UNIVERSIDAD POLITÉCNICA DE MADRID
ESCUELA TÉCNICA SUPERIOR
DE INGENIEROS DE CAMINOS, CANALES Y PUERTOS

**ASSESSING SOCIAL AND
DISTRIBUTIONAL IMPACTS OF
TRANSPORTATION POLICIES FOR
OPTIMIZING SUSTAINABILITY**

DOCTORAL THESIS

PAOLA CAROLINA BUENO CADENA

Ingeniera Civil

Magíster en Ingeniería Civil

Máster Universitario en Sistemas de Ingeniería Civil

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**DEPARTAMENTO DE INGENIERÍA CIVIL:
TRANSPORTE Y TERRITORIO**
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LOS VOCALES

EL SECRETARIO

A la memoria de mi madre, por supuesto.

“Nunca releo mis libros, porque me da miedo”
Gabriel García Márquez

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SUMMARY

Attempts to integrate sustainability in the decision-making process for transport policies continue to gain momentum. At this point, there is a general consensus on the need to achieve the dual goals of efficiency and equity when implementing transport planning decisions. Therefore, transport planners are usually involved in designing, implementing and evaluating policies that contribute to favour economic development and to accomplish transportation needs of society in a manner consistent with natural laws and human values.

In this context, social equity has been gaining importance as a requirement for sustainable development, which comprises social, economic and environmental dimensions with a long-term perspective. However, most social assessments of transport planning decisions remain purely qualitative and often very superficial since, in practice, there is little guidance for its comprehensive analysis. Despite the fact that transportation policies and planning practices often have significant and diverse impacts, there is still only a limited evaluation of the equity implications and the distributional incidence of these policies.

As a result, regardless of the widespread implementation of transport policies in many cities and urban areas, few quantitative assessments have been carried out to evaluate whether they meet social needs of the disadvantaged people. Without this kind of analyses, the extent to which they promote social inclusion cannot be determined with certainty.

On the basis of these considerations, the overarching objective of this Thesis is to review, assess and evaluate the social impacts of existing transportation policies and their potential equity consequences from the sustainability viewpoint. To that end, the research evaluates the incidence of different real transportation planning decisions on social inclusion —particularly on income distribution— by applying econometric methodologies and statistical techniques such as regression and discrete choice models. Particularly, the research involves analyses on commonly assumed progressive (transport subsidies and transport benefits) and regressive (road pricing) policy alternatives, taking the city of Madrid, the region of New York-New Jersey and the Spanish interurban toll network as case studies.

Furthermore, a comprehensive framework on the topic of transport evaluation is provided aimed at understanding the role of social and distributional impacts in ex-ante assessments. The research also gives insight for an alternative weighting scheme to embed social equity issues into the existing appraisal process. Finally, the Thesis yielded some interesting conclusions for both policy-makers and practicing planners with regard to the promotion of more efficient and socially inclusive transport policies.

RESUMEN

Los intentos de integrar la sostenibilidad en el proceso de toma de decisiones de las políticas de transporte continúan ganando impulso. En este sentido, existe un consenso general sobre la necesidad de implementar de manera conjunta los objetivos de eficiencia y equidad en las decisiones relativas a la planificación de transporte. En consecuencia, los planificadores del transporte suelen verse en la necesidad de diseñar, implementar y evaluar políticas que contribuyan a favorecer el desarrollo económico y a satisfacer las necesidades de transporte de la sociedad, en consonancia con las leyes naturales y con los valores humanos.

En este contexto, la equidad social ha ganado importancia como requisito para el desarrollo sostenible, que comprende las dimensiones social, económica y ambiental con una perspectiva de largo plazo. Sin embargo, la mayoría de las evaluaciones sociales en el ámbito de la planificación del transporte siguen siendo puramente cualitativas y, a menudo, muy superficiales, ya que en la práctica existen pocas directrices para su análisis exhaustivo. A pesar de que las políticas de transporte a menudo producen impactos significativos y diversos sobre la sociedad en su conjunto, la evaluación de sus implicaciones en términos de equidad e incidencia distributiva es por el momento muy limitada.

