DEMAND FOR PUBLIC TRANSPORTATION AND THE DESIGN OF OPTIMAL PUBLIC POLICIES

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ABSTRACT

Transport and mobility are key factors of quality of life in cities all around the world. In order to choose an optimal transportation system, it is vital to understand well how commuters respond to different designs of the public infrastructure.

In this chapter, we attempt to address that question by reviewing the relevant empirical literature in transportation economics. Our focus is to discuss research that models and estimates demand for the use of public transportation. With that in mind, we first detail the typical approach and specifications used. Then we summarize the main results found in that literature. Finally, we discuss our findings in the context of the future of the sector, taking into account the new challenges, innovations and emerging business models.

Keywords: Public Transportation, Demand, Literature Review, Public Policies

INTRODUCTION

Understanding consumer demand for public transportation is crucial to carefully understand how government policies in the sector affect transportation users, and hence assess the costs and benefits associated with each new project. To correctly determine the best policies, it is vital to quantify clearly how commuters will respond to different designs of the public transportation infrastructure. That is exactly the main goal of estimating demand for transportation.

In this chapter, we review important papers on transportation literature, focusing in particular on empirical papers that estimate demand for public transportation. Our review is

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not exhaustive but attempts to focus on some of the empirical findings that can be useful for policy makers. Our goal is to help governmental and private sector agents, in this field of public transportation infrastructure, to be able to make informed decisions about the future.

We start our review by discussing the work by McFadden. His 1974 work is one of the first papers to highlight the importance of studying travelers’ behavior in demand estimation for public transport. By using a random utility maximizing framework, McFadden rationalized aggregate demand estimation as an outcome of individuals’ decision-making behavior that is affected by key factors. His view has influenced academics and policymakers to draw attention to which factors impact travelers’ behavior and hence urban travel demand.

Next, we follow Paulley et al (2006). They consider four main factors that influence transport users’ decision-making: fares and fuel prices, car ownership, income, and quality of service, and discuss through which mechanisms each of these attributes affect different types of travelers.

We then turn our attention to relevant parameters estimated by transport demand literature and present some key parameters and literature findings, commenting further on policy simulations and some relevant counterfactuals.

Finally, we address the state-of-art of literature on transport demand in Brazil and conclude by discussing the future of Brazilian transportation sector.

FACTORS AFFECTING DEMAND FOR URBAN TRANSPORTATION

Discussing relevant factors that influence demand for urban transportation is crucial to better understand current traveler’s behavior and, at the same time, how passengers will respond to changes in the sector. Thus, it is paramount for academics and practitioners to address which aspects determine demand for public transportation in order to properly assess whether different policies will yield desired outcomes.

Several studies and surveys have been carried out to examine which factors are relevant for estimation of urban travel demand. Paulley et al (2006) presents the findings of a comprehensive collaborative study conducted in the UK that highlights the influence of four main factors: fares and fuel prices, car ownership, income, and quality of service. In this section, we comment on the expected impacts of those factors on travelers’ behavior and discuss how they influence urban travel demand.

When accessing local transportation systems, customers frequently face clear monetary costs and hence it is natural to assume that such costs are taken into account when travelers decided their mode of transportation. Fares and fuel prices are the most obvious examples of such monetary costs, and for this reason, most authors analyzing transit ridership consider these factors, as pointed out by Taylor & Fink (2003). According to Paulley et al (2006), increases in fares of one mode of transportation will reduce patronage for the same mode, and generally increase demand for alternative modes due to substitution effects. Fuel prices affect

1 In this chapter, we do not address how macroeconomic variables such as unemployment and inflation rate, aggregate GDP growth influence directly demand for urban transportation, focusing only on their indirect effects via microeconomics variables, such as local income and prices. For an analysis on how transport demand is affected directly by changes in macroeconomic variables, see Hughes, Knittel & Sperling(2008).
private demand similarly, as stated in Graham & Glaister (2002), Hughes, Taylor & Fink (2003), Hughes, Knittel & Sperling (2008), and Donna (2015).

The effects of fares and fuel prices in turn depend heavily on local population idiosyncrasies; according to Small & Verhoef (2007), fuel prices are closely related to activities that occur on a particular location and to local demographics, and for this reason local population idiosyncrasies should be considered when estimating demand for urban transportation. McFadden (1974), for instance, proposes to estimate a discrete choice model where the utility of each individual is a function of the characteristics of each alternative, demographic variables and an independent and extreme value distributed error term. In this seminal paper, the author finds that population density, number of minutes traveler can arrive late2 and car ownership are statistically significant variables.

