnover, and emission and consumption fuel. As for NEMS, those modules are inter-linked, i.e. the output of one module serves as input for another

[1] A detailed survey of the mainstream energy models appears in Timilsina and Bhattacharyya (2009).

one. *Emissions and fuel consumption* are obtained, at least for road transport, using a methodology mostly based on the COPERT 4 model (Gkatzoflias et al., 2007), providing most of the emissions of different types of gases from road vehicle traffic. Both the vehicle stock module and the demand module provide inputs to this module, and essentially it simulates the estimated kilometres driven by each vehicle class.[2]

A *vehicle stock module* determines the fleet composition for each year, estimating the surviving stock and the new sales (two steps: first total amount and then specific characteristics of the new vehicles). The per-vehicle mileage is calculated through a *demand for transportation module*, demand that is represented as a nested CES (constant elasticity of substitution) utility function and described as a decision tree representing the choosing process for the consumers. [3]

Another example of this model application in the literature is the one from Zachariadis (2005). Considering the 2030 horizon, the author assesses different types of policies then compared to a reference scenario with a different kind of modes and technologies interacting (public transportation, electric vehicles and rail transport). Final remarks suggest that just a mixed and comprehensive set of policies can help in improving sustainability in the sector.

An earlier attempt to model transportation and, more specifically, urban transportation, is TRENEN (Van Dender and Proost, 1996). This model is less detailed than TREMOVE, and the purpose is different as well. It is characterised by a bottom-up structure although the approach can be either optimisation or simulation. Proost et al. (2002) propose an application of this model to four main cities (Amsterdam, Bruxelles, London, and Dublin), attempting to evaluate the difference between the current and the efficient (considering external costs) pricing policies. Although not assessing sustainability, results here show large room for improvement in all the cases for achieving a correct pricing for transportation with the help of taxes and other policy instruments.

Two recent models SASI and ASTRA try to represent transportation interactions through dynamic systems, as in TREMOVE. SASI (Wegener, 2008) concentrates more on the relationships between territory and transport. Using a model that focuses on how transport connections influence the territory planning and the

[2]Vehicle classes in COPERT 4 differ for the type (car, bus, motorcycle), age, size, energy source, emission standard (EURO I, EURO V), and engine size and power. TREMOVE extends this methodology to the train fleet, not originally included in COPERT.

[3]Although assuming a constant elasticity of substitution may seem too simplistic given the complexity of a transportation demand, this can be taken as a fair enough representation of agents behaviour for a given population and relatively small changes in income and prices. A more detailed discussion of the tools for extrapolating these parameters will be provided afterwards in this section. The applications of this model are many, some of which appears in more general energy model.

regional economic growth, the author tries to provide very useful insights on how infrastructure and transport network could affect the economy.

On the other hand, the ASTRA model (Fiorello et al., 2010), while keeping a geographical setting, deals with the possible interactions with the whole economy and the transport sector. In this case, different scenarios on technology and prices are used to simulate the evolution of the modal use and the changes in transport demand. The use of system dynamics captures important aspects of the modal shift and vehicle fleet evolution. These elements are important for assessing energy and sustainability impacts of transportation policies.

An application of both models by López et al. (2011) assesses the sustainability of different policies under different oil price scenarios and evaluates them through the use of multi-criteria analysis. In this case, considered policies were a demand-oriented policy (e.g. a tax-scheme) and an energy efficiency policy (e.g. a CAFE-like scheme). Results show that implementing any policy would improve the sustainability with demand-oriented policy being more effective in reducing fuel consumption and related emissions.

Given the importance of transportation in the energy sector, various energy models introduce a module to assess how policies in the transport sector can affect the energy system and its sustainability. POLES (Criqui, 1996), for instance, represents one example of a partial equilibrium model of the global energy economics like the models used by institutions such as IEA or OECD to develop world outlooks and forecasts on energy prices and consumptions. In this sense, the transport sector is simple, represented as an aggregate consumer of oil products and electricity depending on the technology scenario taken into consideration.

Although with similar limitations in representing transportation, TIMES (Loulou and Labriet, 2008) has a structure flexible enough to permit a high level of detail for each sector, the representation of economies of scale and learning curves, crucial in many activities. For instance, Proost et al. (2009), to evaluate the impact of a fiscal transportation reform on total GHG emissions, integrate results from a TREMOVE experiment with the TIMES model for Belgium. In a similar fashion, PRIMES incorporates a version of TREMOVE as the mobility module to represent the transport energy needs and how they interact with the other EU energy sectors, on which it focuses.

Unlike TIMES, both PRIMES and NEMS have high detail level of the different energy sectors then enclosed in a wider economic model, which computes the overall equilibrium prices and quantities. According to the definition, both models can be called bottom-up, preferring a sectorial partial equilibrium with a detailed representation of the technology in the energy market. Differences between the two are mostly related to the "market" they try to represent, being the European Union for PRIMES and the United States for NEMS.

For instance, NEMS transport module has a well-developed description of vehicle market and technologies advances and opportunities, for all car, truck, and air industries. However, it lacks an accurate representation of the public transport modes (buses, passenger trains) since in the U.S. these modes have a relatively small impact on the total mobility demand when compared to Europe. Hence, PRIMES adopts much more developed transport modules regarding those transport modes like, for instance, the use of diesel cars. These last have a significant share of the actual fleet, being close to one-third of Western Europe total fleet in 2007 (according to Eurostat) and representing almost one-half of the new private cars sales (according to ACEA). In the U.S., diesel private vehicles sales are around 5% (Schäfer et al., 2009).

At a technical level, NEMS Transportation Sector Module (DOE/EIA, 2010) is structured in four different submodules, each of them differing from the other mainly on the modes involved. *LDV* (light duty vehicles) and *air modules* mainly use a simulation/econometric approach in estimating the responses from agents (demand for mobility and technology advances such as efficiency and performance of the new vehicles). The *freight module* relies on a simulation/econometric structure as well, but it takes as input macroeconomic variables such as GDP. The last module, *miscellaneous*, collects the different energy needs from the other modules and estimates the ones for public transportation. The final output is the input of the last module, which computes energy consumptions and other gas emissions to feed the main NEMS model.

As before, economic activities and personal preferences have a high impact on both private and business transport decisions. Taking into account those aspects and their relation with the activity is essential for the accuracy of modelling.

2.2.1 Assessing the demand for transportation

The use of econometric techniques in estimating the demand for energy and transportation is common to most of the models, especially the ones that use a simulation approach. In the literature those methods are used for two main reasons: first to investigate how agents (both consumers and producers) behave and react to changes in the socio-economic framework and second to develop the techniques for improving the goodness and reliability of the results.

The literature on this topic is broad and growing. Just recently (February 2012) the “Energy Policy” Journal dedicated a whole special issue to the demand for energy in transportation. As Ajanovic et al. (2012) suggest in the introduction to the issue, there are many concerns about the effects of increasing population, wealth and the variability of prices. Research on this matter needs powerful econometric instruments to deal with the high complexity of the demand and its link with the technology.

Depending on the different approaches and data used, parameter estimation results may vary in a significant way. Espey (1998), in a review of more than 90 papers on gasoline demand estimation, lead a meta-analysis experiment on the price and income elasticities.[4] Among the different characteristics affecting the results, the author highlighted the period covered by the experiment and the region along with the estimation techniques involved.

The estimation of the aggregate consumption of fuel has also been the main subject in Baltagi (1983); Baltagi et al. (2003); Baltagi and Griffin (1997); Pock (2010) among others, suggesting the substantial relation between gasoline (in these cases) and socioeconomic variables. These works suggest an elasticity of gasoline on its price between -0.1 and -0.2. Ceteris paribus, these findings mean that an increase in the price of 1% will lead to a drop in consumption of 0.15%. As for income, the elasticity estimates range between 0.1 and 0.5, suggesting that an increased income (or its aggregate equivalent, i.e. real GDP) will produce an increase between 0.1% and 0.5%. Figures for the long run show higher absolute elasticities for both prices and income with almost double the values compared to the short term. Danesin and Linares show differences in behaviour between gasoline and diesel but mostly to income, with a gasoline consumption almost inelastic (0.07) with GDP.

How to explain these differences in gasoline (and diesel) price and income elasticities? What are the hidden drivers for the oil products demand in transportation?

Danesin and Linares (2015), for instance, show how the different compositions of vehicle fleet (diesel and gasoline private cars, in the particular case) affect in various ways diesel and gasoline consumption once coupled with the divergent tax rates (and final prices). [5] One of the main conclusions is that both gasoline and diesel consumption have to be derived separately from the same data set, given their distinct but highly connected markets. Deriving these two consumptions together will lead to describe incorrectly how agents' behaviour changes when reacting to price fluctuations or other variations in, for example, total income.

Even though fuel consumption for road transport represents a reasonable proxy for transport demand and energy needs, the literature shows how technology advances affect these measures. Those estimates can hardly capture the overall impact just described. The so-called *rebound effect* essentially pictures the situation where users, facing lower per-km costs, are willing to travel more (Schipper et al., 1993). According to the definition provided in the literature, the rebound effect is

[4] In this case, the meta-analysis of the price and income elasticities is an econometric experiment which tries to relate the elasticities found in the literature to the characteristics of the data and methods used to estimate those elasticities.

[5] For example in Spain the average diesel price in 2007 was almost 8% cheaper than gasoline, while the pre-tax price was 10% more expensive.

the elasticity of the fuel consumption concerning the efficiency ($\varepsilon_{F,E}$, with F the fuel consumption and E the overall efficiency).[6]. How to measure efficiency is still in debate. Even if, in principle, it could be measured by the weighted efficiency of the total fleet (actually measured by lab tests by each car manufacturer), this is barely a good proxy for real world fuel economy: consumers actively choose the efficiency of their car and decide how (and how much) to travel (also) according to this variable.

Traditionally (e.g. Sorrell et al., 2009), efficiency has been taken as exogenous, studying how the demands change on this variable. Few examples try to correct this bias. For instance Small and Dender (2007) focuses on the rebound effect of fuel without assuming the exogeneity of this variable, applying it to an aggregate dataset of 50 US States for the period 1966-2001. Concerning the literature, results suggest a much lower rebound effect in the short run and a similar one in the long term (20-25%). More interestingly, authors find that the rebound effect is declining over time and decreasing in income. So gains in efficiency will have a lower adverse effect on the total mobility demand and the associated externalities. The reason could come from a *demand saturation*: most of the users simply are not willing to drive more even if the cost of the driven kilometre goes down. Car buyers' preferences could fall in vehicle's specifications others than just fuel economy: acceleration, size and security are just a few but important aspects that consumers do take into account (Johansson and Schipper, 1997). This has to be noticed in both U.S. and E.U. with consumers increasingly interested in buying light-duty vehicles (LDVs) such as pick-up or sport utility vehicles (SUVs).

When designing a model, all these aspects should be taken into account, especially when trying to project the current demand into the future. The interrelation between the available technology and the users' preferences can be critical, especially in the transportation market. In the next section, we propose a methodology to approach some of the issues presented above, taking into account the state-of-the-art for transportation modelling, Thus allowing to investigate how policies can effectively tackle the sustainability concerns of the transportation sector.

2.3 The Gap to be filled

We have already discussed the need for a modelling approach for studying the economic, social and sustainability issues related to the transport sector. We have reviewed as well some of the previous and valuable attempts to model the demand for transportation. Hereafter we explain why to develop and use a novel model

[6]The three different definitions of direct rebound effect are in Sorrell and Dimitropoulos (2008). Applications of these methods are in Sorrell et al. (2009) (a review of other works), Frondel et al. (2008), and Frondel et al. (2010).

to quantitatively assess the sustainability of the transport system in Spain, in particular for urban areas.

In many different ways (bottom-up vs. top-down), the past and current models have tried to reflect the situation and evolution of transportation into a formally consistent model. At the same time, empirical evidence has shown how a multitude of aspects (both from the technological and consumer's side) have a large impact on the system. As said before, this variety and complexity of interactions make it difficult to provide a unique modelling solution for all the research questions.

Consolidated models like TIMES (Loulou and Labriet, 2008) and NEMS (DOE/EIA, 2010) (previously reviewed) tried to answer similar questions for transport with both robust and highly detailed models for large systems like the U.S. and Europe. Both the focus and the approach adopted in these models need some refinements to better adapt to the purposes of our research question. Demand representation is clearly one of them. As for demand representation in TIMES, although flexible, tends to be too simple, only focusing on a least-cost perspective of the energy system. NEMS, on the other hand, relies on an econometric approach, which has been (at least in part) investigated in our previous research for a better understanding of the fuel demand. Both models, considering extended time frames, consider that macroeconomic indicators such as GDP and resource prices are the "moving" factors for transport service demand, not considering modal shifts and public transportation. Supported by the extended scientific evidence, we believe that these *partial* approaches are not enough to fairly represent the complexity in the transportation sector.

As for the transport-specific models, TRENEN (Van Dender and Proost, 1996) and TREMOVE (Ceuster et al., 2007) both present a flexible and detailed representation of consumers' behaviours. Representing modal choice is both necessary and crucial when studying how transport sector reacts to changes in prices, technology, or policy. For instance, since transportation is a time-consuming activity and congestion represents one of the highest external costs generated by private transportation (Van Dender, 2009), not including this aspect of the assessment will lead to a partial understanding of the effects on the transport system. Both TRENEN and TREMOVE include this modelling aspect. However, why do not use these two models for our research purposes?

In TRENEN, a model mostly related to fiscal policies, the technological side is rather simple. Conversely, TREMOVE describes in high detail both the demand and technology side provided the broader variety of research questions it aims to. The complexity of the project, the integration of many different submodels (COPERT-IV for fleet composition and emissions, SCENES-ASSESS for the network) strongly connected one with the other, and the strong reliance on a vast amount of data, make it difficult to handle the questions proposed here in a confident way. Moreover, the complexity of this model's structure should lead to a difficult integration with more general economic and energy models. From our perspective, being able to evaluate the effects that prices, technology, or fiscal policies could have on the whole energy system is both relevant and essential.

Characteristics to take into account when modelling urban transport and assessing sustainability are many, each depending on the level of detail and the objective of the study. One of the main struggles for local governments during the rapid growth of many cities (and the easier access to transportation for many users), was the traffic congestion problem as well as air quality. Static modelling approaches to these issues can be found in, for instance, TRENEN as well as in De Borger and Proost (2013) with the study of the effects of policies to restrict car use in the city centre on the externality produced by the same, especially regarding the air quality and noise. Tirachini (2012), when trying to assess the optimal pricing for buses, considers the service comfort, or the so-called crowding effect of buses and metro trains, suggesting that it is a crucial aspect when considering route design, the frequency of service, and, prices.

Recent works add a dynamic dimension to the description of the interaction in the transport sector, providing a different perspective. Guzman et al. (2014) for Madrid and Liu et al. (2015) for Beijing are just two examples of the use of dynamic system analysis of the problem. Their findings suggest that each implementation of policies have to be sustained for many years to have a positive effect, especially when considering overall welfare.

In this sense, our model would take advantage of the research in modelling energy developed by the same research group inside the IIT. Among the contributions to the literature, worth mentioning are the linear programming model for energy service demand MASTER, which results appear in Lopez-Pena et al. (2012) and the CGE model GEMED (Rodrigues and Linares, 2014, 2015) That will allow a deeper detail in assessing the effects on both the energy and the transport system.

Table 2.1 compare briefly the models described in this section, suggesting the gaps to be filled to answer the research question and the characteristics of the model presented in chapter 4. The importance of a robust modelling design and availability of data, which will be the in the chapters hereafter, is the main reason to design an ad-hoc model, adapting the features and methodology presented in this literature review.

In such a framework, what could be the impact on the energy needs and sustainability of the transport system and its fiscality? Which could be the role of the public transportation sector compared to the new technology advances in private transportation (e.g. electric vehicles)? The answer to these questions, which are at the centre of both scientific and political debate, should lead to contribute to the current state of the research. Some of the details about the formal structure of the model will be presented in the next section.

	POLES	M-TIMES	NEMS	ASTRA	TRENEN	TIRACHINI	TREMOVE	proposed
modal technology det.	+	+	+	=	+	+	+	+
energy	+	+	+	=	=	=	+	+
emissions	+	+	+	=	=	=	+	+
other externalities	-	-	=	-	+	+	+	+
bottom-up	-	+	=	=	+	=	-	+
top-down	+	-	=	+	-	-	=	-
fuel/energy consumption	+	+	+	+	=	=	+	+
travel	-	=	+	=	+	+	+	+
modal choice	-	-	-	-	+	+	+	+
congestion	-	-	-	=	+	+	+	=
travel comfort	-	-	-	-	-	+	-	-
comparative statics	+	+	+	+	=	=	+	+
optimisation	-	=	=	-	+	+	=	=
integrability	-	+	+	=	=	=	+	+
flexible data entry	-	-	-	-	=	=	=	+
applicability to other regions	-	-	-	=	=	=	+	+
dynamic component	+	+	+	+	-	-	+	=
open-source	-	=	-	-	+	=	=	+

Table 2.1: Review of models for transportation and comparison of main charachteristics. For each model and each chararacteristic, a sign provide an evaluation of the level of detail, with (-) representing low level, (=) average, and (+) high. On the right it stands the model proposed in chapter 4.

Chapter 3

An estimation of fuel demand elasticities for Spain: an aggregated panel approach accounting for diesel share[1]

We already learned that one method to assess demand for transportation is through the analysis of one of its principal energy sources, i.e. gasoline and diesel. In this chapter, we provide an econometric estimation of the demand highlighting the role of the share of diesel vehicles.

The two primary methods used for estimating the relationship between the demand for fuel and prices/income can be distinguished by the structure of the data. One method relies on aggregate data, mostly coming from national accounts, while the other is based on disaggregated data like household surveys[2].

In Spain, the price elasticity of fuel products has been studied mainly using disaggregated models with data coming from the Spanish Statistics Institute's (INE) Family Budget Survey. Using a seven equation model, Labandeira et al. (2006) consider how price changes in gasoline, electricity and other energy sources result in changes in demand. For gasoline, findings suggest that there is no substitution effect between this product and other energy sources, mainly because of technological limits[3]. Romero-Jordán et al. (2010) use the same survey but focus on fuel

[1]This chapter is based on Danesin and Linares (2015) published in Journal of Transport Economics and Policy on January 2015.

[2]For a broad review of past works on this topic, Goodwin (1992) and Graham and Glaister (2002) give a full view of methods and conclusions, while the meta-analysis by Brons et al. (2008) and Espey (1998) provide a comparison of the determinants in the formulations of the estimation models and the data that are affecting the different results.

[3]Future developments and the diffusion of electric vehicles might change the substitution in

demand, providing an extensive analysis of its state in Spain. The model adopted in this last case is the so-called AIDS (Almost Ideal Demand System) which is adapted to fuel demand. The suggestions they give is that the low price elasticities they found for fuel are an obstacle for using gasoline tax increases for reducing oil consumption in private transport, at least in the short term. Although similar in the dataset used, the results for the two papers differ significantly, especially regarding the price elasticity (-0.1 in Burguillo versus -0.6 in Labandeira). Reasons could be the problem formulation, the different period taken into consideration or, most probably, the estimators choice, a crucial point in the discussion later.

However, these two papers do not distinguish between diesel and gasoline demand (due to the impossibility to separate these two from the INE's dataset). This might be a relevant limitation, because of the different evolution in diesel and gasoline shares (both in fuel demand and in car fleet structure). The effects of the increasing diesel share and the related policies are the focus of a large debate in the literature. Sterner (2007), for instance, argues that a large effect on the difference between fuel demand in Europe and US could be explained by the higher tax levels for oil products in the European Union, and also the different treatment in taxing diesel and gasoline can play a role in this gap.