En este sentido, a pesar de la amplia implementación de políticas de transporte en zonas urbanas, se han llevado a cabo muy pocos análisis cuantitativos para evaluar si realmente responden a las necesidades de los estratos sociales más desfavorecidos. Sin este tipo de análisis, no es posible determinar con certeza el alcance real de estas medidas en la promoción de la inclusión social.

Sobre la base de estas consideraciones, el objetivo general de esta Tesis es revisar y evaluar los impactos sociales de diversas políticas de transporte existentes, así como y sus posibles consecuencias en términos de equidad desde el punto de vista de la sostenibilidad. Para ello, se evalúa la incidencia de diferentes intervenciones reales de planificación sobre la inclusión social –particularmente sobre la distribución del ingreso– aplicando técnicas econométricas y estadísticas, como los modelos de regresión y de elección discreta. En particular, la investigación analiza el impacto de políticas de transporte comúnmente asumidas como progresivas (subsidios y beneficios al transporte) y regresivas (tarificación vial), tomando como casos de estudio la ciudad de Madrid, la región de Nueva York-Nueva Jersey y la red de autopistas de peaje de España.

Asimismo, la Tesis proporciona un marco general sobre la evaluación de las intervenciones de transporte con el fin de comprender el papel de los impactos sociales y distributivos en las evaluaciones ex-ante. La investigación también propone un esquema de ponderación alternativo para integrar las cuestiones de equidad social en el proceso de toma de decisiones. Finalmente, la Tesis obtiene conclusiones relevantes tanto para los responsables de la formulación de políticas como para los profesionales del sector, con el objetivo de promover políticas de transporte más eficientes y socialmente incluyentes.

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1. INTRODUCTION

Attempts to integrate sustainability in the decision-making process for transport projects continue to gain momentum. Despite the increasing interest in equity issues within the concept of sustainable development (which balances economic, social and environmental objectives), scholars agree that social impacts and their distributional effects have traditionally received less attention than economic and environmental aspects. One of the drawbacks of including social impacts in the evaluation of public policies is the current uncertainty as to what a social impact is, how to measure it, and how to evaluate its distributional effects and equity issues (Geurs et al., 2009). Frequently, transport projects are evaluated by using methods such as cost-benefit analysis which make extensive use of financial costs and benefits but do not thoroughly consider social impacts at a disaggregated level (Beyazit, 2011).

In actual practice, the evaluation of social impacts has been implemented by using several approaches. However, these analyses have often been less well-developed than economic and environmental assessment approaches. As an example, currently there are very few standardized methods for performing comprehensive social and distributional analysis of transport projects and transport planning decisions. As a consequence, most social assessments remain purely qualitative, and often very superficial. The lack of appropriate tools to assess social impacts quantitatively is one of the most frequently cited challenges to effectively carry out social assessments (TEP and CEPS, 2010).

Despite the fact that transportation policies and planning practices often have significant and diverse equity impacts, much less is known about their consequences on people's economic and social opportunities. The limited availability of these studies is surprising since the impact of transportation policies on individual welfare is far from being small. For example, equity concerns associated to fare policies have been subjected to very little detailed analysis, as it is commonly assumed that subsidies always have progressive distribution effects. On the other hand, equity considerations associated with road pricing policies

have not been fully analyzed as, *a priori*, they may be considered regressive fare measures as they establish, in relative terms, a higher burden to low-income travelers.

In summary, up to date, limited contributions have been made to better understand the social and distributional effects of sustainable transportation policies. This introduction chapter summarizes the theoretical basis underlying the equity analysis of transportation policies and transport planning decisions, including different travel demand management measures which have been proposed in diverse contexts. This review explores the importance of the assessment of transport policies according to the social sustainability principles, identifies the critical points of current knowledge and the contributions conducted up to date to deal with them. The ultimate goal of this section is to identify research gaps in the existing literature and strategies to address them.