A comprehensive analysis of overall urban travel demand should address not only demand for public transportation, but also private transportation in the form of car ownership3, accounting for interactions and substitution effects of one segment on the other. Car owners have more alternative modes to choose from than users of public transportation systems, leading to a reduction in demand for public transportation, as indicated by Paulley et al. (2006).

Car ridership is the most frequently used mode of transportation in several countries, considering both private and shared rides. In particular, as reported in Lucinda et al (2015), drive and shared rides combined accounted in 2015 for the greatest share (36.15%) of the total of surveyed trips in Brazil’s largest city, Sao Paulo. Rides can take the form of carpooling, which should also be considered for transport demand estimation, as it might be thought of a non-conventional alternative to public transportation, since fuel and other driving costs per passenger are reduced for drivers that rode alone, but have a strong preference for traveling in a private vehicle, as argued by Bento, Hughes & Kaffine (2013). Carpooling riders also benefit from lower traffic congestion in high-occupancy vehicle (HOV) lanes, which leads to faster trips and lower in-vehicle time.

Car ownership and carpooling in turn are strongly correlated with travelers’ income, as summarized by Paulley et al (2006). According to these authors, an increase in income could lead to an increase in car ownership and, as discussed previously, it would in turn result in a reduction in demand for public transportation. Holmgren (2013), on the other hand, argues that a higher income stimulates greater mobility and hence an increase in the number of public transportation trips is likely to occur. The author shows, using reduced-form model that, although relevant to explain overall urban travel demand, income has opposite effects on public transport demand, and the direction of such effects is unknown a priori.

Fare and fuel prices, car ownership and income, are easily measurable variables that influence urban travel demand, as discussed previously, and hence should be included as covariates in any transport demand estimation. Nonetheless, as pointed out by Paulley et al (2006), quality of service frequently involves a wide range of subjective attributes that affect

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2 Choice of when arrive to work can be determined endogenously through a discrete choice model that depends on demographic and work characteristics, as developed in Small (1982). According to the author, distinct family status, occupation, transportation mode, and employer’s policy toward work-hour flexibility yield different effects on scheduling times.

3 Here we use the term “car ownership” indiscriminately to refer to privately owned vehicles, assuming vehicle type choice as exogenous in the short-run. In Hensher et al. (1990), travelers face alternative vehicle technologies and choose the one that maximizes the joint utility of vehicle choice and use.
travelers’ choice of mode transportation, and thus defining suitable proxies is crucial for correctly estimating overall transport demand.

Moreover, as indicated by Small & Verhoef (2007), the most typical aggregate-level proxies for service quality are annual vehicle-miles or vehicle hours of service. Following Paulley et al (2006), distance to and from the station, service intervals and in-vehicle time can be easily incorporated in transport demand forecasts. Considering individual travel behavior, time-related measures, such as in-vehicle, walking and waiting times, also influence travelers’ transportation mode choice, as postulated by Currie (2005), and hence impact on overall transport demand. An increase in overall time spent in a particular transportation mode tends to reduce demand for that same mode and increase for alternative ones, due to substitution effects. According to Small & Verhoef (2007), estimating how travelers value time is vital for police-making, since it is a key parameter of interest in transport demand estimation, as will be discussed in the next section.

**MAIN EMPIRICAL RESULTS IN THE LITERATURE**

One of the main goals of estimating demand for transportation is to assess the overall response of travelers to changes in relevant attributes. In order to accomplish such aim, it is vital to define adequate measures of travelers’ response. In this section, we discuss the measures most frequently found in the literature and present the direction and magnitude of these findings.

Elasticities are the most frequently used metric to measure demand response in transportation sector. This might be explained by their ease of understanding and because they are tested by experience, according to Goodwin (1992). For this reason, we dedicate most of this section to analyze different types of elasticities calculated by the literature and to discuss how they change for distinct scenarios.