Schipper et al. (2002) (recently updated in Schipper and Fulton (2009)) show that the aggregate "real world" fuel savings coming from the increasing diesel car share are somewhat negligible or even null once compared to the potential fuel efficiency gain. Looking for the causes for this (somehow counterintuitive) phenomenon, Schipper et al. (2002) consider different possibilities. The reasons proposed are all linked to the economic principle of "rebound effect" that could affect both the vehicle use or the vehicle purchase. Those effects are an obvious example of how the shift from diesel to gasoline has non-linear effects on the demand for both gasoline and diesel and is one of the reasons that moved the estimation in this chapter to use aggregate instead of disaggregate data.

Indeed, we argue that using an aggregate model is the only way to uncover how the economic context and the fleet composition affect the gasoline and diesel demand separately and how each one differs from the other. Although the aggregate data lack some detail to separate the private and commercial market, it allows a better insight of the fleet composition and some economic determinants such as real income and prices. Moreover, using a dynamic panel data as in this case allows us to estimate the long-run effects of those economic variables hence providing insights from a medium/long horizon perspective.

By making explicit the impact of the number of diesel vehicles on the total fleet, this work wants to capture the effect of an aspect which has been for a long time the centre of a both political and scientific debate, the one regarding the increasing

domestic demand between oil and electricity adoption of diesel. This discussion is still lively given the growing interest in the energy and environmental impact of road transportation.

The model is an adaptation of the well-documented flow adjustment model presented in Houthakker and Taylor (1966) that takes into account the frictions of the demand in responding to the price changes. Moreover, the formulation tries to directly include the significant diesel share variable, an attempt made, although in different ways, by Pock (2010).

The differences here, concerning Pock (2010), are the data set used (Spanish instead of European), the model specification (addressed in the next section), and that it studies diesel, gasoline and total fuel demand (Pock's study is about just the gasoline demand). The timespan and the general objectives are common to Pock.

The formulation and approach differ from Marrero et al. (2012). In their paper fuel demand depends on the population and not on the actual fleet. Other differences are the prices considered to explain each fuel demand and the estimators chosen, as well as the long-run effects of the independent variables.

In particular, the study of these three different demands for fuel (although with some limitations) should provide interesting insights into both the short and the long-term reactions of consumers to changes in fuel prices and income.

Moreover, a simulation of two different tax reforms is presented in section 3.3. The tax reforms are those proposed by Labandeira (2011), following the suggestions of the European Commission (European Commission, 2011c,b) for tax rates in energy products and transportation. To do the simulation exercise, we apply to the estimation results the relative price changes referring them to a reference year (2007, in this case). This should provide a hint about the effects of a taxation reform from the energy saving point of view and how it can contribute to lower CO_2 emissions in the transport sector.

3.1 Model and Data Specifications

3.1.1 The classical approach and the diesel car share

A large part of transport fuel demand depends on fuel prices and on the income of the consumer (larger incomes and cheaper gasoline makes people drive more), but also the fleet size, composition and efficiency affect the amount of energy demanded in the transport sector.[4]

According to previous papers by Sweeney (1978) and Baltagi (1983), a general specification of the so-called "ideal demand" of fuel per car (variable GAS^*) is a

[4]For a qualitative assessment of the movers of the transportation demand in Spain, see Romero-Jordán et al. (2010)

function of the income per capita Y/POP, the price of fuel P, the number of cars per capita CAR/POP.[5] The formulation is presented in equation (3.1):

$$(GAS/CAR)^* = \alpha(Y/POP)^\beta(P)^\gamma(CAR/POP)^\delta. \tag{3.1}$$

where the fleet size per capita CAR/POP is a correction for the "per vehicle" demand since households that own more than one vehicle do not drive twice as much as households that own just one.

Consumers need time to adapt their behaviour to changes in economic context. Most of the decisions that are part of these reactions are taken once every many years. In the case of transport, those decisions are the car purchase, driving habits, and living and working locations which are not taken more often than every few years in the vast majority of the households.

For this reason, Houthakker and Taylor (1966) came up with the introduction of a different (and not directly observed) demand, called the "ideal" demand, representing consumers' decisions in the absence of any friction. That is what they would like to consume given income or prices, among other aspects, when there are no constraints regarding technology (vehicles, modes) or location (house, work).

The relationship between the "ideal" (without frictions) and "actual" (with frictions) demand is described in Houthakker and Taylor (1966) as presented in equation Equation (3.2) where $(GAS/CAR)^*_t$ represents the first while $(GAS/CAR)_t$ represents the second. This formulation is typical in the literature especially regarding energy and transportation (Baltagi, 1983; Baltagi and Griffin, 1997; Baltagi et al., 2003; Pock, 2010)for example: and it allows to distinguish between the effects on the short and the long term on the consumption. In (3.2) the term θ should be interpreted as the speed of adjustment or the inverse of the time necessary for the short term to converge to the long term after a change in the initial conditions.

$$\left(\frac{(GAS/CAR)_t}{(GAS/CAR)_{t-1}}\right) = \left(\frac{(GAS/CAR)^*_t}{(GAS/CAR)_{t-1}}\right)^\theta, \text{ with } 0 < \theta \leq 1. \tag{3.2}$$

$$(GAS/CAR)^*_t = \left(\frac{(GAS/CAR)_t}{(GAS/CAR)^{1-\theta}_{t-1}}\right)^{\frac{1}{\theta}}, \text{ with } 0 < \theta \leq 1. \tag{3.3}$$

Finally, plugging (3.3) into (3.1) will allow to get rid of the "ideal" term, as in equation (3.4) from which we can take logarithms, leading to the final baseline

[5]In the original formulation an efficiency index was included as well, but the lack of data and the difficulty in defining an appropriate proxy for that led to not include this variable in many models(Baltagi and Griffin, 1997; Baltagi et al., 2003; Pock, 2010)for example:. This chapter follows the latter omitting a direct proxy for efficiency.

of the estimation presented in equation (3.5) to which has been added the classic error term u_t:

$$\left(\frac{(GAS/CAR)_t}{(GAS/CAR)_{t-1}^{1-\theta}}\right)^{\frac{1}{\theta}} = \alpha(Y/POP)^{\beta}(P)^{\gamma}(CAR/POP)^{\delta}. \tag{3.4}$$

$$\begin{aligned}\log(GAS/CAR)_t = \\ &\theta\log(\alpha) + (1-\theta)\log(GAS/CAR)_{t-1} + \theta\beta\log(Y/POP)_t + \\ &\theta\gamma\log(P) + \theta\delta\log(CAR/POP)_t + u_t,\end{aligned} \tag{3.5}$$

where u_t represents the usual error term.

In contrast with the formulation in Pock (2010), here the diesel car share has been introduced as a single variable (DS, equal to $CARD/CAR$, where $CARD$ represents the quantity of diesel-powered cars circulating and CAR the total number). The total fuel demand will take the form as in (3.6):

$$\begin{aligned}\log(GAS/CAR)_t = \\ &\theta\log(\alpha) + (1-\theta)\log(GAS/CAR)_{t-1} + \theta\beta\log(Y/POP)_t + \\ &\theta\gamma\log(P)_t + \theta\delta\log(CAR/POP)_t + \theta\sigma\log(DS)_t \\ &+u_{i,t}.\end{aligned} \tag{3.6}$$

The formulation in (3.6) is the baseline that allows the estimation of gasoline, diesel and total fuel demand, as explained in section 3.1.2.

3.1.2 Gasoline, diesel, and total fuel demand

Although previously cited papers (Baltagi, 1983; Baltagi and Griffin, 1997; Baltagi et al., 2003; Pock, 2010) used similar formulations for estimating just the gasoline demand, avoiding to deal with the diesel demand, here a more general representation of the both is provided[6].

In order to study the particular demands (gasoline and diesel) in different regions, a modification of equation (3.6) is required. This is done simply through the introduction, along with the region index i, of an index $k = \{G, D, F\}$ which will refer to the fuel type being G gasoline, D diesel and F total fuel. For instance $GAS_{G,i,t}$ will be the gasoline demand that take places in region i at time t, and $p_{D,i,t}$ the real price of diesel in region i at time t.

[6]Diesel figures include commercial demand, which would require a different modeling not considered here due to the lack of data.

Accordingly, equation (3.7) represents the more general demand:

$$
\begin{aligned}
&\log (GAS_k/CAR_k)_{i,t} = \\
&\quad \theta_k \log(\alpha_k) + (1-\theta_k)\log(GAS_k/CAR_k)_{i,t-1} + \theta_k\beta_g \log(Y/POP)_{i,t} + \\
&\quad \theta_k\gamma_k \log(P)_{k,i,t} + \theta_k\delta_k \log(CAR/POP)_{i,t} + \theta_k\sigma_k \log(DS) \\
&\quad +u_{i,t},
\end{aligned} \tag{3.7}
$$

It is interesting to note that both the car share CAR/POP and diesel fleet share DS parameters remain untouched in the last formulations. As previously said, this is because the effects of the total car share (people drive less per car when there are more cars per household) should not be related to the particular technology considered. The effects of the different technologies are, in our model, addressed by the technology share variable DS and the associated parameter σ.

For comparison, the alternative model to equation (3.8) that exclude the DS variable (which comes directly from equation (3.5)) will be estimated later:

$$
\begin{aligned}
&\log (GAS_k/CAR_k)_{i,t} = \\
&\quad \theta_k \log(\alpha_k) + (1-\theta_k)\log(GAS_k/CAR_k)_{i,t-1} + \theta_k\beta_g \log(Y/POP)_{i,t} + \\
&\quad \theta_k\gamma_k \log(P)_{k,i,t} + \theta_k\delta_k \log(CAR/POP)_{i,t} + u_{i,t}.
\end{aligned} \tag{3.8}
$$

3.1.3 Data description

Data cover fleet composition, fuel demand, fuel prices and incomes for 16 regions in Spain for the years 2000 to 2007 with annual frequency. Autonomous cities as Ceuta and Melilla and the autonomous community of Las Canarias have not been taken into consideration due mainly to the different fiscal setting. The primary source is the National Statistics Institute (INE). Fuel demand data comes from the National Energy Commission (CNE) while the fleet composition source is the Transit General Directorate (DGT). Regarding fuel prices, the source is a yearly bulletin published by Spanish Ministry of Industry, Commerce and Industry (MITyC) which collects price data from a sample of final resellers.

Both fuel prices and gross domestic products are discounted for each region to the year 2000 by the consumer price index, one of the few available (and reliable) indexes for deflating variables from nominal to real terms.

Table 3.1 shows the descriptive statistics of the variables used in the model (3.6). It is interesting to see that while the between variability explains most of the variability of the fuel demand, the per capita income, and the car share, the within variability is the one that explains the diesel share variability, suggesting that the way it changes is homogeneous among the regions. The price variability is not surprisingly explained by the within variability since nominal prices are moved mostly by the national and international oil markets, being almost homogeneous across the regions.

Table 3.1: Data descriptive statistics.

	$\ln(GAS/CAR)$	(Y/POP)	$\ln(P)$	$\ln(CAR/POP)$	$\ln(DS)$
Min	0.974	0.098	6.426	0.398	0.237
Max	2.806	0.245	7.950	0.923	0.577
Mean	1.792	0.167	7.118	0.653	0.402
Overall var.	0.500	0.046	0.500	0.127	0.115
Within var.	16.9%	24.1%	91.5%	24.0%	60.3%
Between var.	83.1%	75.9%	8.5%	76.0%	39.7%

3.1.4 Estimators

The literature on this topic has devoted many pages to comparing estimators and trying to evaluate which estimation tool could perform better in the particular case of aggregate demand. Comparing the performance in gasoline demand of 11 homogenous and 13 heterogeneous estimators in 30-years-long dataset for 13 OECD country, Baltagi and Griffin (1997) found that homogeneous estimators outperform heterogeneous ones in both forecast trials and plausibility, contrasting with the theoretical prediction. These results are confirmed in a later paper by Baltagi et al. (2003) using a data set from 21 French regions, with evidence leading not to consider heterogeneous estimators in this work.

Nevertheless, Marrero et al. (2012) show how both FD-GMM and sys-GMM perform quite well in determining the estimates for a well-documented dataset similar to the one used here, although showing high p-values for most of the variables when estimating diesel demand.

Finally, Pock (2010), confirming findings by Baltagi et al. (2003) about IV and GMM estimators, suggests the suitability of the fixed effect estimators for the estimation of aggregate fuel demand. Moreover, the author proposes a corrected version of the Within estimator, affected by biases (Nickell, 1981). This corrected estimation (called LSDVc) applied to unbalanced data relies on procedures developed for statistical software STATA by Bruno (2005) through the adaptation of the methods suggested in Kiviet (1995) and Bun and Kiviet (2003).

The superiority of the estimators proposed is supported by the structure of the panel. The fact of treating the whole population of individuals (the autonomous communities), and a sample of the years, suggests a much better performance of fixed effect estimators, as the same evidence by Baltagi and Griffin (1997) shows.

	$ln(GASD)_{t-1}$	$ln(YPOP)$	$ln(P)$	$ln(CARPOP)$	$ln(DS)$
$ln(GASD)_{t-1}$	1				
$ln(YPOP)$	-0.2792	1			
$ln(P)$	0.3273	-0.4687	1		
$ln(CARPOP)$	0.1257	-0.2257	-0.1586	1	
$ln(DS)$	0.2143	-0.1032	-0.3677	0.2898	1

Table 3.2: Correlation matrix corresponding to the diesel model

Since the aim of this chapter is not to investigate the goodness of the estimation techniques but rather to study the characteristics of the different fuel demands and what affects them, only the classic and corrected version of least square dummy variable (LSDVc) estimators will be applied to the formulation presented in section 3.1.2.

Nevertheless, for the sake of completeness, the authors conducted the estimation experiments applying classic OLS, IV, GLS, and GMM estimators with results, not shown here, in most cases inconsistent with both expectations and theory (like the speed of adjustment greater than one).

3.1.5 Testing the hypothesis

One concern could arise regarding the presence of collinearity in the dependent variables, as suggested by Pock (2010). In particular, the relationship between income and vehicle ownership could lead to higher variances in the estimated coefficientsalthough the consistency of estimation results is still unaffected. Tests for collinearity conducted to show how our model is not affected by such issue with the dataset used. Table 3.2 shows the correlation matrix of the coefficients for the total fuel consumption model, showing that all values lie between -0.5 and +0.5, far below the perfect correlation between pairs of variables.

Moreover, as suggested in e.g. Kennedy (2003), Belsey et al. (1980) or Hill and Adkins (2003), a corrected version of the condition index for the three models (diesel, gasoline, and total fuel consumptions) has been computed, as presented in table 3.3 showing low values (below 2), thus suggesting that multicollinearity is not affecting the sample. Also, Eigenvalues and condition indexes for the three models, computed for the multicollinearity test, show values lower than 2.5.

For a more general conclusion, in all models (gasoline, diesel, and total fuel), Fisher Test reject the null hypothesis that all coefficient are equal to 0. Also adjusted R-square is about 99% for diesel, 90% for gasoline and 98% for total fuel, suggesting that the estimator can predict the consumption for most models.

To test for the heteroskedasticity of the model, we study the distribution for

	Diesel	Gasoline	Total
$\ln\text{GAS}_{k,t-1}$	1.37	1.47	1.26
$\ln(\text{Y}_t)$	1.23	1.27	1.21
$\ln(\text{P}_{k,t})$	1.65	1.35	1.54
$\ln(\text{CAR}_t)$	1.32	1.34	1.29
ln(DS)	1.68	1.34	1.51
Mean Value	1.45	1.35	1.36

Table 3.3: Variance infation factor (VIF) for the three models.

	Gasoline	Diesel	Total Fuel
chi square(5)	15.8	15.988	10.46
p-value	0.0074	0.0069	0.0631

Table 3.4: Breusch-Pagan test results for the three models.

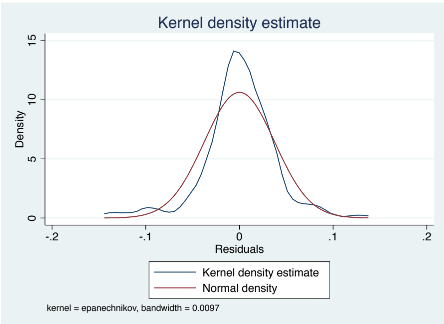
the residual term of the model. The graphic in figure 3.1 shows that the distribution closer to the normal is for the total fuel model. To further support this intuition, we test for the null hypothesis of homoskedasticity, applying the Breusch-Pagan test (Breusch and Pagan, 1980). Results of the test, presented in table 3.4, reject the null hypothesis of homoskedastic disturbance in all but the total fuel consumption model, for which the p-value is (barely) over 5%, providing evidence of heteroskedasticity, thus suggesting that the simple OLS estimator is not consistent.

Finally, given the structure of the panel, we assume a “fixed effect”, distinctive for each region, and to check whether the use of within estimator model is consistent. To study the estimator, we apply the Hausman test (Hausman, 1978), comparing the fixed and random effects and the null hypothesis for the difference in coefficients being not systematic. Results of the test for all three models show p-values lower than 1% (table 3.5) suggesting that the feasible GLS estimator is inconsistent, supporting the choice of the fixed effect estimator over the random effect estimator.

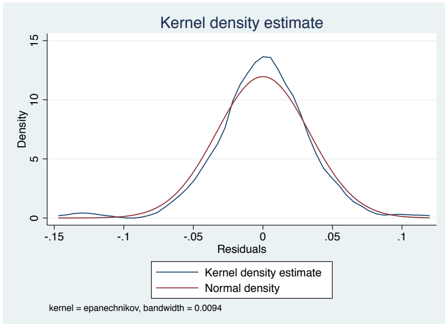
As observed in the previous section, the structure of the panel motivated the choice of the corrected version of the within estimator.

	Gasoline	Diesel	Total Fuel
chi square(5)	21.28	18.95	16.3
p-value	0.0007	0.002	0.006

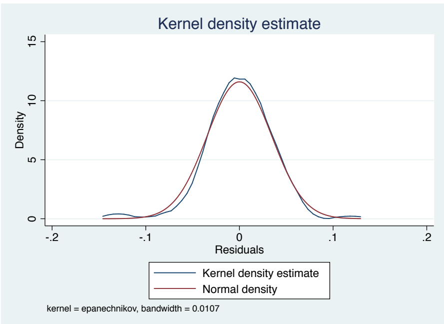
Table 3.5: Hausman test results for the three models, testing the H_0: difference in coefficient not systematic, for fixed effect against random effect estimators.



(a) Gasoline



(b) Diesel



(c) Total Fuel

Figure 3.1: Plots of the Kernel density with the normal distribution overlaid.

3.2 Results

3.2.1 Fuel demand estimation results

	Gasoline		Diesel		Total Fuel	
	Within	LSDVc	Within	LSDVc	Within	LSDVc
Short run estimates						
$ln(GAS_{k,t-1})$	0.527^{***}	0.698^{***}	0.724^{***}	0.861^{***}	0.727^{***}	0.889^{***}
	(4.62)	(9.60)	(7.89)	(22.53)	(6.96)	(13.88)
$ln(y_t)$	0.0576	0.0687^{***}	0.300^{***}	0.217^{***}	0.252^{**}	0.162^{***}
	(0.57)	(3.42)	(3.39)	(7.82)	(2.73)	(4.19)
$ln(p_{k,t})$	-0.264^{**}	-0.246^{***}	-0.243^{***}	-0.231^{***}	-0.293^{***}	-0.276^{***}
	(-3.31)	(-5.82)	(-6.07)	(-8.54)	(-5.35)	(-8.65)
$ln(CAR_t)$	-0.142	-0.0832	-0.328^{**}	-0.204^{**}	-0.297^{**}	-0.165
	(-1.38)	(-1.34)	(-3.13)	(-2.96)	(-2.86)	(-1.94)
$ln(DS_t)$	-0.128^{*}	-0.100^{*}	-0.251^{**}	-0.126^{**}	-0.0926	-0.0655
	(-2.11)	(-2.18)	(-2.76)	(-3.09)	(-1.78)	(-1.77)
Long run estimates						
$ln(y_t)$	0.122	0.228^{*}	1.086^{**}	1.564^{***}	0.924^{*}	1.460^{*}
	(0.55)	(2.18)	(2.93)	(3.57)	(2.33)	(2.18)
$ln(p_{k,t})$	-0.558^{*}	-0.815^{*}	-0.880^{*}	-1.667^{**}	-1.072^{*}	-2.491
	(-2.43)	(-2.51)	(-2.54)	(-2.64)	(-2.16)	(-1.50)
$ln(CAR_t)$	-0.301	-0.275	-1.187^{**}	-1.472^{***}	-1.088^{*}	-1.492^{**}
	(-1.30)	(-1.41)	(-2.94)	(-3.79)	(-2.26)	(-2.76)
$ln(DS_t)$	-0.271^{*}	-0.333^{*}	-0.908^{***}	-0.911^{***}	-0.339	-0.590
	(-2.13)	(-2.27)	(-5.33)	(-3.74)	(-1.65)	(-1.22)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.6: Fuel consumption estimations including the DS variable.