While different dimensions of equity can contribute to the analysis, this Thesis focuses on vertical equity with regard to income and social class. It implies that transport planning decisions should favor economically and socially disadvantaged groups to be considered equitable. This category of equity is of special interest as there is little quantitative analysis of the distributional incidence of transportation policies on different levels of economic well-being. Furthermore, the emphasis on the issue of vertical equity resides in the interest of determining if these policy instruments guarantee a fair treatment among individuals regardless of their socioeconomic status and tend to compensate for overall inequities.

The document is structured as follows. Section 1.1 explores the concept of social impacts within the transport framework —especially equity impacts— and summarizes the contributions made up to date and the issues that still remain to be addressed in this field. The following Section 1.2 examines the theoretical framework guiding research on typically progressive and regressive policies within the transport planning context. In particular, sub-section 1.2.1 briefly summarizes equity implications of transport fare and subsidy policies, including the special case of subsidies provided to commuters. Next, sub-section 1.2.2 presents the acceptability of road pricing as a factor depending on the perceived fairness associated with the distribution of gains and losses among users. Section

1.3 discusses the role of social impacts in transport decision-making. Specifically, sub-section 1.3.1 considers the sustainability appraisal of transport policies and planning practices according to the equity principles, while sub-section 1.3.2 attempts to provide a comprehensive conceptualization of the incorporation of social and distributional impacts in the existing appraisal process. Lastly, Sections 1.4 to 1.6 identify the research objectives and questions that were developed on the basis of the literature reviewed, discuss the research methodology and present the Thesis structure.

1.1 Defining and measuring social impacts

Defining social impacts is not a simple matter and there remain ambiguities and differences in how this term is understood. In the transport sector, “social impacts are defined as changes in transport sources that might positively or negatively influence the preferences, well-being, behaviour or perception of individuals, groups, social categories and society in general” (Geurs et al., 2009, p.71).

As displayed in Figure 1.1, these authors provide a comprehensive explanation of how transport planning decisions may have a different impact on various groups within the society, thereby introducing the concept of equity.

Figure 1.1 The source-effects-impacts-receptor chain
Source: Adapted from Geurs et al. (2009)

For example, a transport planning decision such as the provision of subsidies to public transport users can change the share of household expenditure on transport. However, this impact may affect differently to economically disadvantaged people since public transport expenditure generally represents a higher share of income for low-income households. If a significantly higher percentage of the lowest-income families benefits from the subsidies compared with the wealthiest ones, there will be evidence that the policy tends to promote social justice.

As pointed out by Litman (2012), equity refers to “the distribution of impacts—benefits and costs—among members of the society and whether that distribution is considered fair and appropriate” (p.2). Then, equity is closely related to the concept of fairness. For a policy to be considered equitable, it should distribute its costs and benefits in a fair way throughout the society (Burton, 2000). In that respect, an equitable distribution of impacts is gaining importance since it constitutes a requirement for a complete sustainable development —comprising three dimensions, namely: social, economic and environmental.

According to Delbosc and Currie (2011), “there are two general categories of transportation equity: horizontal and vertical equity. Horizontal equity (fairness or egalitarianism) is concerned with providing equal resources to individuals or groups considered equal in ability. It avoids favoring one individual or group over another, and services are provided equally regardless of their need or ability. Vertical equity (social justice, environmental justice or social inclusion) is concerned with distributing resources among individuals of different abilities and needs. Vertical equity favors groups based on social class or specific needs in order to make up for overall societal inequalities” (p.1252).

The definitions described above are extended in Levinson (2010) by mentioning other dimensions across which equity can be quantified, including:

- Spatial or territorial equity, where the resources are distributed equally for individuals living in all parts of a given area;
- Longitudinal or generational equity, associated with the balance of gains and losses across generations (from the present to the future);

- Market equity, which refers to the proportionate allocation of benefits and losses on the basis of the price paid;
- Social equity, where the distribution of impacts is proportional to the needs.

As a consequence, the analysis of equity can be intricate since several dimensions of the concept are frequently involved and they often overlap or conflict each other. Despite this fact, there appears to be a general consensus on the need to achieve an equitable distribution of impacts derived from a transport planning decision. Then, equity has been gaining importance for most practitioners and decision-makers. Nevertheless, in practice there is little guidance for its comprehensive analysis.