As detailed previously, changes in public fares and fuel prices both affect public and private demand transportation. Most authors seeking to understand the impact of prices and fares on urban travel demand calculate own and cross elasticity (the impact of a change in price on, respectively, the same mode and alternative modes demand). Moreover, they often distinguish between short- and long-run elasticities, as pointed out by Goodwin (1992) and Paulley et al (2006).

Goodwin (1992), Graham & Glaister (2002) and Paulley et al (2006), report different short- and long-run estimates of own price elasticities, but all reach the same conclusion: both measures are negative and short-run elasticities are often lower (in absolute value) than long-run counterparts. On the other hand, Bento, Hughes & Kaffine (2013) find positive short-run elasticities of fuel prices in high-occupancy vehicle (HOV) lanes, suggesting that an increase in fuel prices do not necessarily lead travelers to reduce the number of car trips, but instead choose to carpool in the short-run. According to the Goodwin (1992), long-term to short-term elasticities ratio ranges from 1.5 to 4.0 (depending, among other factors, on the level of aggregation of the data and if cross section or time series variation is used for identification).

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4 In this section, we restrict our analysis to factors that are most frequently cited in the literature to influence urban demand transportation. We admit there might be other attributes that affect demand for urban transport that were not contemplated in this chapter.

5 The notions of short- and long-run usually exhibit some variation according to each author’s choice.
Travelers are more sensitive to fuel prices and fares in the long-run, because not only can they adapt to other mode alternatives, such as carpooling (Bento, Hughes & Kaffine 2013) and bus rapid transit systems (BRT) (Currie 2005), but they might also choose more efficient cars that reduce fuel consumption.

Nonetheless, long-run cross-elasticities might be in fact lower (in absolute value) if there are costs in substituting one mode for other. Donna (2015) assumes that travelers face costs from switching from one mode to an alternative, i.e. travelers incur in switching costs. According to Donna (2015), switching costs for travelers might associate to, for instance, obtaining new information on transit services and automobile routes, as well as purchasing ridership tickets and searching for new parking facilities. His estimates show that long-run cross-elasticities both for car and for public transportation are less than 20% of their respective estimates obtained if switching costs are not considered.

Fare and fuel price elasticities estimates also vary according to local population characteristics, such as location (if close to rural or urban areas), different trips purposes (work or not), and time of day (rush hours) as exemplified in Goodwin (1992), Pauley et al (2006) and Small & Verhoef (2007). Travelers located in urban areas have fewer alternative modes of transportation to choose from, and hence fare elasticities tend to be greater. On the other hand, trips made for work purposes often face schedule and flexibility constraints, as argued in Small (1982), and hence off-peak fare elasticities are often greater than peak values, being about twice as greater for the UK according to Pauley et al (2006).

Another important type of elasticity frequently estimated in the transportation literature is income elasticity of demand. As highlighted in the previous section, changes in income have opposite effects on public transport demand due: direct positive effects and competing negative effects on car ownership. Holmgren (2013) disentangles these opposite effects, yielding estimates of direct income elasticity for public transportation of 0.34 and estimates of car ownership elasticity with respect to income of 0.21, which in turn result in total income elasticity of public transport demand of 0.052, i.e. the total effect is close to zero in this case.

In spite of being straightforward and tested by experience, the different types of elasticities discussed previously fail to capture how changes in key factors affect travelers’ welfare and how they value such attributes in monetary terms. Considering the relevance of those measures to assess the impact of distinct government policies and structural changes in the sector, detailed in the next section, we present and comment here how the literature of transportation have defined and estimated such measures.

Marginal rates of substitution are especially suitable for characterize substitution patterns for the same level of consumers’ welfare. In the context of transportation sector, this concept is particularly applied to time-related attributes. Small (1982) estimates marginal rates of substitution of different time schedules by each mode of transportation, finding that on average, urban commuters shift their schedules by 1 to 2 minutes earlier than previously scheduled, or by 1/3 to 1 minute later, in order to save one minute of travel time.

The concept of value of time, mentioned in the previous section, can be expressed quantitatively as a particular type of marginal rate of substitution. Lam & Small (2001) and Wardman (2004) define value of time as the ratio of marginal utilities of time and money, which equals to the marginal rate of substitution of travel time for money, i.e., how much

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6 The term welfare in this paragraph refers loosely to indirect utility levels that are assumed constant when calculating marginal rates of substitution.
travelers are willing to pay to save one hour of travelling. Small & Verhoef (2007) argue that value of time, similarly to elasticities, also depend, among other factors, on demographics and local population characteristics, trip purpose, and total duration of trip.