In this section the results of applying equation (3.7) at page 30 to data presented in section 3.1.3 are discussed. As said in the previous section, the estimators applied are classical Within Group estimator and a corrected version of it (LSDVc) proposed by Kiviet (1995) and Bun and Kiviet (2003). The estimates using LSDVc will be discussed more broadly throughout this section using results from Within estimations for comparison. Table 3.6 shows the estimation results for gasoline, diesel and total fuel demands and the dependent variables are divided into short and long-run estimates. Following (3.2) and (3.5), the long-run estimates for price, income, car and diesel share are simply obtained by dividing the respective short-run estimates by $1 - \theta_{SR}$, where θ_{SR} is the estimate associated with the lagged demand $ln(GAS_{k,t-1})$.

At a first look, it seems that most of the estimates are in accordance the economic theory predictions, showing a positive income elasticity and a negative price elasticity. Going into deeper detail, it seems that short-run price elasticities are similar for all the demands and between -0.23 for diesel and -0.28 for total fuel when considering LSDVc estimators, with gasoline in between with an elasticity -0.25. Although a little bit higher, the Within estimator shows similar results, with elasticities of -0.26 for gasoline, -0.24 for diesel and -0.29 for total fuel.

Regarding income, estimates for the different fuel demands are far more disperse. Diesel's short-run elasticity of 0.22, is three times higher than gasoline's estimated elasticity of 0.07. Total fuel shows an intermediate result of 0.16. Estimating income effects with the Within estimator shows higher values for diesel (0.3) and total fuel (0.25), but not for gasoline as the Within estimate is lower (0.057) than the LSDVc and not significant.

These results seem to be consistent with the ones that can be found in the previously cited works. Even if in the literature the income effect appears to be stronger (larger elasticity in absolute terms) than the price effect, as showed in Dahl (2012), similar studies show low-income elasticities. For gasoline, Pock (2010) obtains an income elasticity of just 0.07, while in Marrero et al. (2012), the result for the same variable was -0.011. Our results are more divergent with this latter work in the case of diesel. There, both income and price elasticities appear to be around 0 and not significant (-0.027 and 0.044, respectively), and the same can be said for the parameters related to the fleet composition, as opposed to our results showed in table 3.6 and presented above. As said in the introduction, the reasons for these differences can lie on the estimator used and, more importantly, on the particular model adopted. As stated in Basso and Oum (2007) the estimator used and the model can affect the results, as the comparison with Marrero et al. (2012), with whom we share a similar data set, clearly shows.

The car index parameter (share of cars per adult) shows a negative sign as expected, but it is significant only in the case of diesel demand estimation (-0.20). Finally, regarding the diesel share, the estimates suggest not only that an increase of this variable has a significant negative effect on gasoline demand (-0.10), but also that it has a negative effect on diesel demand (-0.13). Although smaller and not significant, the effect turns out to be negative for the total fuel demand (-0.07) as well.

What should economic theory expect from an increasing diesel share in car fleet? As seen in the introduction, more accessibility and increasing performance of diesel vehicles lead to procedures these vehicles to the gasoline-powered ones (also given the lower cost per-km of diesel). Although it is not possible here to investigate the distribution of kilometres driven by each technology, evidence shows that, on average, diesel-powered vehicles have a higher mileage than gasoline-powered ones. This fact relies on the concept of break even mileage between gasoline and diesel that is the annual mileage at which one user is indifferent between purchasing a diesel or gasoline vehicle, provided their average lifetime costs (Mayeres and Proost, 2001). An increasing share of diesel cars means that gasoline drivers with high annual mileage (compared to other gasoline users) will shift to a now more convenient diesel car as a consequence, for example, of the lower cost of diesel vehicles, thus becoming a low diesel consumer (compared to the average diesel consumer and assuming irrelevant change in its mileage). It is easy to observe that the average per car demand decreases for both gasoline and diesel, as a "heavy" gasoline consumer does not use gasoline anymore and becomes a "light" diesel consumer.

	Gasoline		Diesel		Total Fuel	
	Within	LSDVc	Within	LSDVc	Within	LSDVc
Short run estimates						
$ln(GAS_{k,t-1})$	0.576***	0.743***	0.908***	0.996***	0.751***	0.910***
	(4.96)	(9.60)	(18.58)	(34.18)	(7.24)	(12.71)
$ln(y_t)$	-0.124*	-0.0701	0.0708	0.145**	0.103*	0.0550
	(-2.02)	(-0.95)	(1.13)	(2.67)	(2.28)	(0.76)
$ln(p_{k,t})$	-0.256**	-0.245***	-0.231***	-0.227***	-0.289***	-0.281***
	(-3.12)	(-5.30)	(-5.50)	(-7.10)	(-5.30)	(-8.14)
$ln(CAR_t)$	-0.0210	0.0103	-0.128	-0.145	-0.198*	-0.0871
	(-0.23)	(0.10)	(-1.57)	(-1.52)	(-2.19)	(-0.73)
Long run estimates						
$ln(y_t)$	-0.293**	-0.273	0.771	32.39	0.414	0.610
	(-3.00)	(-1.01)	(0.76)	(0.16)	(1.96)	(0.90)
$ln(p_{k,t})$	-0.603*	-0.953*	-2.512	-50.77	-1.163*	-3.111
	(-2.23)	(-2.10)	(-1.73)	(-0.15)	(-2.00)	(-1.14)
$ln(CAR_t)$	-0.0496	0.0402	-1.400	-32.37	-0.798	-0.966
	(-0.22)	(0.10)	(-1.12)	(-0.17)	(-1.75)	(-1.01)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.7: Fuel consumption estimations excluding the DS variable

Worth noting is that the DS estimate for the total fuel demand is negative (-0.07) but not significant suggesting that this increasing share in diesel is not favouring a lower oil consumption, in spite of its higher efficiency. This could be explained in different ways, but it could mainly be related to the so-called rebound effect: cheaper operative costs induce higher demand (ceteris paribus). Then, even if for the two demands (separately) DS has negative effects, when considering the demand for total fuel, the share of diesel vehicle has a lower or even insignificant effect given the higher mileage or performance of the vehicle.

The long-run estimates show how the independent variables (price, income, and car fleet indexes) affect fuel demand on the longer horizon. These measures are widely influenced by the lagged variable of the fuel demand and why, for instance, close values for short-run estimates turn out much disperse in the long-run (-0.82 for gasoline, -1.67 for diesel and -2.91 for total fuel). These results should be taken into account when designing fiscal adjustments as it represents a measure of how demand might change in a longer-term perspective.

The exclusion of the diesel share in the fuel demand model in (3.7), presented in equation (3.8) leads to the estimation presented in table 3.7. It is worth noting that although short-run price elasticity estimates have values almost identical in tables (table 3.6) and 3.7, the other estimates are far less similar. For instance, the income elasticity presents a negative estimated value for gasoline demand, significant when considering the Within estimator (-0.12). This result seems to be counter-intuitive from the theoretical point of view, although it might be representing a shift to diesel cars. Regarding the long-run estimations, values for diesel do not seem to be reliable since the estimated values appear to be far too high and not significant, suggesting a lower quality of the formulation of equation (3.8). The result confirming findings in Pock (2010), but could also indicate that gasoline is an inferior good or neutral to income changes, as in Marrero et al. (2012).

3.3 Simulating energy fiscal reforms

3.3.1 Simulation setting

In this section, we present the results from a simulation exercise of the impact of a tax reform. For that the estimated elasticities will be used to see how changes in the fuel taxation may affect energy usage and CO_2 emissions. The tax reform taken into consideration is the one proposed by the European Union in (European Commission, 2011c,b). In these two documents, the necessity of linking energy and emissions with taxes has been formalised into a plan for a fiscal reform with deadlines in 2013 and 2018 (these two years will be considered the two steps of the reform).

What would the adoption of these reforms entail for the Member States? Labandeira (2011) discusses the case of Spain deeply. In this paper the author proposes two different fiscal reforms of the entire energy system, analysing the impacts in 2013 and 2018. The simulation provided in this section uses the very same tax reform scenarios while assessing how energy and CO_2 emissions change compared to a reference scenario which in our case is the year 2007, and not focusing on revenues as Labandeira.

		nominal tax levels			*final price*	
year	fuel type	CO_2	Energy	Total	absolute	rel. change
Reference year						
2007	gasoline	0.00	14.30	14.30	32.08	
	gasoil	0.00	8.39	8.39	25.52	
Reform A						
2013	gasoline	1.38	9.60	12.96	30.74	-4%
	gasoil	1.48	8.20	11.42	26.79	+5%
2018	gasoline	1.38	9.60	12.96	30.74	-4%
	gasoil	1.48	9.60	13.07	28.44	+11%
Reform B						
2013	gasoline	1.38	9.60	12.96	30.74	-4%
	gasoil	1.48	8.20	11.42	26.79	+5%
2018	gasoline	1.38	13.69	17.78	35.56	+11%
	gasoil	1.48	13.69	17.89	25.27	+27%

Table 3.8: Disclosure of the tax reforms (in thousand euros per GJ) used in the simulations. The price changes are relative to the 2007 levels.

Yet, this simulation exercise does not take into account several factors affecting fuel demand such as the general equilibrium indirect effects, the role of technology advances or the many limitations of the policy simulations through econometric results[7]. However, the results presented in this section should provide a hint about the order of magnitude of the effects of such a reform in the abatement of CO_2 emissions and the reduction in energy use (if any).

The tax reforms (A and B) simulated are essentially the same as those presented in Labandeira (2011) and quantitatively presented in table 3.8. Reform A just tries to correct the gap between diesel and gasoline by applying an indirect tax related to the carbon content of the fuel, to be 1,384 Euro/GJ for gasoline and 1,480 Euro/GJ for diesel for all the different scenarios, and an increasing energy-related tax which starts at 9,600 Euro/GJ for gasoline and 8,200 Euro/GJ for diesel in 2013 to an equal 9,200 Euro/GJ in 2018 for both fuels. Reform B shares with A

[7]Lucas (1976) clearly shows how the econometric models cannot forecast the effects of monetary policy due to construction limitations.

most of the values, although the taxation in 2018 is assumed to include some of the external costs produced by transportation and to move taxation levels closer to the ones adopted by the other European Union member states.[8]

			Energy Cons. Change		*CO_2 Emission Change*	
year	fuel type	elasticity	abs. (GJ)	rel.	abs. (tonnes)	rel.
Short run results						
Reform A						
2013	gasoline	-0.25	+2760693	+1.03%	+145848	+1.03%
	gasoil	-0.23	-12055084	-1.19%	-730959	-1.19%
2018	gasoline	-0.25	+2760693	+1.03%	+145848	+1.03%
	gasoil	-0.23	-25121720	-2.47%	-1523254	-2.47%
Reform B						
2013	gasoline	-0.25	+2760693	+1.03%	+145848	+1.03%
	gasoil	-0.23	-12055084	-1.19%	-730959	-1.19%
2018	gasoline	-0.25	-7136258	-2.67%	-377011	-2.67%
	gasoil	-0.23	-63248297	-6.22%	-3835059	-6.22%
Long run results						
Reform A						
2013	gasoline	-0.81	+9138768	+3.42%	+482805	+3.42%
	gasoil	-1.67	-86994914	-8.56%	-5274934	-8.56%
2018	gasoline	-0.81	+9138768	+3.42%	+482805	+3.42%
	gasoil	-1.67	-181289643	-17.84%	-10992493	-17.84%
Reform B						
2013	gasoline	-0.81	+9138768	+3.42%	+482805	+3.42%
	gasoil	-1.67	-86994914	-8.56%	-5274934	-8.56%
2018	gasoline	-0.81	-23623277	-8.83%	-1248028	-8.83%
	gasoil	-1.67	-456428193	-44.92%	-27675513	-44.92%

Table 3.9: Simulation results for the gasoline and gasoil consumptions and related emissions under the two different reforms taken into consideration.

3.3.2 Simulation Results

Table 3.9 represents the detailed results for the demand for both gasoline and diesel. This is done by just multiplying the estimated demand elasticities (the corrected LSDV in table 3.6) to the relative price changes proposed in table 3.8.

[8]According to the data from European Commission, the tax share for oil products in Spain is almost 20 percent lower compared to the European average(European Commission, 2011a).

Those results are then processed for calculating the overall changes in oil consumption in transport and the shifts in the entire energy sector and the related CO_2 emissions as in table 3.10.

Regarding gasoline and diesel demand, results appear mixed. The outcome of reform A is a small but positive increase in gasoline demand (+1.0 percent in the short term and +3.4 percent in the long run), given the lower taxation compared to the reference case (the year 2007). Diesel, on the other hand, will always experience a decrease in demand given that retail prices will always be higher when adopting the reforms. Compared to the first step of the reform (the year 2013) the counter-intuitive in both demand and CO_2 emissions is estimated to be around 1.2 per cent in the short- and 8.5 percent in the long-run (given the high (-1.6) long-run elasticity estimated). These figures are even more prominent when we consider the second step of the potential reform A (the year 2018): estimated energy reductions in diesel demand are then 2.5 per cent in the short- and 17.8 percent in the long-term.

Similarly, the adoption of reform B suggests a substantial decrease in diesel demand. Moreover, the second reform step (the one which differs from reform A) shows a decrease in both fuel demands, which is estimated to drop by almost 45 percent for long-run diesel demand. The "true" value should be probably in the estimated 95 percent interval of the reduction, that is between -75 per cent and -11 per cent, an interval too broad to provide a reliable figure. Nevertheless, the short-run estimate can be considered a better instrument for determining the reduction of the demand since, as for diesel, it should be included in the (-0.077, -0.048) interval (at 0.95 level) but the effect on the longer horizon, interesting as well, is hard to predict.

The overall estimated savings are presented in table 3.10. It is worth noting that in all cases the proposed reforms produce savings in the overall energy use, mainly given the greater share of diesel in the total fuel demand (comparing gasoline and diesel absolute figures in table 3.10 shows this clearly).

The impact of adopting just reform A is rather small resulting in a reduction of 0.4 percent in the short-term for both overall energy demand and CO_2 emissions in 2018. The long-term estimate suggests a decrease, in average, of less than 3 percent, although in this case, the reduction of energy from overall oil products in transportation is around 13.5 per cent.

Reform B should have larger repercussions once compared to the just assessed reform A given much higher tax levels for both gasoline and diesel. In this case, results suggest a greater impact on the overall energy use and CO_2 emissions from fossil fuels for transport, that, although just around -1.2 per cent could reach -8 percent in the long run. It is worth reminding that this last result should go together with its confidence interval which suggests, at 95 percent level, a decrease

year	*Energy Cons. Change* abs. (GJ)	relative	*CO_2 Em. Change* abs. (tonnes)	relative	*Overall change* Energy	CO_2
Short run results						
Reform A						
2013	-9294390	-0.72%	-585111	-0.77%	-0.15%	-0.16%
2018	-22361027	-1.74%	-1377406	-1.82%	-0.37%	-0.37%
Reform B						
2013	-9294390	-0.72%	-585111	-0.77%	-0.15%	-0.16%
2018	-70384556	-5.48%	-4212071	-5.56%	-1.17%	-1.14%
Long run results						
Reform A						
2013	-77856145	-6.07%	-4792129	-6.33%	-1.29%	-1.29%
2018	-172150874	-13.41%	-10509688	-13.88%	-2.86%	-2.83%
Reform B						
2013	-77856145	-6.07%	-4792129	-6.33%	-1.29%	-1.29%
2018	-480051470	-37.40%	-28923542	-38.19%	-7.97%	-7.80%

Table 3.10: Simulation results for the total fuel consumption and related emissions and the impact on overall energy demand and CO_2 emissions.

between -2 per cent and -13 per cent in the total energy consumption coming from fossil fuels (not just oil but coal and natural gas as well).

In a nutshell, given the small short-run price elasticities estimated in section 3.2.1, the taxation reform for gasoline and diesel seems to be affecting little the overall energy use and the related CO_2 emissions. Results for a long-run impact of reforms suggest much higher savings in energy usage and lower emissions. However, the high variance of those estimates does not help in identifying a precise value for this estimate but rather a wide interval.

3.4 Summary and Concluding Remarks

Uncovering the key aspects of the sustainability in the transport sector is one of the primary goals of this thesis. Private transportation has a huge role in how transportation affects both economy and sustainability, especially in the energy sector. Assessing the demand for fuel is one of the widespread ways to evaluate which are the main drivers in this market. Here we want to adapt this method, first, to find some evidence of the role of the diesel and its increasing share, and, second, to understand how significant would be the impact of an energy reform on the transport sector itself.

Moved by the "increasing diesel fleet" phenomenon affecting Europe in the last 20 years, the diesel share of the total vehicles is directly taken into account in the estimated equation. Only recently Pock (2010) and Marrero et al. (2012) tried to formally correct the estimation bias coming from omitting the increasing diesel share. The small panel used here is composed of data from 16 autonomous communities of Spain during the period 2000-2007.

The qualitative results of the estimation are in line with both the predictions of economic theory and the literature results like Baltagi and Griffin (1997), Baltagi et al. (2003) and Pock (2010), showing positive income elasticity, negative price elasticity and negative effects of the per capita car ratio. The quantitative results differ from Pock's in that the speed of adjustment appears to be lower. The long-run price elasticity estimates are comparable, while in our results, short-run elasticity seems to be much higher. Regarding income elasticities for gasoline, both short and long-run show lower estimates, closer to 0, even if the same does not hold for diesel. Regarding Marrero's results, results here show a similar elasticity for income (although significant, in many cases), but a higher price elasticity, partially explained by the different approach used.

The correction of a variable summarising the diesel car share when estimating the three different fuel demands (gasoline, diesel and total fuel) seems to be affecting two of them (the "specific ones"). A way to interpret this is that the bias affects are just the particular fuel demand, but once the overall demand is considered, the effect of the technology should be captured directly by the economic variables, such as price and income.

The two simulated tax reforms primarily propose to close the gap between gasoline and diesel prices (per energy unit) and in one case to raise the taxation level to include some of the externalities produced. Both results show, in the short run, a rather small impact on energy use. Nevertheless, long-run estimates of the energy savings show a much larger impact, but the high variability of those estimates are not able to provide a reliable value for this drop in demand.

The exercise carried out in this chapter underlines the importance of the diesel fleet and the economic frame (prices and income), but also the necessity to investigate the interactions in the market deeply.

For instance, as we saw in the previous chapters, the mobility in the metropolitan areas is both relevant and complex. Understanding what would be the effects of policy in different areas, what would be the role of public transportation in metropolitan and how significant could be the impact regarding emission reductions, air quality improvements, is the objective of the next chapters.