As a result, despite the widespread implementation of transport policies in many cities and urban areas, there is still only a limited evaluation of the equity implications of these policies, and scarce quantitative assessment of its distributional incidence. Although the concept of equity is a major premise of transport subsidy policies, the social and distributive dimensions of urban transport subsidies have received scarce attention both from a theoretical perspective and in real-world applications. According to Serebrisky et al. (2009), despite the large number of subsidy policies adopted for urban public transport, “there are virtually no quantitative assessments of their distributional incidence, making it impossible to determine if these policies are pro-poor” (p.715).

The social impacts of transportation policies can take many forms which may be particularly difficult to estimate with precision. Furthermore, the current knowledge is fragmented across a large number of different disciplines including spatial planning, human geography, social policy, sociology, public health, engineering, and –of course– transportation; each one with its own dominant approach and methodology (Markovich and Lucas, 2011). Consequently, the concept of equity is addressed in the literature from different perspectives such as traffic fatalities —see for example Anbarci et al. (2009) and Anderson (2010); noise pollution —see for example Brainard et al. (2004) and Neitzel et al. (2009); air quality —see for example Schweitzer and Zhou (2010) and Zuurbier et al.

(2010); and the bond between accessibility and social exclusion —see for example Geurs et al. (2003).

Despite transport policies often have a significant impact on equity, the literature mainly focuses on economic and environmental rather than social and distributional impacts. One possible reason for this is detailed by Litman (2013), who states that there is no single way to evaluate transportation equity, as equity evaluation depends on the type of equity, how people are categorized, which impacts are considered, and how they are measured.

1.2 Transportation policies and equity implications

Despite transportation projects often have significant equity impacts, only a smaller subset of the literature examines their distributional effects (Markovich and Lucas, 2011). Nevertheless, new contributions on methods and techniques to accomplish this issue are emerging. Additionally, unlike the literature for transport system changes, in general much less is known about equity consequences of transport policies and planning practices. “The limited availability of studies on equity of public transportation policies compared to car taxation is surprising as the impact of public transportation on individual welfare is far from being negligible” (Bureau and Glachant, 2011, p.74)”.

This section summarizes the overall findings of the literature review conducted for three different transport policies, two typically understood as progressive (public transport fares and subsidies and transport benefits for commuters—sub-section 1.2.1) and the other mainly assumed to be regressive in terms of income (road pricing— sub-section 1.2.2).

1.2.1 Social and distributional effects of public transport fares and subsidy policies

In the context of transit fares, equity is defined as how “just” pricing is among various constituents of riders (Nuworsoo et al., 2009). These authors suggested the following three possible criteria for setting fares in an equitable way:

- The benefit criterion which states that people should pay for services in proportion to the benefits they receive from them;
- The cost criterion which states that people should be charged for the use of transit services in proportion to the cost of providing the service to them;
- The ability to pay criterion that asserts that people should be charged for the use of transit in proportion to their wealth. To promote vertical equity with regard to income and social class more effectively, transit fares should consider this criterion.

The Transit Cooperative Research Program (2003) suggests equity and environmental justice concerns as key issues for the fare decision-making process. The objective is to ensure that all population groups—including the low-income segment— receive a fair treatment with regard to transit fares. However, while pricing level decisions are increasingly being influenced by equity concerns, this is not the only criterion considered for setting fare structures. Decision-makers usually have to decide the importance given to each criterion and to consider the level of financial support required for these transport subsidies.

In that respect, the adoption of subsidy policies for making public transport more affordable to disadvantaged groups may impact the available budget and resources of transport authorities. As an example, the case of Madrid may serve to illustrate the last point: the travel pass, a highly subsidized public transport fare, has had negative consequences on financial sustainability as the coverage ratio (revenues from users/operation costs) of the public transport system has been decreasing steadily over the years, leading to the need for progressive increases in the amount of public subsidies (see Figure 1.2).