In order to assess the impact on transport demand of actual or hypothetical changes in the sector, recent papers in literature have frequently calculated welfare estimates in terms of Consumer Surplus (CS) and Equivalent Variation (EV). As defined in the text-book Mas-Colell et al (1995), the concept of equivalent variation (EV) expresses how much, in monetary values, a significant change in key sector variables is equivalent in terms of welfare impacts. In the next section, we detail how welfare measures are estimated in transport literature to evaluate relevant changes and alternative scenarios in the sector and describe their policy implications.

**Counterfactual scenarios and policy implications**

One of the main purposes of estimating transport demand is to carefully understand how government policies and structural changes in the sector initially affect travelers’ behavior and then analyze travelers’ response. Here we discuss briefly the goals of some transport policies and their underlying mechanisms, addressing how these different policies and structural changes in the sector impact on urban travel demand.

Transportation policies should be designed to achieve economic efficiency, i.e. should create an environment that maximizes overall welfare of users and providers and reduce the impact of market failures. Externalities are the most expressive market failures that affect transportation users by introducing additional costs in travelers’ decision-making process, and hence transportation policies should act to alleviate these negative effects.

Congestion is one type of negative externality prevalent in transportation sector, according to Bento et al (2014), and, as argued by Lucinda et al (2015), leads to lower productivity levels, increased fuel consumption and negative environmental effects. Academics and policy makers have criticized and proposed several mechanisms designed to mitigate problems associated with congestion, such as increasing fuel and congestion taxes, and introducing rotation systems, as discussed by Parry & Small (2005) and Lucinda et al (2015).

According to Parry & Small (2005), fuel taxes are appealing because are administratively simple and well-established; nonetheless, as authors argue, they are an imperfect instrument for controlling distance-related externalities like congestion, because travelers can respond to increases in fuel taxes by purchasing more fuel-efficient vehicles, rather than reducing miles travelled. Parry & Small (2005) propose instead a second-best optimal fuel tax that reflects, among other components, external costs of congestion and air pollution, and show that actual United States and Britain fuel taxes differ dramatically from their second-best value.

Two possible alternatives are either charge road usage directly, via imposing an urban toll fare per trip, or introduce rotating systems to reduce total number of circulating vehicles, as suggested in Lucinda et al (2015). The authors compare these two policy alternatives that

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7 We partially reproduce here policy objectives indicated by Balcombe et al (2004).

8 Fuel prices have been used in the transportation sector as an instrument to reduce traffic congestion, as studied in Bento, Hughes & Kaffine (2013), but it also been used in policies to reduce greenhouse gas emissions and in optimal taxation analysis (Hughes, Knittel & Sperling(2008)).
yield the same traffic reduction, estimating an equivalent variation (EV) for urban toll of about 2.28 BRL, while for the rotation system EV is around 3.5, and therefore, although yielding the same results, rotation systems makes travelers worse off.

Finally, policy-making in transportation sector should also address the effects of new transportation modes before their introduction and the impacts of new traffic and environmental initiatives on travelers’ welfare. For example, McFadden (1974) use logit estimates to forecast demand for rapid transit system in San Francisco Bay Area (BART) before fully implementation of the system, whereas Bento et al (2014) study the implementation of Clean Air Vehicle Stickers, an initiative that encourages the ultra-low emission vehicles by allowing solo-hybrid drivers to use high occupancy vehicle lanes (HOV). Authors show that welfare effects of this policy are negative, due to increased congestion costs, illustrating interaction effects of different types of externalities in transportation sector.

**THE FUTURE OF TRANSPORTATION**

The transport industry is living a huge transformation process. The industry innovation is traditionally promoted by changes in technologies of the vehicles or infrastructures. At this time the source of transformation are the changes on the new social trends, business models, types of service and technological developments, especially in the area of the Information and Communication Technologies (ICTs). This ongoing trend, that is shared with others network industry, is developing as a co-evolution between technological change and institutional change (see for example, Nelson 1994, Nelson and Sampat 2001, Von Tunzelmann 2003, Murmann 2003, Reinstaller 2005 and Fatas-Villafranca et al. 2008). They, together, are paving the way for the establishment of new disruptive business models. Examples of this are the UBER platform, which provides over 1 million rides per day worldwide, or the significant investment in self driving technologies by important players such as Google, Tesla or UBER.