Chapter 4

A Simulation Model for Assessing Transport Policies

4.1 Introduction

Fuel has is significant element in the transportation sector. Its relevance in the mobility and in how (and how much) people move is a central part of our assessment. In the previous section we investigated the relationship between economic variables and the consumption of diesel and gasoline. The benefits of using such approach to study transport sector are many including the availability of data. However the need to assess the demand for mobility services and a particular assessment of metropolitan areas, suggest the need to explore additional methods able to represent the complexity of interaction between mobility, economy and sustainability. For this reason, we adopt some features that allow reproducing characteristics of the real-world interaction of agents involved in the market for transport services.

Schäfer (2012) highlights the necessity to represent these elements to capture the effects of economy and policy, in particular on the overall energy market, remarking the importance of internalising external costs and the links between investments in infrastructure and changes in lifestyle.

In the framework of E3 models, where the model represents energy, economy, and environment, the evaluation of investments and changes in preferences makes sense, since the time horizon of the study is long. Our purpose is to explore the effects of policies connected to price and command-and-control measures, with a shorter horizon than E3 models, although more comprehensive energy models already account for many of the features.

Our modelling design takes account of several economic characteristics affecting mobility, leaving outside others. The price of transport, modal choice, time-of-the-day preferences, tax and subsidies, externalities, are all taken into consideration, dropping other aspects like vehicle purchase, pooled mode crowding, and infrastructure congestion.

The interaction between these last points and policy is relevant, as shown in many papers such as Greene (1998), Schipper and Fulton (2009), and Meyer et al. (2012) just to name a few, highlighting the effects of a policy on the available fleet. Greene (1998) suggested limit the overall gas consumption of vehicles by setting mandatory cap (CAFE in the U.S.), while Schipper and Fulton (2009) and Meyer et al. (2012) studied the issues of incentivizing the use of diesel, like the favourable tax rates for diesel in Europe. These policies have ultimately large effect on the available fleet and consequently on fuel consumption.

Previous chapter (3) showed how fleet composition would affect consumption choices, and ultimately, the effects of fiscal policies on it. In the design of a simulation model for urban transport in metropolitan areas, we take into consideration this interaction, leaving outside of the scope of the thesis how the fleet changes according to the policy.

Among the factors that lead us to put aside these features on the model design, there is the lack of a detailed-enough data source, sufficient to study the interactions of these components, and so to compare in a larger number of areas and thus to have some breakthrough on the effects of a set of policies.

We do consider an elastic demand for transport services, as well as a linear supply and prices and quantities limited and affected by subsidies and taxes. In the market also non-transport goods are represented. The flexibility of the model design allows for a variety of application and a variety of improvements, like the inclusion of a broader energy model (like E3 model) or the study of specific measures.

In chapter 5 we apply the model to the study of how a "green" energy reform (the same considered in chapter 3) would affect the mobility market in five different metropolitan areas. In the following section, we propose the modelling structure to tackle these questions and provide the insights.

4.2 Methodology

4.2.1 Model Components

The economic framework in which we develop our model is the computable partial equilibrium model, with constant elasticity of substitution for demand, and linear costs for supply. The assumption of constant elasticity seems reasonable in the context of our study, and the nested structure allows clustering modes, thus avoiding the need to create a large matrix of elasticities. We follow the original work of Keller (1976), sharing some of the notation and definitions.

We define final goods as the specific goods or transport services. These goods are "aggregated" into Utility Components and, according to their characteristics after many steps (or levels) building the overall Utility. The latter allows to assess many different aggregated prices and to define intermediate goods. The general structure resembles the tree in TRENEN (Van Dender and Proost, 1996) , although the data availability and the purpose of the study, and is shown in the graph in picture 4.1.

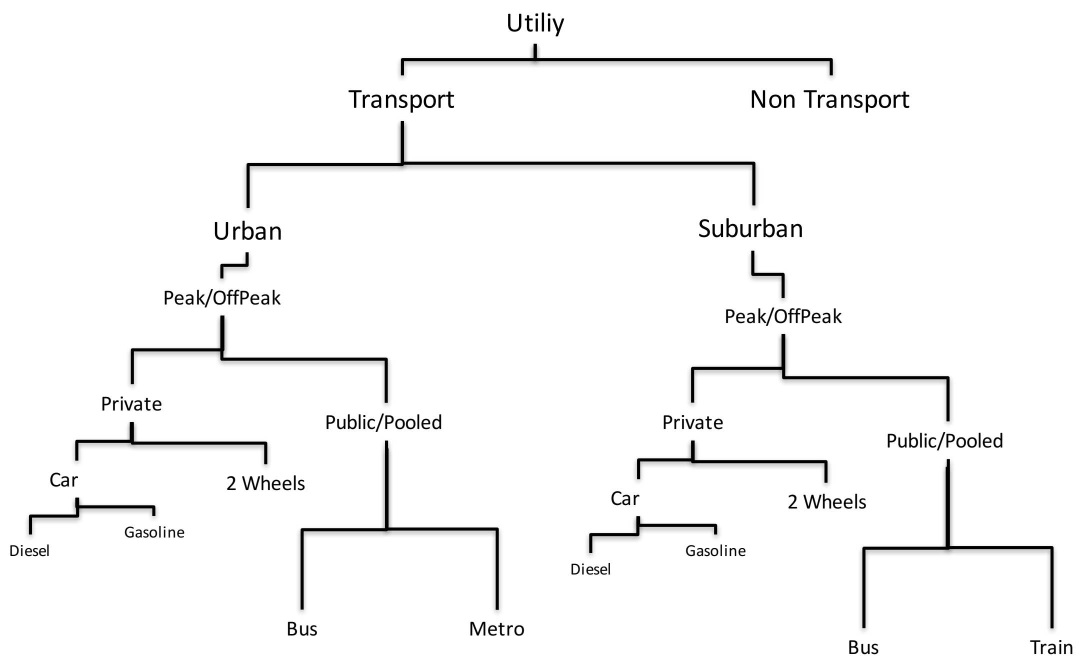


Figure 4.1: Nested Structure of the demand.

The components at the bottom of the (upside-down) tree are the particular transport modes that define the overall demand. These, in Keller's notation, are the *components*. The number of levels, not counting the commodities, is 6. The lowest levels refer to specific characteristics of the vehicle used for the transport (car/bus/train), while upper levels refer to more general aspects of the trip to the time of day (peak/off-peak) or the location (Urban/Suburban). On top lies the distinction between aggregate transport and a representative non-transport good.

Representing the demand in this form allows assessing changes prices that can be general or particular to each specific mode. For instance, a taxation that could tackle the use of private vehicles during peak hours, or discounts for residents living outside the main municipality. It is important to understand that the design of the tree has to fit the purpose of the study and the data availability for this we present the model, developed and used in the case study in chapter 5.

The key components of the demand are the elasticity of substitution between goods and the share of each one. While the first comes from previous results and the literature, the second depends on the constructed base scenario, thus relying on the collected data. The process on how to translate the data in model components consists of a calibration, explained in section 4.2.2. Here follows a description of the components adopted in the model, descripted in detail in Appendix A.

As already said, the model used here takes inspiration from other well-established models such as TRENEN and TREMOVE. While the second is designed to model with high level of detail a whole region or nation and introduces the dynamic dimension of the transport system, the first is a static partial equilibrium model aiming to optimise welfare in local areas, such as cities or small regions. We, therefore, follow the structure of TRENEN, and we adopt from it the utility and cost function design, as well as the use of the Marginal Utility of Income (MUOI, hereafter) to monetarize the utility and so construct the welfare function.

The model presented here differs from the previously presented models. The lack of data and the scope of the study led us to the construction of an apropos configuration. The objective of the model is to evaluate how local and central policies affecting transport have an effect on local transport systems and the associated welfare. For this, we use a comparative static approach. We also had to drop some requirements for the time dimension description, given the difficulty to gather the information about travelling time in the metropolitan areas: a congestion function is not included, thus allowing for an easier description of the time-dependent patterns, using a simple external cost to the trip consumption.

Specifically, the maximization problem of the consumer is as follows (equation (4.1)), where x_l is the transport mode consumption and x_{NT} is the non-transport good consumption:

$$\max_{x_l, x_{NT}} U(x_l, x_{NT}), \tag{4.1}$$

subject to the budget constraint in equation (4.2), where p_l and p_{NT} are transport-modes and non-transport prices, τ_l is the linear tax level associated with a particular mode (a subsidy when taking negative values), and Y is the available income.

$$p_l(1 + \tau_l)x_l + p_{NT}x_{NT} \leq Y. \tag{4.2}$$

In a nutshell, the consumer chooses the consumption bundle of both a non-transport good (x_{NT}) and all the specific transport modes (x_l) that maximise her utility under the budget constraint. In the latter, total expenditure does not exceed the available income, taking income, market prices, and taxes as given (Y, p, and τ respectively),

The nested-CES utility function U (Keller, 1976) is a model representation of consumers that allows allocating between different modes, thus picturing modal shifting in transport. For each metropolitan area, we distinguish each mode by the location of the demand (inside the main municipality vs. outside), the time of the day (peak vs. off-peak), the service provider (public versus private) and the vehicle used (for example diesel car versus two wheels). Quantities are expressed in passenger-km (or pkm) while prices are in Euros per passenger-km. The parameters of this function partially come from the literature (for example elasticities), then calculated through a calibration process, which is started by a real-data-fueled reference scenario and discussed in section 4.3.

To represent supply, we adopt a linear cost function that takes into account the cost of fuel, of vehicle operation and maintenance, insurance and the per-km cost of depreciation of the vehicle. Also to represent the fleet limitations, we adopt for each fuel-technology combination a constraint, and also another constraint for the usage of each technology.

Each supply and cost refer to a particular vehicle type and fuel, with supply measured in vehicle-km (or vkm) and its costs are in Euro per vkm. Technology, in our example, represents the used vehicle, which can be, for instance, diesel bus, metro train or gasoline car, while fuel is energy source (diesel, electricity or gasoline).

We also include constraints characterising fleet availability and utilisation rates, being, for example, much higher in the public services.

The occupancy rate (pkm/vkm), exogenous in this model, connects the service demand with the supply side. So, being $v_{m,k,f}$ the vehicle-km offered by each specific mode m, using technology k and fuel f, and c its associated variable cost, we develop the transport service provider problem as follows in equation (4.3):

$$\min_{v_{m,k,f}} \sum_{m,k,f} c_{m,k,f} v_{m,k,f}, \tag{4.3}$$

With the minimisation problem subject to the technology and fuel constraints $\bar{k}$ and $\bar{f}$ as in equations (4.4) and (4.5):

$$\sum_{f \in k} v_{m,k,f} \leq \bar{k}_{m,k}, \; \forall (m,k) \tag{4.4}$$

$$v_{m,k,f} \leq \bar{f}_{m,k,f}, \; \forall (m,k,f) \tag{4.5}$$

In simple words, the supplier provides certain levels of transport service v while minimising the total costs, and respecting the technological and fuel constraints

($\bar{k}$ and $\bar{f}$).

Market clearing determines prices and quantities at equilibrium, stating that the demanded quantity has to be at most equal to the produced quantity weighted by the exogenous occupancy rate o_m as in equation (4.6):

$$x_m \leq o_m \sum_{k,f \in m} v_{m,k,f}. \tag{4.6}$$

4.2.2 Calibration and Comparative Statics

The process to translate the reference scenario into input parameters is the calibration of the model. On the supply side, input parameters include costs and constraint, all measured in Euros per vehicle-km (Eur/vkm) and vehicle-km (vkm), respectively. On the demand side, there are equilibrium prices and quantities, these measured in Euros per passenger-km (Eur/pkm) and passenger-km (pkm). Others parameters, like tax rates, will also be an exogenous input, specific for each metropolitan area.

While reference scenario costs and constraints are calculated for each metropolitan area and kept constant after the comparative statics, equilibrium quantities and prices are the variables computed in each scenario. The parameters necessary to these computations, on the demand side, are the elasticities (*sigma*) and Keller's alphas (*alpha*). While the firsts are taken from the literature and are common to all Areas studied, the alphas are Area-specific computed through the calibration. The process involves the computation of a set of equations, the solution being the parameter alphas. For the calculation, we derive the equations from the demand, adapting the optimality conditions from (Keller, 1976). These conditions are carefully described in Appendix section A.8.

The aim of the model is to simulate the effect of (mainly) policies that act on the final price of transport services or their availability. Each set of tax rates specifies a particular scenario, leading to the computation of different scenario-specific prices and quantities or the specific output of the model. The process is the so-called "comparative statics": the objective is not to determine optimal tax levels, but it is what-if simulation exercise tuning some parameters. From there, we assess energy consumption and greenhouse emission variations, as well as simulated changes from the total welfare or fiscal revenues. Chapter 5 shows the "comparative static" experiment for a tax reform proposal that involves all the transport sector.

4.3 Building the dataset for the model

A major objective of the thesis is to represent in detail the demand for mobility services, capturing how changes in prices or availability of technologies can affect travel choices in urban areas, with an accurate quantitative description of consumers' preference. The quality of the data is essential, from the selection to the manipulation. In the model, the properly handled raw data serve as input for the *calibration process* that will give the parameters for the CES Utility Function described hereafter.

Data inputs, apart from elasticity parameters[1], are quantities and prices in transportation, with the first measured in yearly passenger-km (pkm hereafter) and the second in Euros per pkm. The use of these measures allows to better describe not only the use of energy in transport and the greenhouse gas emissions but also effects of local pollution and congestion, and their social costs.

In the previous section, we focused on the model structure and its features. However, the data availability, necessary to link the policy simulation process with reliable results, depends deeply on the quality of the initial data and how data integrate with the model.

Assessing mobility patterns, modal choices, fleet composition, and peak hours is essential in carrying out the simulation experiment. The many limitations come from both the detail of the information available, the homogeneity both across the sources and across the metropolitan areas. Collecting, assessing, and making it compatible with the simulation framework has been a hurdle, yet an essential stage point in providing rigorous results in the policy analysis exercises.

4.3.1 Source Review

The variety of sources for the Spanish transport system and mobility is diverse in many ways: the information provided, the period considered, the level of detail in both geographical terms and time dimension determine the quality of the data and its use in our modelling deeply. There are many surveys and databases that we will not mention either because are already in the sources listed below, or because they are not sufficient to fill the data gaps.

For instance, the *Observatory on Metropolitan Mobility* (OMM hereafter) directly collects yearly data from most of the local transport authorities and agencies, representing the main reference for data gathering on urban transportation in metropolitan areas, particularly for public services. *Infrastructure and Public Work Ministry* (Ministerio Fomento) provides official data from main road usage

[1] The main source for elasticity values is TRENEN (Van Dender and Proost, 1996) with which we share some of the model design solutions.

and collects information from controlled agencies such as railways and airports. Moreover, through *Movilia*, it provides main statistics about user choice and behaviour in both urban and extra-urban situations.

The former *Spanish Energy Commission* CNE (now Commission for competition) offers information about the fuel prices and consumption while DGT (the *Spanish General Directorate of Traffic*) collect and make information about the state of the road vehicle fleet available.

Observatory on Metropolitan Mobility The Observatory on Metropolitan Mobility is an annual report on the state of the Metropolitan personal transportation, published by the Ministries of Agriculture, Food, and Environment and Public Work and Transport. Data are collected and assessed by TRANSyT Transport Research Centre of the Politécnica University of Madrid.

The Observatory on Metropolitan Mobility collects and publish information about urban mobility from the main local transport authorities (PTAs) in Spain and homogenises it. The areas considered in Observatory are eighteen and include Madrid, Barcelona, and Valencia among the most populous and Pamplona, Girona, and León among the less populated.

Among the topics covered by the OMM, public transportation in the metropolitan areas fills a central role. In there, the information contains a detailed description of the fleet and network compositions and their usage, economic results and tariff schemes, and, more importantly for our purposes, the travel demand by users both measured in trips and passenger-km. Other topics are the general composition and demography of the areas and the results from previous mobility household surveys.

Tables 4.1 and 4.2 summarise the available data that could serve our purpose of building the reference scenario. Along with references to the document, table 4.1 defines the considered services and modes, together with the level of detail. In addition to that, table 4.2 considers every statistic in each table, providing information about the reference and its unit, crucial for homogenising the data collection.

Fomento Another essential information set comes from the official statistics database of Ministerio de Fomento, the Spanish Ministry of Public Works and Transport. It collects data about traffic on main roads, railways and airports, as well as some results about mobility on public coach services, taxis and freight, representing the official picture of the demand for transport in Spain. Since many national operators for both public transport–like RENFE, the national train operator–and infrastructure–as ADIF, the railway infrastructure operator, DG Carreteras for public roads– refer to the Ministry, its official database is the

Table name	Reference	Geo def.	Service
General char.	Tab. 1, p. 9	MA/CC	
Socioeconomic char.	Tab. 2, p. 11	MA	
Motorisation index	Tab. 3, p. 12	MA/CC	Private (cars)
Mobility char.	Tab. 4, p. 13	MA	Public/Private (undistinguished), ref. to last surveys
Modal Share	Fig. 1 to 6, p. 14 to 16	many	Public/Private (distinguished), ref. to last surveys
N. of trips, publ. transport	Tab. 5, p. 17	MA	Public (urb/extrurb buses, metro, tram, train)
Demand of publ. transport	Tab. 6, p. 20	MA	Public (urb/extrurb buses, metro, tram, train)
Tariffs	Tab. 35, p. 51	min and max zones	Public (urb/extrurb buses, metro, tram, train)
Tickets sold	Tab. 37, p. 53	MA	Public (urb/extrurb buses, metro, tram, train)
Economic results	Tab. 39, p. 57	MA	Public (urb/extrurb buses, metro, tram, train)

Table 4.1: Main characteristics of the tables and figures in OMM, including area and modes considered. MA stands for Metropolitan Area, while CC stands for Capital City, or the main centre of the area.

Table name	Reference	Statistic	Unit
General char.	Tab. 1, p. 9	Area	square km, abs.
		Population	inhab., abs.
		Constr Area	square km, abs.
Socioeconomic char.	Tab. 2, p. 11	Household Size	inhab. per househ., rate
		Activity Rate	active pop, perc.
		Unemployment rate	unempl pop, perc.
		GDP per capita	euros per capita, rate
Motorization index	Tab. 3, p. 12	Car ownership	vehicles per thou. inhab.
		Motorbike/Moped ownership	vehicles per thou. inhab.
Mobility char.	Tab. 4, p. 13	Workday trips	million trips, abs.
		Average trip time	minutes per trip, rate
		Average trip length	km per trip, rate
		Intermodal trip rate	intmod. trips, perc.
Modal Share	Fig. 1, p. 14	Work Purp.	trips per mode, perc.
	Fig. 2, p. 14	Other Purp.	trips per mode, perc.
	Fig. 3, p. 15	All Purp. (whole met. area)	trips per mode, perc.
	Fig. 4, p. 15	All Purp. (Capital City)	trips per mode, perc.
	Fig. 5, p. 16	All Purp. (Outside Capital City)	trips per mode, perc.
	Fig. 6, p. 16	All Purp. (whitin and outside CC)	trips per mode, perc.
N. of trips, publ. trans.	Tab. 5, p. 17	Number of Trips	million trips, abs.
Demand of publ. trans.	Tab. 6, p. 20	Demand	million pkm, abs.
Tariffs	Tab. 35, p. 51	Prices of public transport	euros per ticket
Tickets sold	Tab. 37, p. 53	Number of Tickets used	million tickets, abs.
Economic results	Tab. 39, p. 57	Revenues	million euros, abs.
		Subsidies	million euros, abs.

Table 4.2: Main Statistics included in the tables considered in OMM.

most reliable source of information.

Movilia 2006 The *Movilia* survey samples information about trips for urban mobility (2006 edition) and extra-urban mobility (2007 edition). A randomly selected sample of the Spanish population represents the source of this information that, for the 2006 edition, provide quantitative insights about the everyday journeys and commuting, regarding the purpose, mode usage, time spent travelling and time starting the trip. This last feature is the one that will be included in our analysis since Movilia is the only one that does consider this aspect thus allowing the characterisation of the time dimension, providing the peak and off-peak hours and shares.