Despite a growing literature addressing the subject of equity, only few authors have looked at equity aspects of transit fare policies per se (Nuworsoo et al., 2009). Equity considerations associated to fare policies and the distributional incidence of subsidies have been subjected to very little detailed analysis, as the common perception is that subsidies always have progressive distribution effects (Vassallo et al., 2009).

Figure 1.2. Evolution of the coverage ratio in Madrid

Source: Author's elaboration based on information provided by the Madrid Regional Transport Consortium –CRTM.

Although there are few studies on the distributional incidence of transport subsidy policies, a number of methodological approaches have been developed to analyze the equity effects of urban transport subsidies and fare policies. Table 1.1 presents a descriptive summary of some of the most relevant and recent studies evaluating the equity impacts of transit fares. Other examples aimed at understanding equity and distributional concerns of transport subsidies are found in the literature —see for instance Cervero et al. (1980); Cervero (1982); Deakin and Harvey (1996) or Serebrisky et al. (2009).

As can be inferred from Table 1.1 and from other studies in the literature, there are different opinions and results with regard to the progressiveness of targeting subsidies to the people in most need. While some researchers have shown that the effects of urban transport subsidies are generally progressive, other authors have concluded that transport subsidies show either a neutral or regressive distributive impacts.

Table 1.1 Overview of previous studies

Author	Context	Title	Main Characteristics and Results
Asensio et al. (2003)	Madrid, Barcelona, Valencia, Sevilla, Zaragoza, Málaga. Spain	Redistributive effects of subsidies to urban public transport in Spain	<ul style="list-style-type: none"> • By using microdata from the Spanish Household Budget Survey, this research studies the redistributive effects generated by the subsidization of urban public transport services and measures the progressiveness of the subsidies for different income groups. • The main result is that the subsidies received by each household as percentage of its income decrease sharply as income rises, thus revealing a clearly progressive effect. However, in larger urban areas this effect is considerably more important than in small ones.
Bureau and Glachant (2011)	The Paris Region. France	Distributional effects of public transport policies in the Paris Region	<ul style="list-style-type: none"> • Using disaggregated data from the Global Transport Survey, it evaluates the distributional effects of alternative urban public transport scenarios in the Paris Region (fare reduction and increase in the speed of public transport). • These authors found that the changes were progressive, and that low-income populations perceived more benefits from fare reductions than from increases in public transport speed.
Bondorevsky (2007)	The Buenos Aires Region. Argentina	A distributive analysis of public urban transport services in the Metropolitan Area of Buenos Aires between 2002 and 2006	<ul style="list-style-type: none"> • This study calculates the error of exclusion (the percentage of the target population of the policy that does not receive any benefit) and the error of inclusion (the percentage of benefiting households that should not be receiving this benefit) of three transport subsidies (subsidy for the metro, the sub-urban rail and the bus system). • The results showed that these subsidies were regressive in all cases. Moreover, when comparing data between 2002 and 2006, it is found that subsidies are becoming more regressive.
Flynn (2007)	Mexico City. Mexico.	Measures to make urban transport affordable to the poor: Mexico City case study	<ul style="list-style-type: none"> • This paper calculates the error of exclusion and the error of inclusion of three transport subsidies in Mexico City: subsidies for the Metro, subsidies for buses and for trolleys. • The results showed that transport subsidies in Mexico City “are not particularly pro-poor”. With the exception of the subsidy for buses—which is mildly progressive—these subsidies were neutral in terms of their distributive impact.
Farber et al. (2014)	Utah. USA	Assessing social equity in distance based transit fares using a model of travel behavior	<ul style="list-style-type: none"> • This study develops and applies a Geographic Information System-based Decision Support System for assessing social equity impacts of distance-based public transit fares. • The analysis revealed that overall distance-based fares benefit low-income, elderly, and non-white populations. Distance-based fares progressively provide price-reductions to those who need it most, and ask those in higher socioeconomic positions to pay more for their travel.
Nuworsoo et al. (2009)	Alameda-Contra Costa, California. USA	Analyzing equity impacts of transit fare changes: Case study of Alameda-Contra Costa Transit, California	<ul style="list-style-type: none"> • This paper analyses five alternative fare proposals introduced for public discussion, paying particular attention to the impact on certain riders (gender, income group and race). • Using the agency’s 2002 on-board survey data, it acknowledged that certain of the riders’ characteristics (such as income, age, and trip purpose) make them more sensitive to price changes than others. In particular, the impacts from the proposal that eliminates passes have the least favorable and highly regressive impacts on minority groups.