The empirical evidence on how consumers respond to incentives in the transportation sector is ever more relevant as the sector faces new challenges that will require new public policies to be created and old rules to be adjusted. In this section we detail those new challenges.

On the technological field, communications and information technology, systems, and applications have evolved at a rapid rate. These factors ultimately led to innovative research initiatives and an explosion of new transportation apps, often combining the use of vehicles as probes with enhanced geographic location and mapping systems in the form of user-friendly mobile and in-vehicle user interfaces. Increasingly, ITS applications are considered in two contexts—for automated purposes and/or for connected vehicle purposes. In addition to these technologies, commercial applications based on geolocation and cell phones, such as Waze and Uber, are influencing the ITS market and are part of a larger trend of shared mobility (U.S. Department of Transportation, 2016). Shared mobility—the shared use of a car, bicycle, or other low-speed mode of transportation—is one aspect of the sharing economy and enables users to obtain short-term access to transportation modes as needed, rather than requiring ownership.

Regarding the institutions, nowadays, the systems of established and prevalent rules that structure the market and technological systems operation are increasingly becoming a
governance rule; i.e., the rules, norms and actions of the industry are produced, sustained, regulated and held no longer by government, but by other entities, private and/or international. This trend was possible because the ICT technologic innovation is developing from more centralized to distributed and decentralized. It is a result of the information and communication affecting all the technology.

Therefore, the result from the institutions and technology development is a playing field for the increase of new disruptive business models and market actors. Existing relationships between actors in the value chain are been replaced by new organizational forms, which allow for the creation of dynamic networks among individuals and transport services firms. The focus is on the customers rather than on infrastructure or on the providers of mobility. In other words, historically the different transportation modes were separated, both from the view of the companies, users or regulation. With digitalization, a digital layer can connect information about multiples transport mode and consumers, enabling developers to build quite sophisticated transport services for the end users start to compare prices, routes and qualities of different or combination of modes.

As the data that is generated is based on the clients, the user do not need to be a transport operator to generate data about transport, that is, the client no longer need to be linked to the operator, they are linked to the platform. The innovation is that, ultimately, the user will buy mobility and no longer transport. New technologies, as self-driving cars, buses and drones can accelerate this process. For the users, the focus is no longer on the transport mode, but rather on mobility. As a consequence, mobility will increasingly be seen as an information service with physical transportation products, rather than a transportation product with additional services.

This growing role of the ICTs developed a new concept of transport, the ‘Mobility-as-a-Service’ (MaaS). It is a mobility distribution model in which a customer’s major transportation needs are met thanks to one single interface with services offered by one single integrated service provider combining transportation infrastructures, transportation services, information and payment services, and others more. It works out the best option for every journey – whether that is a taxi, public transport, a rental car or a bike share. From office commutes to weekend getaways, it manages daily travel in the smartest way possible. For extra convenience, MaaS may include value added services like deliveries services (Finger, 2015).

Few studies have been carried out to simulate the impacts of news trends in urban transportation. ITF (2015) models the impact of replacing all car and bus trips in a city with mobility provided through shared mobility delivered by a fleet of six-seat vehicles (“Shared Taxis”) that offer on-demand, door-to-door shared rides in conjunction with a fleet of eight-person and 16-person mini-buses (“Taxi-Buses”) that serve pop-up stops on demand and provide transfer-free rides. Rail and subway services keep operating in the current pattern. The objective is to simulate effects on congestions, CO2 emissions, use of public space and social inclusion measured in the level of accessibility of jobs, schools and health services.

The general methodology framework is based on simulation of the daily mobility of the city, as the actual traffic environment, transport infrastructure and the interaction between people (clients) and vehicles, simulating their connection and how, in terms of timing and location, the trip services are performed. The alternative shared trip routing are based on an algorithm that generates the lowest time path between any pair of nodes of the network, managed by a central dispatcher system that uses the location of shared vehicles, their current
occupancy level and the location of clients as its main inputs. The author uses Viegas and Martínez (2010) synthetic travel simulation model. Each trip is characterized by its time of occurrence, origin and destination, as well as other traveler's information, as age, gender, income, the owning a driving license, pass car, motorcycle, parking spaces at home and at work (Moura et al., 2007; Martinez and Viegas, 2009; Santos et al., 2011). Having the full characterization of the trip as input, the probability of choosing each mode is assigned to the client by simulation where modes with higher probability will be chosen more often (Eiró and Martínez, 2014).