Limitations of the data provided are evident. First, the data refer to the year 2006, that may look inconsistent with other databases. Second, there is no geographical definition of the data, only about the size of the municipality and if it belongs to a (no better defined) metropolitan area or the province where it takes place. Last, about the length of the trip, the lack of information makes it difficult to determine the actual demand for travel, which should appear in passenger-km.

In the survey (that can be found online as an Excel document), tables 74.1 and 74.2 show the number (in millions) of trips for each mode per workday (the first) and per weekend days (the latter), suggesting how modes and services are used differently across daytime.

The difficulties coming from a different (and less detailed) database structure compared to another source like OMM, makes it necessary to carefully state the needed assumptions to integrate the information to the model input. Regarding location, for instance, peak hours may differ from area to area, leading to a "smoother" aggregate picture of the hourly demand for transport. The diagram in picture 4.2 clearly shows that, although there is a clear peak around 9 a.m., the demand during the afternoon hours is both lower and wider than the morning peak, which can be linked to the issue just mentioned.Observing the relative distribution of trip starting time for each province in the Metropolitan Areas considered, Figure 4.3 and comparing it with the previously cited picture 4.2, we can observe that the pattern found in the general statistics persists with small exceptions. The conclusion is that peak hours are similar throughout the provinces.

Directorate General of Traffic Directorate General of Traffic or DGT is a subdivision of the Ministry of Interior in charge of the public registry of transport vehicles, among other duties such as traffic safety. It collects and publishes the official statistics on the private and public vehicle fleet registered in Spain, from the new vehicles registered, to the active fleet and its age. It is represented with a favourable level of geographical detail, providing data for the transport fleet at

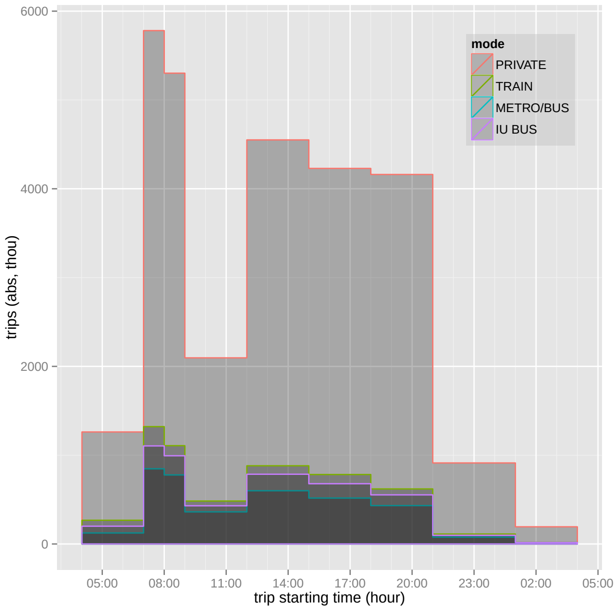


Figure 4.2: Trip starting time for urban transportation for each mode.

the municipal level, allowing us to replicate the metropolitan area in the most accurate way.

Spanish Energy Commission The Spanish Commission for Energy Markets (CNE), now assimilated into the Commission for Market Regulation and Competition (CNMC), was in charge to monitor and control the whole market for oil products, and also collecting and publishing data on both prices and consumption of road fuel. It is worth noticing that data on consumption do not allow to differentiate between passenger and freight transport, thus not easily allowing to determine which portion relates to private or public transport demand. The final price of oil products can be used as a useful measure for the price of private vehicle use, representing one of the main components for the use of cars and two wheels.

Although not having the same level of geographical detail as the vehicle fleet in DGT, the data allow detail the price levels in the different areas, provided province-specific prices, but not within each metropolitan area.

French Survey on motorised two-wheelers The French Government published in 2011 a survey on various aspects of the use of motorised 2-wheelers. The proximity and similarity in socio-economic aspects suggested the benefits of adapting the information provided by the results of this survey. The database includes the total demand and fleet composition in both urban and metropolitan areas,

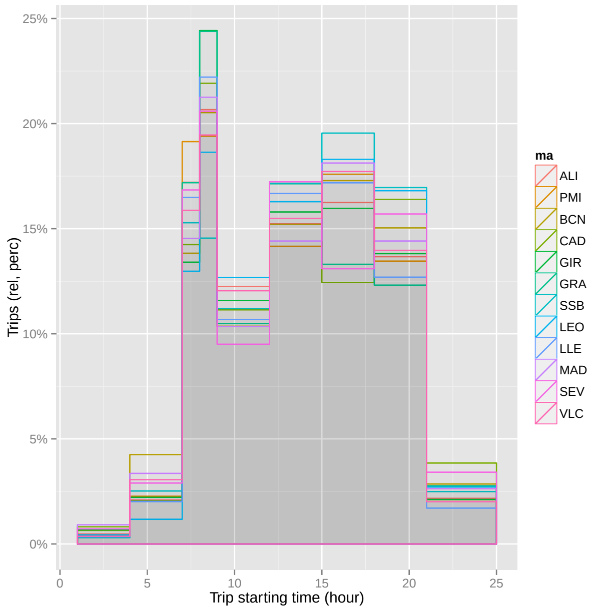


Figure 4.3: Trip starting time for urban transportation for each province.

along with other statistics like average consumption, useful for determining the price of using such vehicles.

The Table in Figure 4.3 summarises the information we can get from each source. It is easy to see that none of them, alone, fully comply with the needs for our model calibration. In the next section, a thorough assessment of the gap between data and model will lead to the choice of the appropriate sources.

4.3.2 Integrating the data sources

To better represent both the assumptions, the selected sources, and their alternatives, we focus on four main subjects: public transport, private transport, their modal shares, and the time dimension.

As seen previously, data for public transportation is gathered by the OMM data collection. The assumption, kept throughout the analysis, is that certain transport modes do coincide with the geographical location. Metro trains and urban buses are limited to the main municipality of the area, while metropolitan train and inter-urban buses are assumed to be outside of it. Although alternatives such as the surveys (conducted by the same PTAs and included in the OMM) add some detail to the location, they would lose all the essential information about trip length and specific share.

These surveys are also used to obtain some measure of the private transport in

Provider	Table name	ref	statistic	Trips	pkm	eur	Oth	Area	Loc	Time	Private	Public
OMM	General charact.	omm.tab1	Area				**	**	**			
			Population				**	**	**			
			Constr Area				**	**	**			
OMM	Socioec. charact.	omm.tab2	Household Size				*	**				
			Activity Rate				*	**				
			Unemployment rate				*	**				
			GDP per capita			**		**				
OMM	Motorization Index	omm.tab3	Car ownership				**	**	**		*	
			Motorbike/Moped ownership				**	**	**		*	
OMM	Mobility characterstics	omm.tab4	Workday trips	*				**				
			Average trip time				**	**		*		
			Average trip length	*	*		**	**				
			Intermodal trip rate	*			*	**			*	*
OMM	Modal Share	omm.fig1	Work Purp.	*				**			*	*
		omm.fig2	Other Purp.	*				**			*	*
		omm.fig3	All Purp. (whole met. area)	*				**			*	*
		omm.fig4	All Purp. (Capital City)	*				**	**		*	*
		omm.fig5	All Purp. (Outside Capital City)	*				**	**		*	*
		omm.fig6	All Purp. (in between CC and outside)	*				**	**		*	*
OMM	N. of trips, publ. trans.	omm.tab5	Number of Trips	**				**	*			**
OMM	Demand of publ. trans.	omm.tab6	Demand		**			**	*			**
OMM	Tariffs	omm.tab35	Prices of public transport			**		**	*			**
OMM	Tickets sold	omm.tab37	Number of Tickets used			**		**	*			**
OMM	Economic results	omm.tab39	Revenues			**		**	*			**
			Subsidies			**		**	*			**
DGT	vehicle fleet	dgt.es Stat DB	registered vehicles per fuel, per town				**	**	*		**	*
MOVILIA	trip starting time	2006.tab77-1	weekdays on the mode	*						**	*	**
MOVILIA	trip starting time	2006-tab77-2	weekend days on the mode	*						**	*	**
MOVILIA	trip starting time	2006.tab75-1	weekdays on the province	*				*		**		
MOVILIA	trip starting time	2006.tab75-2	weekend days on the province	*				*		**		
MOVILIA	trip starting time	2006.tab74-1	weekdays on the size of the munic.	*						**		
MOVILIA	trip starting time	2006.tab74-1	weekend days on the size of the munic.	*					*	**		
CNMC	CNE fuel prices	CNE database	average fuel prices			**		*				
CNMC	CNE fuel cons./em.	CNE database	fuel consumption				*	*				
FOMENTO	Main roads trans	Ch8 Tab7.8	pass. transport on the main road network		*						*	*

blank	*characteristic missing*
*	*characteristic available and providing some evidence*
**	*characteristic available and providing strong evidence*

Table 4.3: Table summarising information from the sources and evaluating the potential contribution to each of the characteristics the model needs.

metropolitan areas, where sources like Fomento or Movilia cannot provide any local information. The OMM surveys provide an overall measure of the trip number for private vehicle users, which should be adjusted using the average trip length for public transport users to obtain the total demand in passenger-km.

The next step is to define the private modes further. For instance, to differentiate between diesel and gasoline car usage, as well as two-wheel vehicles, we rely on the vehicle fleet data provided by DGT. Here, the modal share in private consumption is defined by the number of vehicles on the road, weighted by a parameter. This strong assumption is far less demanding compared to the one involving the fuel consumption, which data, as shown before, are far less specific.

The design of the weight relies on data and studies that tackle specifically the demand for private transportation. For the difference in use of the gasoline and diesel fleet, we use previous econometric analyses on this specific topic (González and Marrero, 2012; Danesin and Linares, 2015; Mendiluce and Schipper, 2011). As for motorcycles, the usage of motorised two wheels in France (de Solere, 2010) served to overcome the lack of data for metropolitan Spain, with the help similarities between the two contexts. These data are not used for total demand, but just to specify the fleet use compared to the overall demand for private transport.

The only available option to comply with the model needs for the time dimension is the information provided by Movilia. Once again, strong assumptions are unavoidable, mostly because the data measures are in trips rather than passenger-km and modes do not always coincide with those in OMM. Also, the geographical definition covers provinces instead of just metropolitan areas. Finally, the reference year is different; yet, the lack of alternatives required to adapt our scenario to the information available.

Provided the assumptions stated before, we can construct the data input to be used by the calibration process and, to formally represent this construction, we introduce some parameters and indices. Demand, to be measured in passenger-km (pkm) and named x, is defined by the metropolitan area a (Madrid, Barcelona, for example), the location l (Intra and Extra-Urban), time t (Peak and Off-Peak), and mode m (diesel- and gasoline-car, urban bus, train, for example). The particular demand for a mode will be then $x_{a,l,t,m}$.

Metropolitan Areas (presented as a in equations) included in this paper are the ones presented in OMM, dropping the ones with significant gaps in data coverage. Namely, the areas are Madrid, Barcelona, Valencia, Málaga, and Girona. To further define the demand geographically we introduce the *location*-dimension, as l in equations. These can be intra- or extra-urban, defining trips that take place within the main municipality or not, respectively. *Time* (t) can be either peak and off-peak and for modes, the set PU contains the public ones (metro, train, intra- and extra-urban bus) while the set PR the private ones (gasoline and diesel cars, two-wheelers).

OMM provides the demand in passenger-km for each mode, providing the data for $x_{a,l,m\in PU}$. The surveys, also in OMM, provide the aggregate measure for private transport in trips, together with public ones, which is then used to obtain the overall private travelled passenger-km. Defining $\mathbf{shr}_{a,m,PR}$ and $\mathbf{shr}_{a,m,PU}$ as the modal shares of the private and public transport from OMM, we get the overall demand for private modes:

$$\sum_{m\in PR} x_{a,l,m} = \frac{\mathbf{shr}_{a,m,PR}}{\mathbf{shr}_{a,m,PU}} \cdot \sum_{m\in PU} x_{a,l,m}. \tag{4.7}$$

To obtain the precise demand for each private mode, we introduce the relative fleet component $flt_{a,l,m\in PR}$ and the weight $a_{m\in PR}$ that relates the different modes (diesel and gasoline cars) to their different usage. While the $flt_{a,l,m\in PR}$ component is measured in vehicles, the weight $a_{m \in PR}$ is here measured in annual vehicle-km (vkm) per vehicle. The final result will be the relative mileage of a specific mode, compared to all the fleet:

$$x_{a,l,m \in PR} = \frac{\mathbf{flt}_{a,l,m \in PR} \cdot a_{m \in PR}}{\sum_{m \in PR} \mathbf{flt}_{a,l,m \in PR} \cdot a_{m \in PR}} \cdot \sum_{m \in PR} x_{a,l,m}. \tag{4.8}$$

Finally, we introduce the time dimension through the parameter $\mathbf{tm}_{a,t,m}$, derived from the Movilia surveys, thus completing the parameter definition of the demand model input:

$$x_{a,l,t,m} = \mathbf{tm}_{a,t,m} \cdot x_{a,l,m}. \tag{4.9}$$

Along with quantities, the price (in Euros per pkm) represents the main aspect of the model input. Once again, the wish to rely on official data makes necessary a thorough assessment of the available sources.

For both public and private modes, the lack of a *per-pkm price* published data leads us to combine different sources, already shown in table 4.3. Then, the resulting assumptions and the alternatives are compared to check whether the information obtained is robust enough to be used as input.

For public transport, the various sources that can bring information about pricing are all included in OMM and come from the official public service providers. The pricing scheme together with the number of trips sold and the average trip length can be a viable option. The shortcoming of this alternative is the impossibility to determine which mode (bus or metro, for instance) has been used and paid. Moreover, multiple and seasonal passes can be utilised on different occasions (and so transport modes) making it difficult to determine the expenditure in each trip.

The chosen alternative is the use of the economic revenues for each mode, together with the total passenger-km figures coming from the demand side, allowing to consider pass distribution and so trip price per transport modes across modes. The limits, as before, underline the impossibility to determine the different allocation of revenues across peak and off-peak.

Recalling the notation in (4.3.2) we introduce some parameters for the information included in the tables just considered above: first the revenues collected in OMM are defined as $\mathbf{Y}$, while final price is called $\mathbf{p}$ instead. Recalling $\mathbf{x}_{a,l,m \in U}$ as the demand for public transport modes, we derive the equation for the prices for public transport modes in equation (4.10):

$$\mathbf{p}_{a,l,m \in PU} = \frac{\mathbf{Y}_{a,l,m \in PU}}{\mathbf{x}_{a,l,m \in PU}}. \tag{4.10}$$

Determining the price of private modes is trickier, due to the lack of an accounting system as for public transport. The indirect measure of this, as it has been done extensively in the literature (De Borger and Proost, 2001; Mayeres et al., 1996; Schäfer, 2012), is to consider the private costs per use of the vehicles, and adopt an average occupancy rate.

The construction of the price of private vehicle usage depends on the fuel component and others such as the maintenance and insurance costs. While the first depends on vehicle efficiency and the type of fuel, the other two are rather similar across the fleet. Values of the private vehicle efficiency are taken from the corrected official values of a reference car model. The correction is the 15% of the laboratory tests, a measure in line with the recent literature Mock et al. (2014). IAE databases provide the energy content of fuels and the relative conversions.

The source of the fuel prices is the already covered CNMC dataset, while the source of the other costs is the DG Ground Transportation of the Spanish Ministry of Public Works through the Observatory Of Transport and Logistic of the same Ministry. The price will be computed as follows, with occupancy rate being $\mathbf{o}$ (in passenger-km/veh-km), efficiency rate $\mathbf{e}$ (in toe/veh-km), fuel price being $\mathbf{f}$ (in eur/toe), and $\mathbf{c}$ other complementary costs (in eur/vkm):

$$\mathbf{p}_{a,l,m\in PR} = \frac{(\mathbf{e}_{m\in PR} \cdot \mathbf{f}_{a,m\in PR}) + \mathbf{c}_{m\in PR}}{\mathbf{o}_{m\in PR}}. \tag{4.11}$$

Having already discussed the impossibility of discriminating prices without taking into account users' cost of time, the final relation will provide the price for all the modes, being equal in both peak ($peak$) and off-peak (off) situations, as follows:

$$\mathbf{p}_{a,g,t,m} = \mathbf{p}_{a,g,\mathbf{peak},m} = \mathbf{p}_{a,g,\mathbf{off},m} = \mathbf{p}_{a,g,m}. \tag{4.12}$$

All these equations provide the full framework for the dataset required by the model, leading to the reference scenario, used for the parametric calibration of the model and the comparison with the simulation results.

In summary, the exogenous variables of the model include the availability of transport and the per-km cost of them, the tax rate structure, and the elasticity of the demand. The reference scenario, as presented in this section, leads to the definition of the last exogenous variable, i.e. the Keller's Alphas.

Chapter 5

An Application to Five Spanish Metropolitan Areas

5.1 Introduction

In chapter 4 we introduced a model design to simulate the transport sector, specifically in metropolitan areas. Now we carry out an experiment, simulating the effects of a nation-wide reform at the metropolitan-area level.

In Spain, estimations have been done mostly at the national scale, e.g. Sobrino and Monzon (2014), who adopt the TREMOVE model (Ceuster et al., 2007) to estimate the increase of the greenhouse gases in the period 2000-2006. Studying only the case of Madrid, Wang et al. (2015) experiment with the introduction of a congestion toll (similar to the congestion charge in London), applying system dynamics techniques to evaluate the effects on social welfare over a 40 years span. But they do not compare with other areas, and therefore their results are difficult to extrapolate to wider policies.

Other studies address the effects of changes in price for urban transportation in metropolitan areas, such as Asensio (2002) in Barcelona and García-Ferrer et al. (2006) in Madrid, that assess the effects of changes in prices in the use of public transport modes. One other study, Albalate and Bel (2010), compare the different characteristics of various European cities that determine the demand for public transportation. Sobrino and Monzon (2013) assesses Spanish urban mobility through the Movilia Survey (discussed in chapter 4.3) focusing on daily trips patterns, and the changes between the 2000 and 2006 results of the survey.

However, we are not aware of any study that looks in detail at how fiscal measures for transport would affect welfare in metropolitan areas depending on their different configurations.

Here, we propose a model able to explore these issues, simulating the impacts of a fiscal reform for liquid fuels on five Spanish metropolitan areas, and estimating changes in welfare, environmental impacts, and transport modes use, for each of them, hence providing clues for adapting the policies to their different characteristics.

The reform of fuel taxation has already drawn the attention of many institutions. Here we follow the proposal of Labandeira (2011) who, following the lines included in European Commission (2010) and European Commission (2011b), updates a previous work in Labandeira and López Nicolás (2002) and analyses a tax plan that would involve a broader energy tax reform, thus including both transport fuels, electricity, and heating. The suggested reform proposes the substitution of the actual fiscal structure with one directly linked to the energy and the CO_2 content of the fuel. Along with other implications, this would reduce the current difference that exists between gasoline and diesel. Furthermore, it could help alternative fuel sources, such as biodiesel and ethanol to be more competitive with traditional fossil fuels.

Previous works have estimated the effects of the reform on tax revenues from private transportation in Labandeira (2011) and on energy consumption and CO_2 emissions in chapter 3. Both analyse the outcome at the national level using previous econometric results, finding positive effects of its implementation on both the economy, energy consumption and GHG emissions. On the one hand, Labandeira concludes that the reform would provide an additional 12,000 million Euros in fiscal revenues from the whole sector, with transportation representing an important share of the increase. On the other hand, in our previous results, we show that the reform could lead in the long-run to an overall reduction of energy consumption in the transport sector of up to 480 million GJ while cutting CO_2 emissions by 29 million tonnes.

However, both assessments cited come short in that they do not include all the elements that characterise transport, in particular in the context of the metropolises. The interaction between private and public modes, as well as their availability, can profoundly affect the results and should be taken into account when evaluating the impact of such a proposal. These are the main reasons for which we simulate the reforms in the context of Spanish metropolitan areas, adopting a model that provides the simulation framework for fiscal reforms for transport. By comparing the outcomes of the same fuel tax policy applied to different metropolitan areas we can identify the factors that drive these results, and the extent to which this reform may be sufficient or not, depending on the local context.

In the following sections, we will analyse the effects of the same fiscal reform proposal already studied in the simulation exercise chapter 3. Both focus and methodology will be different since we will study the simulated effects on five metropolitan areas rather than Spain, applying the method presented in 4.

5.2 Comparing the effects of a fuel tax reform on different metropolitan areas

Provided the model and the data frame previously discussed, in this section we will assess the effects of implementing a fuel tax reform in metropolitan areas in Spain, comparing the results obtained in the different areas.

5.2.1 Metropolitan areas studied

Data availability allows for the inclusion of the two biggest areas, Madrid and Barcelona, medium-size areas, Valencia and Málaga, and finally small areas, Girona, thus covering a broad spectrum of the metropolitan situation across Spain. This set allows us for addressing how different areas may respond to a general fuel tax policy, based on their initial conditions.

The effects analysed will be those on total mobility (measured in passenger-km or pkm) and modal shares, variations in welfare and fiscal revenues (in Euros), and the savings in energy (in Megajoules) and CO_2 emissions (tCO2), each differentiated by each metropolitan area, mode and location.

The policy scenarios implemented are the ones presented in the European proposal for a Directive on fuel taxes, a setting already considered in Labandeira (2011) and chapter 3, with the effects of the reforms (quantitively summarised in Table 5.1) reflected on the final price of fuel. It is important to notice that, while in reform B the price rises for both fuels types, in reform A, only diesel prices increase.

Table 5.1: Reform scenario specification.

	Reference		Reform A		Reform B	
	gasoil	gasoline	gasoil	gasoline	gasoil	gasoline
Price (Eur/l)	1.38	1.44	1.56	1.42	1.65	1.50
(% change)			(+12.65%)	(−1.70%)	(+19.56%)	(+4.05%)
Tax (eur/l)	0.59	0.69	0.76	0.67	0.86	0.75
(% change)			(+29.76%)	(−3.55%)	(+46.01%)	(+8.44%)

But before getting into the simulation results, it is useful to describe the different starting conditions of the metropolitan areas analysed, which will also help understand the different outcomes.

As may be seen in Table 5.2, Madrid and Barcelona are the regions with the largest passenger mobility, with over 23,000 and 15,000 million pkm respectively, with figures for smaller areas lying between 7,000 million pkm (Valencia) and 640 million pkm (Girona).

Table 5.2: General Metropolitan Area characteristics for demography, economy and mobility.

	Population	GDP, Mill. Euros	Tot. Mobility, Mill pkm
Madrid	9732087	187847	23335.47
Barcelona	6673000	137596	15087.17
Valencia	2602143	37326	7324.04
Malaga	1589188	17268	2786.04
Girona	352490	5402	634.27

It is interesting to underline how these passenger-km are distributed across modes. In Madrid and Barcelona the rate of public mobility is about 51% in both cases, while in other areas public transport is less of an alternative: Valencia features around 29% and Málaga around 17%, and, finally, in Girona, around 13%, underlying the disparity in the demand (and provision) of public transport services between larger and smaller areas, as can be seen in more detail in figure 5.1.

Furthermore, in our setting, the different mobility patterns translate into energy consumption and carbon emissions. Overall consumption in the urban transport sector shows that bigger areas are also the largest energy users and GHG emitters, with figures lying between 35 million GJ in Madrid and 1.5 million GJ in Málaga. Moreover, the relative energy consumption and carbon emissions differ among areas, following the share of public transport but also the composition of the fleet (e.g. Málaga features an energy intensity and carbon emissions similar to those of Girona, in spite of the larger share of public transport in the former).

Table 5.3: Energy consumption and CO_2 emissions for metropolitan mobility in reference scenario.

	Energy Consumption		CO_2 Emissions	
	(total, Mill. GJ)	(relative, MJ/pkm)	(total, thou. tCO_2)	(relative, gCO_2/pkm)
Madrid	34.47	1.48	2431.20	104.18
Barcelona	22.00	1.46	1534.38	101.70
Valencia	14.70	2.01	1043.34	142.45
Malaga	6.32	2.27	458.49	164.57
Girona	1.45	2.28	105.52	166.37

A closer look at the differences between the two most important areas is necessary, Madrid and Barcelona. On the one hand, in Madrid, although with a highly developed public transportation, the users' preferences are toward diesel cars, reaching 37% of all mobility in the suburban context. On the other hand, Barcelona has one of the largest shares of two-wheel personal transportation across all the areas, leading the usage of other private modes, at least in the urban con-

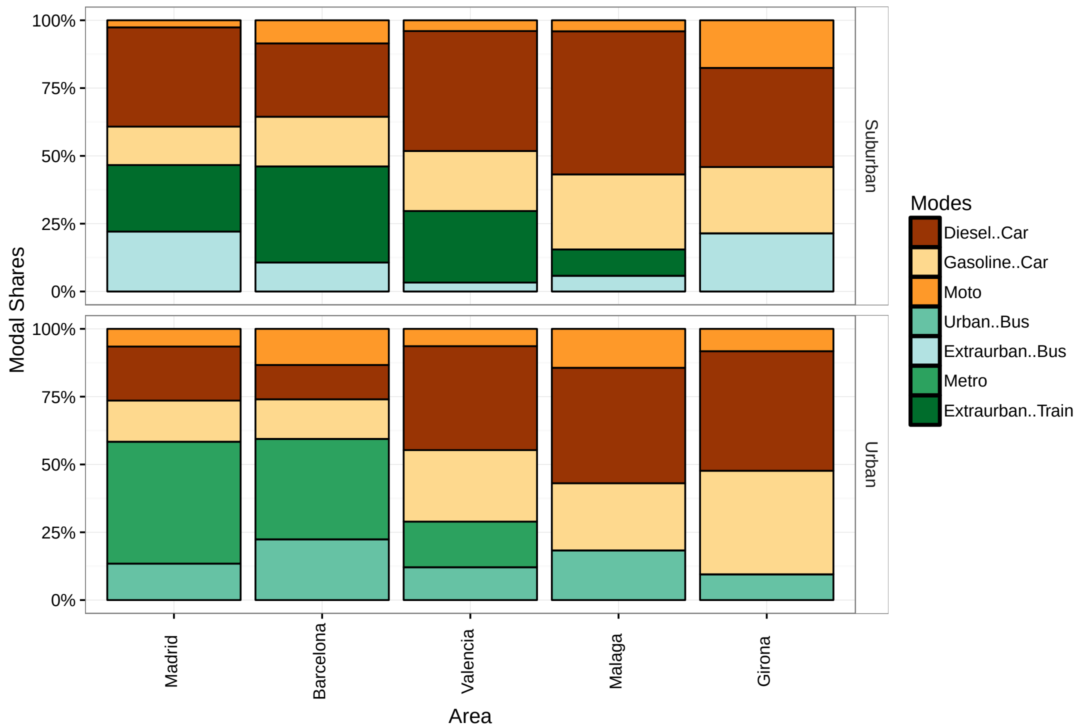


Figure 5.1: Reference scenario of total shares of the public and private mobility in Metropolitan Areas in both Urban and Suburban context and depending on mode.

text. As for public transportation, the metro represents the first choice in both areas, but in the suburban context, the regional train is preferred to extra-urban bus only in Barcelona, while in Madrid the shares are similar.

While gasoline vehicles are more common in the urban context, in suburban locations, the average private vehicle is a diesel car. Quantitatively, the dieselization rate of private mobility in the central municipality is about 43% in Madrid, 31% in Barcelona, 53% in Valencia, whereas in suburban areas it is 69% in Madrid, 50% in Barcelona and 63% in Valencia as shown in figure 5.2. The different car choices can be the driver of these results. The longer trips and lower public transport density, usual outside the principal municipality, leads the consumers to choose diesel vehicles, with lower running costs, as extensively shown in (Schipper et al., 2002).

Energy shares of diesel lie between 63% in Madrid and 48% in Barcelona, connected to both private (diesel cars) and public (buses) transportation. Gasoline, representing the consumption of gasoline cars and motorised two wheelers, features lower shares through all the areas, being as high as 47% in Girona and just 30% in Madrid. Electricity consumption, used only in metro and regional trains, is always

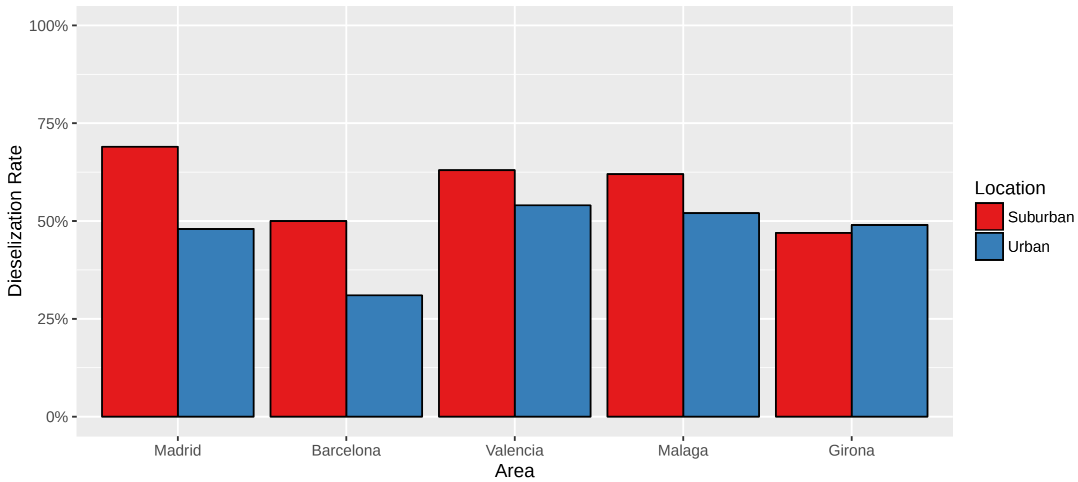


Figure 5.2: Dieselization Rates of the private mobility in Metropolitan Areas in Urban and Suburban context.

below 10%.

5.2.2 Simulation results

The results following the simulation of the reform provide interesting insights. In line with economic predictions and previous literature, these results seem sensible to the economic context and price changes: there is an overall decrease in the demand for mobility following the increase in the cost of the fuel. As shown in table 5.4, this decline ranges from 0.22% (in Barcelona) to 1.37% (in Málaga) in the case of Reform A, with the gap widening to 0.54% and 2.70% for the same areas in Reform B. In economic terms, this means that the overall price for transport increases when adopting the reforms, hence shifting consumption away from transport, even in the case of Reform A, where mixed tax changes could have led to an overall rise in demand.

As for energy and emissions, simulation results share the signs already seen for mobility. After implementing reform A, the decreases are about 2.6% in Madrid, 1.3% in Barcelona and 1.7% in Valencia, and, in the case of reform B, the drops in emission are about 4.3% in Madrid, 2.9% in Barcelona, and 3.3% in Valencia

In absolute terms, the reduction in energy consumption and GHG emissions following Reform A is around 900 thousand GJ and 68 thousand tCO_2 in Madrid, and 300 thousand GJ and 22 thousand tCO_2 in Barcelona. As for reform B, the reduction in energy consumption is almost 1.5 million GJ in Madrid and 112 thousand tCO_2, while in Barcelona is more than 600 thousand GJ and 49 thousand tCO_2. Figure 5.3 shows the decrease in per capita terms, also including changes

Table 5.4: Overall transport demand changes with respect to Reference Scenario

	Reference Total value (Mill pkm)	Reform A Total value (Mill pkm)	rel. change (%)	Reform B Total value (Mill pkm)	rel. change (%)
Madrid	23335	23236	-0.43 %	23170	-0.71 %
Barcelona	15087	15054	-0.22 %	15006	-0.54 %
Valencia	7324	7269	-0.76 %	7210	-1.55 %
Malaga	2786	2748	-1.37 %	2712	-2.67 %
Girona	634	628	-1.02 %	619	-2.35 %

in fuel use.

These reductions may be considered modest, at least when compared with local GHG emission reduction plans.[1] As an example, our reference case accounts for 30% of GHG emissions compared to the official CO_2 Madrid regional emission inventory for 2012 (Comunidad de Madrid, 2016) and, according to the Madrid Regional Plan for emission reductions and air quality *Plan Azul +* (Comunidad de Madrid, 2014), the emission reduction proposal in the transport sector would need to be, for a 2020 horizon, of about 1,500 thousand tCO_2. Therefore, even the more ambitious reform B would only address 7.5% of the total reductions intended, thereby underlining the need to include other measures to reduce carbon emissions in metropolitan areas.

5.2.3 Differences between metropolitan areas

As may be seen in the previous section, there are large differences in the effects of the same policy when applied to different areas, even within the same size.

An example is the relative change of mobility under the reform A, which is twice as large in Madrid as in Barcelona. These areas feature similar shares of public transport, and energy and carbon intensity. However, in Barcelona, the energy proportion of diesel is smaller than in Madrid (48% vs. 63%). Reform A, which de facto incentivizes the use of gasoline vehicles, has a higher impact on the overall mobility in such areas where diesel is more used, as in Madrid versus Barcelona.

In other areas, it is the lower levels of public transport that influences results. The lack of options to shift away from diesel cars results in a larger reduction in mobility. For example, comparing simulation results for Barcelona and Valencia, we find greater mobility reduction in Valencia, in both relative and absolute terms.

[1]It has to be reminded that for the chapter purpose, only metropolitan personal transport has been considered, leaving out long trips and all freight transport

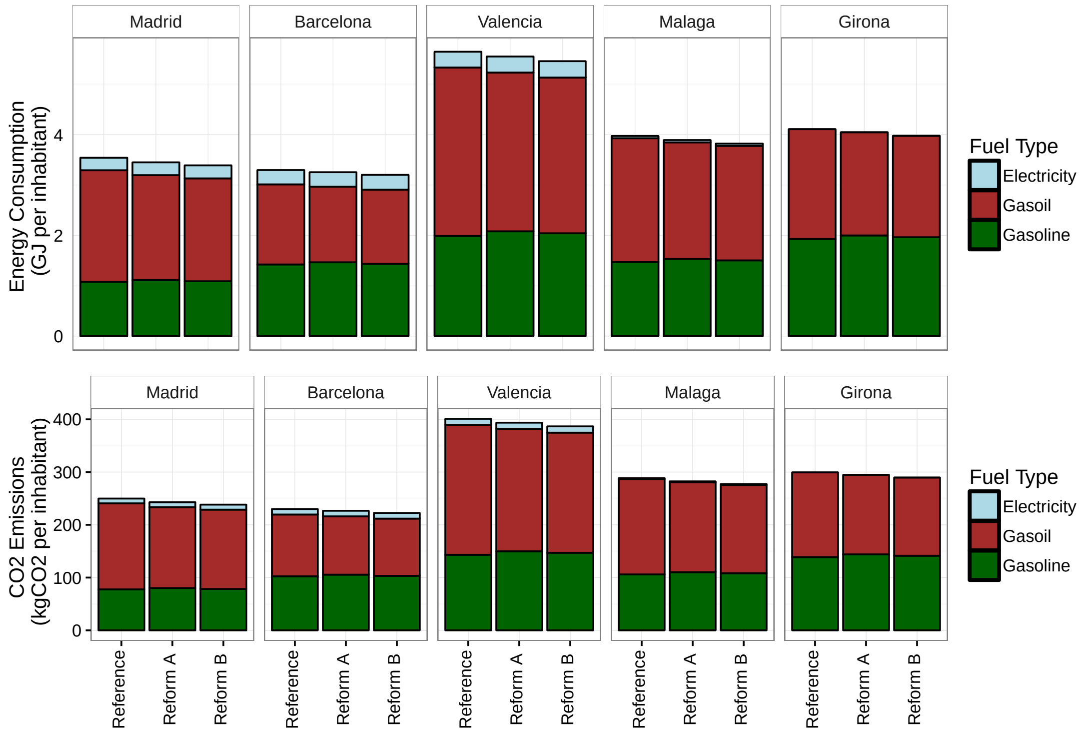


Figure 5.3: Simulation effects details on per capita Energy Consumption and CO_2 emissions.

This lack of flexibility reflects on the reductions obtained in energy intensity. Figure 5.4 provides a graphical representation of the energy intensity index for each area and the simulated changes after the reform. In this figure, it is easily recognisable that larger areas perform better also in energy intensity terms and, after the implementation of the reforms, the improvements are lower in smaller cities such as Valencia (even less in Málaga or Girona). There, the energy intensity of mobility goes from 2.00 MJ/pkm to 1.97 MJ/pkm (-1.8%), while in Barcelona it goes from 1.46 MJ/pkm to 1.42 MJ/pkm after reform B (-2.3%). Finally, in Madrid, the same measure goes from 1.48 MJ/pkm to 1.42 MJ/pkm (-4.1%).

Here it can be seen that the flexibility that public transport provides, as well as a significant share of diesel, make the fuel tax reform much more effective in the Madrid area than in the rest. As an example, in scenario B, diesel car usage decreases by 9% in Barcelona, similar to Madrid, while gasoline car usage increases by 1.8% in Madrid and 2% in Barcelona. In Madrid bus ridership increases by 4.6%, compared to just 2% in Barcelona; also, train mobility shows a larger increase in Madrid (+3.3%) than in Barcelona (+2.6%), explaining the greater effect on the energy indicator in Madrid area compared to Barcelona. In Valencia, however, the

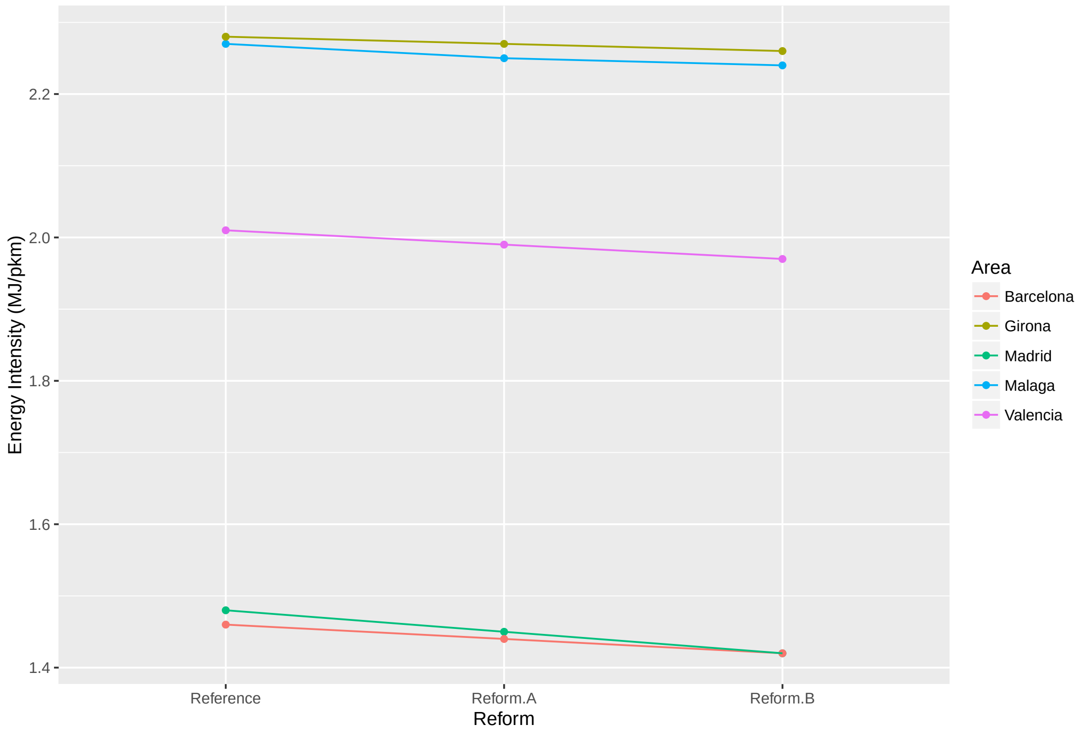


Figure 5.4: Energy Intensity for each Area and Reform.

decrease of diesel car use is around 8% and gasoline increases by 3.3%, and while the use of buses and train grows by 2 and 4% respectively. Their share is still just above 30%, making their contribution to the improvement in energy intensity not as useful as in Barcelona and Madrid.