The main findings are that, not changing the number of daily trips, the congestion disappears and traffic emissions are reduced by one third. The car fleet needed would be only 3% in size of the today's fleet, which would reduce 95% the required space for public parking. Without congestion and higher efficient use of fleet capacity, prices for journeys in the city could be 50% or less of today even without subsidy. The inequality in the access to jobs, schools or health services across the city, a measure of social inclusion, virtually disappeared.

Even though this process is already at a fast pace in develop countries, it is reasonable to expect that there will be a sort of catching up for developing regions. UBER and others e-hailing app’s are already working on several capitals of the country and triggering anger among taxi drivers. As most of the innovations are on business models, and considering that the regulation is held no longer by government, but by other entities, private and/or international, one of the main challenge for the dissemination of the service is regulatory. In Rio de Janeiro, for example, while the Olympic Games took place, the UBER service was being provided through injunction because the then mayor, Eduardo Paes, banned the application in the city. Almost at the same time, the major of Sao Paulo, Fernando Haddad, laid out regulations to allow the use of ride-hailing apps in exchange for a mileage fee of R$ 0,10 per kilometer for drivers, among other quality criterias.

Encouraged by the high cost of public transport fares and new social trends, some sharing economy iniciatives in transports are taking place in Brazil. Ride-sharing apps, that connect car drivers with room in their vehicles with members of the public in search of a ride, are attracting commuters especially in longer travels. Peer-to-peer carsharing apps, whereby existing car owners make their vehicles available for others to rent for short periods of time, are starting operation in the main cities.

There are other iniciatives being promoted by the city halls. Some cities around the country already counts with bike sharing system in which users can acess the service via an app and search the neaest station with available bike. The city of Fortaleza, state capital of Ceara, went further and is operating an electric car-sharing system for public use on a paid subscription basis.

**CONCLUSION**

Transport and mobility are key factors of quality of life in the cities all around the world. Historically, the evolution of urban form and urban transportations system has a fundamental linkage. By 2050, more than 6 billion people, or around two thirds of population, will be urban residents. In many cases, cities respond to growth in demand for mobility by expanding the transportation supply, building new transport infrastructure. However, physical limitation, as restricted space for new roads, or economics constraints for expensive investments forces
the public sector to better plan the strategy to accommodate demand for transportation, current and future, in order to maximize the population’s well-being.

Urbanization, new social trends and innovations in business models and technologies, especially in the area of the Information and Communication Technologies (ICTs), are dramatically changing fundamentally transportation system and utilities. This offers a new way for city planners to deal with mobility problems and moving away from the traditional approach of increasing capacity by building costly new infrastructure. ICTs have a disruptive effect on the transport sector: new technologies enable a new integrated mobility system that focuses on the customers rather than on infrastructure or on the providers of mobility. Furthermore, new technologies such as automated vehicles are entering the transportation system at a steady pace. In a nutshell, there are several new challenges connected to transport that regulation has to take into account.

The existing transport sector’s structure requiring new perspectives in transport regulation and governance. The transformation of business models, especially when it involves disruptive changes, entails regulatory and legal accommodation. Regulatory interventions are needed to guide investments towards a cleaner renewable generation mix, creating conditions for innovation and transformation to generate benefits for all stakeholders. Moreover, it is necessary to mobilize political leadership to ensure the design of appropriate public policies that should include ambitious outcome-based targets.

To draw these policies intelligently, it is necessary to understand the traveler’s behavior and how their response are. Demand systems provide an important component of incentives for market responses to many policy and environmental changes. This article summarizes some of the empirical evidence that can be useful to design the future of transportation.

REFERENCES


Finger, Matthias, Nadia Bert, and David Kupfer. 2015. *Mobility-as-a-Service: from the Helsinki experiment to a European model?* European Transport Regulation Observer


Moura, F., A. Duarte, and J. Viegas. 2007. CAReFUL – Car fleet renewal as a key role for atmospheric emission reduction. CESUR, Instituto Superior Técnico, Lisbon


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