Overall, changes in modal shares (table 5.5) follow the previous evidence: public transport grows equally for the train, the metro, and the bus, while the general decrease in private transport is inconsistent across modes, reflecting the different changes in fuel prices.

Moreover, as a consequence of the simulation of reform B, total share for Madrid public transport (53.3%) is larger than in Barcelona (52.7%), reverting the result for the Reference Scenario (51.0% in Madrid and 51.1% in Barcelona): the initial conditions in the application of the reforms are crucial. Otherwise, results show consistency, suggesting a shift toward public transport and gasoline-powered vehicles, with changes being as large as three percentage points, indicating a small impact on mobility patterns. Moreover, the relative changes are lower in smaller areas, due to the scarce availability of alternatives.

Finally, simulation results also reveal significant differences between urban and suburban areas. Overall, modal shares experience a shift towards public modes

Table 5.5: Simulation results for modal shares for each area and scenario.

	Bus	Metro/Train	Tot. Public	Gas. Car	Die. Car	Moto	Tot. Private
Madrid							
Reference	18.86%	32.13%	51.00%	14.54%	30.40%	4.06%	49.00%
Reform A	19.45%	32.88%	52.33%	15.20%	28.42%	4.05%	47.67%
Reform B	19.87%	33.42%	53.29%	14.90%	27.82%	3.99%	46.71%
Barcelona							
Reference	15.07%	36.03%	51.10%	16.92%	21.67%	10.31%	48.90%
Reform A	15.23%	36.50%	51.73%	17.71%	20.24%	10.33%	48.27%
Reform B	15.47%	37.18%	52.65%	17.36%	19.82%	10.17%	47.35%
Valencia							
Reference	6.97%	22.39%	29.36%	23.90%	41.76%	4.98%	70.64%
Reform A	7.09%	22.98%	30.07%	25.36%	39.54%	5.03%	69.93%
Reform B	7.23%	23.66%	30.89%	25.08%	39.05%	4.99%	69.11%
Malaga							
Reference	11.34%	5.41%	16.75%	26.39%	48.26%	8.61%	83.25%
Reform A	11.63%	5.65%	17.28%	28.10%	45.88%	8.75%	82.72%
Reform B	11.92%	5.88%	17.80%	27.92%	45.54%	8.73%	82.20%
Girona							
Reference	13.81%	−−	13.81%	33.23%	41.36%	11.60%	86.19%
Reform A	14.12%	−−	14.12%	35.13%	39.02%	11.73%	85.88%
Reform B	14.56%	−−	14.56%	34.95%	38.78%	11.71%	85.44%

and gasoline-driven vehicles, as expected. But these effects are more evident in suburban locations where the shift appears to be at least 4 times larger with respect to the urban case. The increase in use of urban public transport (metro and buses) in Madrid (reform A) is just under +0.5%, while for suburban public transit (buses and train) it reaches +3.5%. Reform B show similar results, with suburban public transportation increase being larger than 5% in Madrid, Málaga, and Valencia, compared to changes around 1% in the urban context. This evidence can be easily related to the fleet composition, different in the urban and suburban settings, as observed in Asensio (2002) and mentioned earlier.

5.2.4 Implications for welfare

Welfare change results also show how the impact of the reform varies across metropolitan areas. First, it has to be reminded that the welfare measure includes the monetarization of the utility, the internal and external costs associated with it, the latter including emissions of local pollutants and CO_2, accidents and time loss, all linear on supply. In Madrid, the total variation is a loss of about 52 million Euros-equivalent considering reform A and a loss of 91 million in reform B.

In Barcelona the loss is lower, being around 16 and 40 million Euros, respectively. Valencia shows figures close to Barcelona, with a loss of 16 million Euros in reform A, and 33 in reform B. The relative change, however, is small in all the cases, less than 0.03% of GDP.

Interestingly, and in line with our comments before about the flexibility of transport modes, welfare loss is not necessarily related to emissions reductions or reductions in mobility. For example, the largest relative losses correspond to Valencia, which is not the area with the most significant reductions in mobility or emissions. In this region, the flexibility to accommodate the changes induced by the fuel tax reform is weak. In turn, Barcelona features a slight welfare loss, at the same time being able to reduce its carbon emissions even more than Valencia.

Table 5.6: Reform effects on welfare in Million Euros.

	Reform A Abs. variation, Mill. EU (rel. %)	Reform B Abs. variation, Mill. EU (rel. %)
Madrid	-52.11 (−0.03%)	-91.38 (−0.05%)
Barcelona	-16.03 (−0.01%)	-40.39 (−0.03%)
Valencia	-14.42 (−0.04%)	-32.80 (−0.09%)
Malaga	-7.53 (−0.04%)	-15.44 (−0.09%)
Girona	-0.90 (−0.02%)	-2.50 (−0.05%)

It is interesting to note that a (probably overlooked) fact influences this estimation of welfare: public transport is heavily subsidised. Therefore, under a static analysis, an increase in public transport usage will also raise government subsidies.[2]

Table 5.6 shows how the benefits of the reform regarding economic and the modal shift towards public transportation mitigates fiscal revenues. As an example, the results for Madrid (reform B) show an increase of about 550 million Euros in net tax revenues. However, breaking down this result, it is easy to observe that from the additional revenues from diesel and gasoline (+692 million Euros) the government should deduct other subsidies necessary to cover the increased demand. In this case, it reaches 141 million Euros. Comparing the metropolitan areas of Barcelona and Valencia, it is interesting to observe that the growth in tax revenues from fuel is somehow similar: +120 million Euros in Barcelona and +121 million Euros in Valencia. However, considering the same scenario, the increase in subsidies is notably different, being +25 million Euros in Barcelona, due to the larger availability of public transport, versus only +2 million Euros in Valencia.

[2]The level of subsidy for each public modes comes from the economic results of the public service providers. In this simulation we mantain fixed the levels per-pkm as for the costs, supposing no economy of scale and neither any change in subsidy policy.

Again, we see that the initial conditions regarding fleet composition and availability of public transportation determine to a large extent the results for welfare.Of course, this might not be the case if the more extensive use of public transport improves its profitability and reduces the need for subsidies.

Table 5.7: Reform effects on taxation in Million Euros.

	Fuel Tax Change		Subsidies Change		Net Tax Change	
Met. Area	Reform A	Reform B	Reform A	Reform B	Reform A	Reform B
Madrid	+401.67	+692.22	−81.50	−141.05	+320.18	+551.17
Barcelona	+119.69	+303.65	−24.23	−60.96	+95.46	+242.69
Valencia	+121.50	+260.46	−1.99	−4.58	+119.51	+255.88
Malaga	+61.90	+123.30	−1.26	−2.58	+60.64	+120.72
Girona	+10.36	+24.93	−0.49	−1.24	+9.87	+23.69

5.2.5 Sensitivity analysis

Given the criticisms of the use of constant elasticities in Schäfer (2012) (according to which the reliance on not-so-precise measures of them will affect disproportionally the simulation results), we provide a sensitivity analysis and, for this, we experiment by increasing and decreasing the original values for elasticities. Depending on the data input, the non-linear nature of the utility function does not guarantee a solution of the system; in this case, the algorithm was able to find a solution for almost all areas for values of the elasticities between +50% and -9% of the original ones. Interestingly, the algorithm was not able to provide likely results for some areas: parameters for Valencia area were not calibrated for low values of elasticity nor Málaga for the high ones.

The results themselves appear to be quite robust for changes in elasticities: assuming elasticities 9% lower than the original provide results that only differ by less than 0.3%. Increasing by one-half the elasticity values will have a similar effect, the difference will be from -0.20% up to almost -1%. Of course, a more elastic demand will bring more significant reductions in mobility for a given tax increase.

Moreover, this exercise helps in the definition of a robust range of values to associate to each scenario. According to the sensitivity analysis, the total reduction in mobility in the Madrid metropolitan area lies between -0.4% and -0.59% in scenario A, or between -0.66% to -0.96% in scenario B. In Barcelona the range lies between -0.2% and -0.31% in scenario A and -0.5% and -0.75% in scenario B. For CO_2 emissions the range is a bit wider. The emission savings in Madrid vary from 62 thousand tCO_2 when assuming a less elastic demand to 99 thousand

tCO_2 when assuming a more elastic demand, with the difference widening to 62 thousand tCO_2 in reform B (-102 to -164 thousand tCO_2).

5.3 Conclusions and policy implications

The transport sector is critical for achieving GHG emission reduction goals. However, given its relevance for social welfare, a careful analysis of the implications of the policies required to achieve these reductions is required. Indeed, this consideration of social welfare may not only have a positive effect on the efficiency of the emissions reductions but can also improve the public acceptability of these policies, thus easing their implementation. Local conditions here become essential, since the characteristics of local fleets, the availability of public transport, and other issues may have a large influence on welfare changes and therefore on the effectiveness and acceptability of transport policies.

In this chapter, we have assessed the impacts of a fiscal reform that would increase tax rates for gasoline and diesel on mobility, energy use, carbon emissions, and welfare. In particular, we study the effects on metropolitan areas, due to their prominent role in this regard, and to ascertain the sensitivity of results to the local configuration.

Our results show that this reform can achieve reductions in GHG emissions and energy use, but at a cost in welfare terms. Another very relevant conclusion of our study is that, as suspected, the costs and benefits of the policy will depend on the characteristics of the metropolitan area, and more specifically, on the fleet composition and the public transport availability.

The higher taxes simulated induce a decrease in transportation demand that lies between -0.22% and -2.70% depending on the area and the strength of the tax reform. Modal shares also change: diesel cars reduce their share and the use of gasoline cars and public transport increases. As a result, energy consumption and carbon emissions are also reduced. However, the reduction in energy usage depends again as well on the metropolitan area. Madrid, highly reliant on diesel, and with a significant availability of public transport, shows a total decrease of 4.3% when applying the stronger reform, while Barcelona, with a similar share of public transport, but a lower penetration of diesel cars, only achieves 2.9%.

In smaller areas, this reduction is less pronounced, mostly due to the lower share of public transport. This lack of flexibility results in both a larger reduction in mobility (given that shifts to public transport are not an option) and also in less improvement in energy and carbon emissions intensity.

The results also show increased tax revenues, up to 550 million Euros in the Madrid Metropolitan Area, but lower consumers' welfare, rounding 90 million Euro-equivalent in Madrid and 40 million Euro-equivalent in Barcelona. Increased revenues coming from higher gasoline and diesel taxes are sensibly counteracted (by over 20%), by the higher subsidies implied by the increase in public transport.

Again, the lack of energy-efficient options (such as public transport) in smaller metropolitan regions is revealed: these areas feature larger welfare losses for smaller reductions in carbon emissions and energy use, even considering that less public transport also means lower subsidies increases.

Chapter 6

Conclusions and Future Research

6.1 Concluding Remarks

What are the effects of a reform of fuel prices? How to capture the effects on mobility? What are the tools able to describe these changes? What can we say about the sustainability of the sector?

The transport sector has a high impact on society, being the vehicle for mobility needs, a major energy consumer and greenhouse gas emitter and with a huge dependecy on fossil fuels. Current data show clearly that to improve the sustainability of the energy sector, measures have to be taken regarding transportation. As for Spain, the example studied in this thesis, the transport sector accounts for about a fourth of overall energy consumption and depends on oil products for almost its entire energy needs, thus affecting both the energy, emission and trade balance.

The reforms proposed affect both the demand and the supply of transport services, shifting taxes on products (such as gasoline or diesel), or limiting the supply of certain modes, or imposing restrictions of the specification of new vehicles, affecting the fleet renewal.

The objective of this thesis has been to assess how policy interventions could affect the sustainability of transport sector, analysing the limits and the benefits of its implementation. For this purpose, we first study the demand for transport and in particular one of its main drivers, fuel consumption. We then focus the attention on metropolitan areas, significant for both the economic activity, population density and so number of trips and adverse effects of mobility (air quality, congestion). In both cases we analyse the simulated effects of implementing a green reform proposal that, although proposed for the all energy sector, should have huge impact on the transport sector, providing first homogenezation of the fuel prices based on their energy content and then adding a CO_2 component to correct for the lack of a correct internalization in the price of the effects of emissions.

To carry out this analysis and study the transport demand in Sapin, we first propose an econometric model for fuel consumption (chapter 3) that includes in the usual “ideal” demand formulation, the specification the explicit component for diesel share. This aspect has been barely taken into account in previous literature (see Pock (2010) and Marrero et al. (2012)) thus adding evidence to current research that the dieselization of the private fleet has a large influence on the current problems of the transport sector and also on the design of policies.

Apart from the consistency of the economic assumptions regarding the sign of the elasticities, and in line with the literature, results show a significant negative effect of the diesel share when considering the specific gasoline or diesel consumption. This result alone clearly suggests that a higher diesel share should lower the consumption (per vehicle) of fuel. An interpretation is that increasing shares show shifts for lower-range consumers to more efficient vehicles thus improving the energy consumption.

Simulating the effects of a fiscal policy proposal, we found that an adjustment and harmonization of diesel and gasoline prices (as is the purpose of the green reform) could indeed reduce emissions, although in the short term the CO_2 emissions avoided in the transport sector could reach just 5.5%. For the long-run impact, results could reach up to 38% of emission savings, although the low speed of adjustment suggests that such an evolution would need many years.

From the policymaker perspective, results from the econometric model suggest that the planned tax changes would have an impact not just in the short run (and from the fiscal revenues point of view, as showed in Labandeira (2011)) but in the long-run, providing better incentives that correct consumers behaviour. Both the political strength necessary to carry out those reforms and the need for a large number of alternatives to the current massive use of private transportation (support for electric vehicles and related infrastructure, enhancement of public transportation networks, biofuels) are significant barriers that could prevent governments from adopting them.

Our results suggest that the green reform proposal would bring indeed a positive effect in reducing the consumption of transport fuel. However, the simulated contribution to the emission reduction may be relatively small once compared to the reduction committment European Commission (2011c), thus suggesting the need for more policy iniciatives.

As Sterner (2007) suggests, governments should aim at a reduction of demand, through a commitment to a progressive taxation increase, a better reflection in the prices of the external cost produced and the energy content of them, and an extensive support of the alternatives.

As for the simulation model for five Spanish metropolitan areas, our results reinforce the conclusions previously offered. The first general highlight is that this reform will be more effective the more options available to shift away from diesel vehicles. That means basically public transport modes, particularly those fueled with electricity (e.g. metro). Of course, the larger the share of diesel, the larger are the expected reductions in energy use. And finally, welfare losses are also lower the more flexibility there is in the metropolitan area regarding transport modes.

However, it should also be noted that the simulated reform will do little to reduce environmental impacts, and may result in lower welfare for consumers, at least when considering just the metropolitan areas and not a proper redistribution program. Moreover the sign of the welfare has to be taken as limited since it only takes into account metropolitan areas and not, for instance the (positive) fiscal returns.[1] Our results show that this tax hike would only take care of around 7.5% of the total reductions required. Therefore, even in the metropolitan areas more receptive to it, other measures and policies will be required.

Of course, our analysis has certain limitations that should be highlighted. We have not considered the dynamic effects that this reform may induce in the fleet composition, and the introduction of new technologies. We are not able either to represent the interactions of these policies with a wider energy sector framework, which could be achieved by integrating our model into a more comprehensive energy model.

However, our major messages regarding the policy implications of our study remain valid. First, the stringency of fuel tax reforms or other price mechanisms to reduce the use of diesel fuel or diesel cars should be carefully adapted to the availability of options in each urban area. When these options are not readily available, the welfare costs of the policies may become significant, hence affecting their public acceptability. Therefore, other policies that increase sustainable transport options should be prioritized before tax reforms are implemented. Second, the effectiveness of fuel tax reforms is limited, in that they can only produce a small fraction of the carbon emissions reductions required. Again, other policies may be required to achieve the desired objectives.

6.2 Future Research

The debate on how to effectively reform energy prices is still on debate. Recent news (Xavier Labandeira, 2017) suggest how a reform on fiscality for energy is a

[1] In the simulation model, the computation of the variations in social welfare only accounts for the internal costs and for per vehicle-km of other external costs such as pollution and congestion and the total Utility for consumers. The lack of a more-comprehensive cost function that takes into account, for instance, changes in trip times limits the account for some of the positive effects of reducing or shifting mobility, at least in welfare terms.

necessity from many points of view, starting from the transparency of the market prices, to the revenues, to the need for emission reduction. The same holds for transport fuel. The complexities that characterise this sector point to the necessity of a solid reform and a specific assessment.

The modelling, the data collection, and the analysis in this work provide an overview on how this sector would be affected by such a measure. But what about the other sectors and the interaction between all the energy sectors?

Energy sector is always been seen highly interdependent, with the presence of synergies, the inclusions of some of the modelling aspects would provide a much more detailed picture of the effects on the energy market of such a reform.

Of course there are also aspects that we have avoided that can be taken into account. For instance, in this work we did not directly mention the effects of the policies aimed to alternative transport modes such as walking or cycling, that are gaining attention as a viable alternative from both the metropolitan users and the local governments. Also, the electric vehicle seems to be a role-changer in the future shape of both metropolitan transport and inter-urban transport as the growing battery capacity and lower prices drive up the share of newly registered electric cars.

Moreover, some model features can be added in order to investigate the interaction of transport and congestion and bus crowding. Characteristics as trip time and users' comfort in pooled transport service have been under the scrutiny of the researcher, and improving the model could help in obtain more useful insights in comparing metropolitan areas.

Although these research questions lie outside the scope of this thesis, the methodology and the gathered data can be taken as a starting point to assess these issues.

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Appendix A

Simulation metropolitan model formulation

A.1 Notation

Indices

k	technology
f	fuel type
l	transport specific mode
NT	non-transport good
i_0	commodities, including both l and NT
i **and** j	utility component index, such that, if $i \in l$ the utility component i is associated with the final mode l
n	utility component level, with $n \in \{0, \ldots, N\}$ and $n = 0$ level of commodities, and $n = N$ the level of the overall utility.

Parameters

$\alpha_{n-1,j}$	share between closely associated components, takes values between 0 and 1, and such that $\sum_{j \in i} \alpha_{n-1,j} = 1$.
$\sigma_{n,i}$	elasticity of substitution, takes only positive values
$\rho_{n,i}$	transformation of σ, namely $(\sigma_{n,i} - 1)/\sigma_{n,i}$

Y total income [eur]

p_{NT} exogenous price of non-transport good used as a numeraire

τ_l tax rate (if negative, considered as subsidy)

o_l occupation rate [pkm/vkm]

$c_{l,k,f}$ variable internal cost [eur/vkm]

$e_{l,k,f}$ variable external cost [eur/vkm]

$\bar{k}_{l,k}$ technology upper boundary [vkm]

$\bar{f}_{l,k,f}$ tech-fuel upper boundary [vkm]

Decision variables

$v_{l,k,f}$ supply level for each fuel-tech combination [vkm]

x_l transport demand for each mode [pkm]

x_{NT} non-transport demand

Auxiliary variables

p_l pre-tax market prices [eur/pkm]

$q_{n,i}$ utility component value

$\phi_{n,i}$ aggregate price associated with the utility component

Dual variables

$\nu^{\hat{k}}_{l,k}$ associated with the technology constraint

$\nu^{\hat{f}}_{l,k,f}$ associated with the fuel-tech constraint

ν^{x}_{l} associated with the demand fulfilment

λ^{y} associated with the budget constraint

A.2 Supply

Objective function Here follows the cost minimisation objective function faced by the producers:

$$\min_{v_{l,k,f}} \sum_{l,k,f} c_{l,k,f} \cdot v_{l,k,f} \tag{A.1}$$

Constraints In this section we present the constraints affecting the provision of transport goods. The first depend on the fleet composition and on the infrastructure that can handle certain amounts of traffic and travel. The second is affected by the fuel availability and its storage, as for plug-in electric hybrid vehicles. the last constraint tell the producer to provide at least the quantity demanded in the market. This is a reasonable constraint if we want to resemble a profit-maximization environment without introducing it in the problem.

$$\sum_{f \in k} v_{l,k,f} \leq \bar{k}_{l,k}, \ \forall(l,k) \tag{A.2}$$

$$v_{l,k,f} \leq \bar{f}_{l,k,f}, \ \forall(l,k,f) \tag{A.3}$$

$$x_l \leq o_l \sum_{(k,f) \in l} v_{l,k,f}. \, \forall l \tag{A.4}$$

Lagrangian for supply Dual variables in section A.1 are associated with equations (A.2), (A.3), and (A.4). Together with the minimization problem in (A.1), we construct the supply problem lagrangian $\mathcal{L}_S$ as follows:

$$\mathcal{L}_S : \sum_{l,k,f} c_{l,k,f} \cdot v_{l,k,f} + \nu^{\hat{k}}_{l,k}(\sum_{f \in k} v_{l,k,f} - \bar{k}_{l,k}) + \nu^{\hat{f}}_{l,k,f}(v_{l,k,f} - \bar{f}_{l,k,f}) + \nu^{x}_{l}(x_l - o_l \sum_{(k,f) \in l} v_{l,k,f}). \tag{A.5}$$

A.3 Demand

Objective function The aggregate consumer's problem is to maximise her utility, facing market prices p_l. The problem is developed hereafter, with the structure of $U(x_l, x_{NT})$ as in section A.3

$$\max_{x_l, x_{NT}} U(x_l, x_{NT}). \tag{A.6}$$

Budget Constraint The only constraint affecting the consumer is the budget constraint, that limit the overall expenditure to the exogenous income and profits from the producing firms, here supposed to be owned by the consumer. It is worth noting that market prices faced by the consumer is constructed from the pre-tax prices p_l faced by the producers, corrected by the exogenous tax rate τ_l. Moreover the producing firms are owned by the same consumers, that receive the profits, thus increasing their budget.

$$p_{NT}x_{NT} + \sum_l (1+\tau_l)p_l x_l \leq Y + \sum_{k,f\in l} (o_l \cdot p_l - c_{l,k,f})v_{l,k,f}. \tag{A.7}$$

Lagrangian for demand After associating the multiplier λ^y to the budget constraint in (A.7), we then construct the lagrangian $\mathcal{L}_D$ as follows:

$$\mathcal{L}_D : -U(x_l, x_{NT}) + \lambda^y \left[p_{NT}x_{NT} + \sum_l (1+\tau_l)p_l x_l - Y - \sum_{k,f\in l} (o_l \cdot p_l - c_{l,k,f})v_{l,k,f}\right]. \tag{A.8}$$

Auxiliary equations Utility function presented in section A.3 follows the nested CES presented in Keller (1976), and hereafter developed:

Utility Function

$$U(x_l, x_{NT}) = q_{N,i}, \tag{A.9}$$

$$x_l = q_{0,i\in l}, \quad x_{NT} = q_{0,i\in NT}, \tag{A.10}$$

$$q_{n,i} = \left[\sum_{n-1,j} \alpha_{n-1,j}^{(1-\rho_{n,i})} q_{n-1,j}^{\rho_{n,i}}\right]^{1/\rho_{n,i}}. \tag{A.11}$$

Aggregate prices and expenditure

$$\phi_{n,i}q_{n,i} = \sum_{j\in i} \phi_{n-1,j}q_{n-1,j} \tag{A.12}$$

with,

$$(1+\tau_l)p_l = \phi_{0,i\in l}, \quad p_{NT} = \phi_{0,i\in NT} \tag{A.13}$$

Deriving the Utility Function

$$U'_{x_{NT}} = \frac{\partial U}{\partial x_{NT}} = \frac{\partial q_{N,NT}}{\partial q_{0,NT}} = \frac{\partial q_{N,NT}}{\partial q_{N-1,NT}}, \tag{A.14}$$

$$U'_{x_l} = \frac{\partial U}{\partial x_l} = frac\partial q_{N,l}\partial q_{0,l} \tag{A.15}$$

$$= \frac{\partial q_{N,l}}{\partial q_{N-1,l}} \cdot \frac{\partial q_{n-1,l}}{\partial q_{n-2,l}} \cdots \frac{\partial q_{1,l}}{\partial q_{0,l}} \tag{A.16}$$

$$= \prod_{n=1}^{N} \frac{\partial q_{n,l}}{\partial q_{n-1,l}}, \tag{A.17}$$

that, deriving from the (A.11), will lead to:

$$\frac{\partial q_{n,l}}{\partial q_{n-1,l}} = q'_{n-1,l} = \left(\frac{\alpha_{n-1,j}}{q_{n-1,j}}\right)^{1-\rho_{n,i}} \left[\sum_{n-1,j} \alpha_{n-1,j}^{(1-\rho_{n,i})} q_{n-1,j}^{\rho_{n,i}}\right]^{\frac{1-\rho_{n,i}}{\rho n,i}}. \tag{A.18}$$

A.4 The Market Clearing

Under this setting, market clearing condition state that pre-tax market prices p_l will equal the marginal costs for providing one more unit in mode l, represented by dual variable ν_l^x:

$$p_l = \nu_l^x \tag{A.19}$$

A.5 The Mixed Complementarity Model

Stationary Conditions and associated complentary slackness: Finding the market equilibrium implies deriving the production and the consumption bundles and market prices $(\upsilon^*_{l,k,f}, x^*_l, x_{NT}, p^*_l)$ such that the problem for the both producers and consumer are solved, and market is cleared. This imply first that decision variables are perpendicular to their respective problems, as stated in the stationary conditions that follow:[1]

[1]The very general definition adopted as Mixed Complementarity Problem is the one appearing in Dirkse and Ferris (1995), only demanding the sign of the variable and the function, together with the perpendicularity constrains.

$$0 \leq v^*_{l,k,f} \perp \frac{\partial \mathcal{L}_S}{v^*_{l,k,f}} : c_{l,k,f} + \nu^{\hat{k}}_{l,k} + \nu^{\hat{f}}_{l,k,f} - o_{l \ni (l,k,f)} \cdot \nu^{x}_{l \ni (l,k,f)} \geq 0. \tag{A.20}$$

$$0 \leq x^*_{NT} \perp \frac{\partial \mathcal{L}_D}{x^*_{NT}} : \; - U'_{x^*_{NT}} + \lambda^y p^*_{NT} \geq 0, \tag{A.21}$$

$$0 \leq x^*_l \perp \frac{\partial \mathcal{L}_D}{x^*_l} : \; - U'_{x^*_l} + \lambda^y (1 - \tau_l) p^*_l \geq 0 \tag{A.22}$$

Feasibility and associated complementary slackness: Feasibility of the bundles in both consumption and production is a necessary condition for the equilibrium and, for this, constraints presented in sections A.2 and A.3 must hold, and so perpendicularity of the dual variables associated to these constraints (complementary slackness). The last condition is the market clearing, leading to prices equal to the marginal cost of each final mode l.

$$0 \leq \nu^{\hat{k}}_{l,k} \perp \frac{\partial \mathcal{L}_S}{\nu^{\hat{k}}_{l,k}} : \; \bar{k}_{l,k} - \sum_{f \in l,k} v^*_{l,k,f} \geq 0, \tag{A.23}$$

$$0 \leq \nu^{\hat{f}}_{l,k,f} \perp \frac{\partial \mathcal{L}_S}{\nu^{\hat{f}}_{l,k,f}} : \; \bar{f}_{l,k,f} - v^*_{l,k,f} \geq 0, \tag{A.24}$$

$$0 \leq \nu^x_l \perp \frac{\partial \mathcal{L}_S}{p^*_l} : \; o_l \cdot \sum_{(l,k,f) \in l} v^*_{l,k,f} - x^*_l \geq 0. \tag{A.25}$$

$$0 \leq \lambda^Y \perp \frac{\partial \mathcal{L}_D}{\lambda^Y} : \; Y - p^*_{NT} x^*_{NT} - \sum_l (1 + tau_l) p^*_l x^*_l + \sum_{k,f \in l} (o_l \cdot p_l - c_{l,k,f}) v_{l,k,f}; \tag{A.26}$$

$$0 \leq p^*_l \perp p^*_l = \nu^x_l. \tag{A.27}$$

A.6 Assessing the Welfare

To quantitatively assess the welfare W, we first identify the components that sum up, that are consumer's utility U and the external costs. The Utility is reduced to monetary terms dividing it by μ, that is the marginal utility of income. The value of μ is derived within the algorithm by applying marginal changes to income. Profits are not included and neither are the revenues from taxation.

$$W = 1/\mu \cdot U(x_l, x_{l,k,f}) - \sum_{l,k,f} e_{l,k,f} \cdot v_{l,k,f} \tag{A.28}$$

A.7 Computing the Model

The computation of the system equilibrium is made through the implementation of the MCP (Mixed Complementarity Problem) in the GAMS environment and solved with PATH. Since some of the parameters needed to be adjusted to fit the observed preferences, a calibration process is added to the computation, and discussed in section A.8.

A.7.1 The setup

The GAMS algorithm resemble the notation and equations described in the earlier sections. In order to reproduce the nested structure of the Utility, we introduce some intermediate indices that define each utility component (n, i) or (n, j)

consumption referred to the type of consumption, mainly transport vs non-transport, and urban vs. inter-urban;

time time or length of the transport consumption, distinguish between peak and off-peak and long and short trips;

service public/pooled service vs private one;

final closely related to the type of vehicle used.

Other accessory indices are used throughout the algorithm to indicate some of the parameter and variables used in the model. Notice that most the used notation is the same as described in section A.1.

i_ucomp all utility components i that are not final;

NT Non Transport consumption.

iXj pairs (i, j) such that $(n-1, j) \in (n, i)$. This means that j is directly associated to the near upper level element i.

iXk set containing all the combinations of mode i with technology k

kXf set containing all the combinations of technology k with fuel f, particularly useful when considering hybrid techs.

iXkXf set containing the overall combinations of mode, techs, and fuels.

pl pre-tax market prices.

phi aggregate price.

income aggregate expenditure.

occ_rate occupation rate.

tax tax rate.

A.7.2 the MCP-PATH program

The algorithm developed in GAMS resembles the problem presented in section A.5, adapting the equations in sections A.2 and A.3.

From equation (A.20):

```
de_v (l,kXf)$iXkXf(l,kXf)..
         c_ikf(l,kXf) + nu_kXfHat(l,kXf)
         - nu_x(l) * occ_rate(l) =g= 0;
```

From equation (A.25):

```
de_nu_x(l)..
         sum(kXf$iXkXf(l,kXf), v(l,kXf))
         * occ_rate(l) - xl(l) =g= 0;
```

From equation (A.23):

```
de_nu_kHat (iXk)..
         sum(f$iXkXf(iXk,f), - v (iXk,f))
         + ik_Hat (iXk) =g= 0;
```

From equation (A.24):

```
de_nu_kXfHat (iXkXf)..
         - v(iXkXf) + ikf_Hat(iXkXf) =g= 0;
```

From equation (A.21):

```
de_xNT..
         -u_primeNT + lambda_y * pNT =g= 0;
```

From equation (A.22):

```
de_xl(l)..
         -u_primel(l) + (lambda_y) * (1+tax(l)) * pl(l) =g= 0;
```

From equation (A.26):

```
de_lambda_y..
         income + sum((l,kXf)$iXkXf(l,kXf),
         (pl(l) * occ_rate(l)-c_IKF(l,kXf)) * v(l,kXf))
         - xNT * pNT - sum(l,xl(l)
         * pl(l) * (1+tax(l))) =g= 0;
```

From equation (A.27):

```
eq_mkt_clr(l)..
        pl(l) =e= nu_x(l);
```

Auxiliary conditions: The accessory equations define the utility function, its partial derivatives and the associated condition for aggregate prices.

From equation (A.14):

```
eq_uprimeNT..
 u_primeNT   =e=
        (alpha_NT/xNT) ** (1-rho_U)
        * (alpha_NT ** (1-rho_U)
        * xNT**rho_U + alpha_T ** (1-rho_U)
        * q("Trans","NA","NA","NA") ** rho_U)
        ** (1/rho_U-1);
```

From equation (A.18):

```
eq_qprime(i_notU)..
q_prime(i_notU) =e=
        sum(i_ucomp$iXj(i_ucomp,i_notU),
        (alpha(i_notU)/q(i_notU)) ** (1-rho(i_ucomp))
        * sum(j$iXj(i_ucomp,j), alpha(j) ** (1-rho(i_ucomp))
        * q(j) ** rho(i_ucomp)) ** (1/rho(i_ucomp)-1));
```

From equation (A.17):

```
eq_uprimel(l)..
u_primel(l) =e=
        prod(i_notU$(CiXj(i_notU,l)), q_prime(i_notU));
```

From equation (A.11):

```
eq_qi(i)..
q(i) =e=
        (sum(j$(iXj(i,j) and i_ucomp(i)),
        alpha(j)**(1-rho(i)) * q(j)**rho(i))
        **(1/rho(i)))$i_ucomp(i)
        + xNT$NT(i)
        + xl(i)$l(i);
```

From equation (A.13) and (A.12):

```
eq_phi(i)..
phi(i) =e=
```

```
          (sum(j$(iXj(i,j)), p(j)*q(j)/q(i)))$i_ucomp(i)
          + pNT$NT(i)
          + pl(i)$l(i)*(1+tax(i));
```

From equation (A.12):

```
eq_y(i)..
          y(i) =e= phi(i)*q(i);
```

The overall model

```
MODEL TNT "market equilibrium" /
          de_xNT.xNT
          de_xl.xl
          de_nu_x.nu_x
          de_lambda_y.lambda_y
          de_v.v
          de_nu_kXfHat.nu_kXfHat
          eq_uprimeNT.u_primeNT
          eq_uprimel.u_primel
          eq_qprime.q_prime
          eq_qi.q
          eq_phi.phi
          eq_mkt_clr.pl
          eq_y.y
                    /;
```

Finally, the optimisation statement is as follows:

```
SOLVE TNT using MCP;
```

A.8 The calibration process

Aiming to produce some realistic values for the αs used in the model, the calibration process focuses on the demand side and on the utility function. For this, a reference scenario is introduced, where `ref_price` ($\mathbf{p_{i0}}$ in mathematical notation) and `ref_quantity` ($\mathbf{x_{i0}}$) reflect prices and quantities observed in the actual market.

A.8.1 Notation

For this problem we set some new notation, since problem-specific variables and parameters are needed.

parameters

$\mathbf{p}_{i0}$ (`ref_price`), final good prices in the reference scenario

$\mathbf{x}_{i0}$ (`ref_quant`), final good consumption in the reference scenario

variables

$\hat{\alpha}$ (`alpha_cal`), Keller's alpha, calibrated variable

$\hat{\phi}$ (`phi_cal`), aggregate price variable, calibrated

$\hat{q}$ (`quant_cal`), aggregate consumption utility component, calibrated

A.8.2 Equations

Most of the equations used in the calibration process are derived from those appearing in section A.3, and directly adapted from results in Keller (1976). The first condition is that the sum of the αs associated with the same utility component has to be equal to 1, as described in A.1:

$$\sum_{j \in i} \hat{\alpha}_{n-1,j} = 1. \tag{A.29}$$

Then, both observed market price and consumption quantity have to be equal to their utility-component counterparts:

$$\hat{q}_{0,i0} = \mathbf{x}_{i0}, \hat{\phi}_{0,i0} = \mathbf{p}_{i0} \tag{A.30}$$

Both aggregated consumption $\hat{q}_{n,i}$ and prices $\hat{\phi}_{n,i}$ have to follow the utility CES functional form in (A.11) and the aggregate expenditure in (A.12) respectively:

$$\hat{q}(n,i) = \left[\sum_{n-1,j} \hat{\alpha}_{n-1,j}^{(1-\rho_{n,i})} \hat{q}_{n-1,j}^{\rho_{n,i}} \right]^{1/\rho_{n,i}}, \tag{A.31}$$

$$\hat{\phi}_{n,i} = \frac{\sum_{j \in i} \hat{\phi}_{n-1,j} \hat{q}_{n-1,j}}{\hat{q}_{n,i}}. \tag{A.32}$$

Together with the previous statements, the following (and last) condition tells that the bundle ($\mathbf{x}_{i0}$) is not only feasible, but indeed optimal. For this, the ratio between the aggregate consumption between each and every associated components i and j, have to respect the optimality condition stated in the results in Keller (1976). The adaptation and the result for the calibration of the αs can be seen hereafter:

$$\hat{\alpha}_{n-1,j} = \frac{\hat{q}_{n-1,j}}{\hat{q}_{n,i}} \left(\frac{\hat{\phi}_{n-1,j}}{\hat{\phi}_{n,i}} \right)^{\sigma_{n,i}}. \tag{A.33}$$

A.8.3 GAMS implementation

The solution to the calibration problem will be the set of $\hat{\alpha}^*, \hat{q}^*, \hat{\phi}^*$ that solves simultaneously equations (A.29) to (A.33). The values provided by $\hat{\alpha}^*_{n-1,j}$ will be then used as $\alpha_{n-1,j}$ in the market equilibrium MCP problem. Since there is no maximisation problem, a little trick is adopted. The objective function is represented by a constant variable (`dummy_cal`), that is optimised over the values of $\hat{\alpha}^*, \hat{q}^*, \hat{\phi}^*$, leading to a feasibility problem, solved in GAMS by non linear optimisation compiler CONOPT 3. The following GAMS definitions reflect the previously described equations.

From equation (A.29):

```
eq_alpha_cal (i_ucomp)..
        sum(i$iXj(i_ucomp, i), alpha_cal(i)) =e= 1 ;$
```

From equation (A.30):

```
eq_commodity(i_0)..
        quantity_cal(i_0) =e= ref_quantity(i_0);
eq_ref_price(i_0)..
        phi_cal(i_0) =e= ref_price(i_0);
```

From equation (A.31):

```
eq_quantity(i_ucomp)..
        quantity_cal(i_ucomp) ** rho(i_ucomp) -
        ( sum(j$iXj(i_ucomp,j), (alpha_cal(j)$
        ** (1-rho(i_ucomp))) * quantity_cal(j)
        ** (rho(i_ucomp)))) =e= 0;
```

From equation (A.32):

```
eq_price_cal (i_ucomp)..
        phi_cal (i_ucomp) =e= sum(j$iXj(i_ucomp,j),$
        phi_cal(j)*quantity_cal(j) /q uantity_cal(i_ucomp));
```

From equation (A.33):

```
eq_optimality_ratio(j)$i_notU(j)..
        alpha_cal(j) =e=
        sum(i$iXj(i,j), (phi_cal(j) / phi_cal(i))
        **sigma(i)* quantity_cal(j) / quantity_cal(i) );
```

And the "dummy" objective function:

```
eq_dummy_cal..
        dummy_cal =e= 1;
```

The definition of the model *calibration* collects all the previously presented equations:

```
MODEL calibration "calibrating Keller's alphas" /
        eq_alpha_cal
        eq_opt_quantity
        eq_phi_cal
        eq_ref_price
        eq_quantity
        eq_commodity
        eq_optimality_ratio
        eq_dummy_cal
/;
```

The optimisation statement is as follows:

```
SOLVE calibration MINIMIZING dummy_cal using NLP;
```