Complementing the examples given in the previous table, further cases can be mentioned. For example Pucher (1981) found that transit subsidies in the United States as a whole redistribute income from high-income to low-income classes and thus reduce inequality. He pointed out that there exist different ways to increase the progressivity of transit programs (i.e discount transit passes for the less wealthy people, improving the service in low-income neighborhoods) but these strategies may conflict with other objectives of the transit program. Additionally, Guzman et al. (2017) recently conducted an analysis of a new transport subsidy implemented in Bogotá (Colombia) aimed at alleviating the financial burden of lower-income households for accessing the city's public transport system. By using potential accessibility measures to employment opportunities, this analysis showed that "the current structure of the pro-poor subsidies in Bogotá is progressive" (p.1).

Conversely, other authors have concluded that transport subsidies show either a neutral or regressive distributive impact. For example, a research project conducted by the World Bank analyzed the incidence of transport subsidies in different contexts —such as Buenos Aires (Argentina), Mexico City (Mexico), Santiago (Chile) and Mumbai (India)— finding that these policies are not doing much for the disadvantaged groups in terms of income. With the exception of a direct transfer implemented in Chile, all transport subsidies reviewed show either a neutral or regressive distributive impact (Serebrisky et al., 2009). Similar results were found by Gómez-Lobo (2009) and Frankena (1973) who evaluated several public transport subsidies in the case of Chile and Canada, respectively. Both studies conclude that despite transport subsidies are justified on social grounds, the net effect of subsidization is often quite regressive and that low-income groups do not benefit in general terms.

Scarce contributions aimed at analyzing social impacts in transport policy appraisal, bring to the fore the need for further efforts to analyse whether categorical transport subsidies and fare policies are equitable and tend to favor economically and socially disadvantaged groups. Additionally, inconclusive results obtained from the existing literature regarding the progressive or regressive

nature of the transport policy in question reinforce this research gap. Therefore, the following research questions are established:

RQ1: How to measure the social and distributional impacts of fares and subsidy policies in urban transport? Is it possible to implement transport subsidies with a progressive distribution of benefits?

In order to deeply explore the impact of fare subsidization on vertical equity, it should be useful to analyse an extreme case. In this respect, the City of Madrid in Spain represents a very interesting case in the international context because of the following reasons:

- First of all, urban public transport in Spanish cities is highly subsidized and, for the particular case of Madrid, there has been a need for increasing the amount of public transport subsidies over the years (see previous Figure 1.2). As Matas (2004) pointed out, despite succeeding in reversing the declining patronage trend of public transportation in the city of Madrid, the introduction of the travel card “tended to require an increasing financial support that was not always available” (Matas, 2004, p.212). Moreover, since the public sector is currently facing budget cuts, it is also important to evaluate—together with equity concerns—the impact on revenue derived from this subsidy policy.
- Second, since the introduction of an integrated fare system for the whole public transport network in Madrid in 1987, there has been very little analysis of the distributional incidence of this highly subsidized fare. However, some studies examined how users respond to changes in prices and service characteristics in the Madrid Metropolitan Area (Garcia-Ferrer et al., 2006), and evaluated the impact on revenue due to the introduction of this travel card (Matas, 2004). A broad analysis of urban public transport policy funding in Madrid looked at the evolution of public transport subsidies through 1995-2005 and their relationship with equity aspects (Vassallo et al., 2009). The authors found that in the City of Madrid, the lower the income level, the higher the use of the travel pass. However, this

study was conducted at the macro level so it did not obtain disaggregated conclusions from the equity perspective.

- Third, according to the Gini index, Madrid is one of the most unequal capital cities in Europe (Musterd et al., 2015). This socio-economic segregation underlines the importance of evaluating whether all population segments are fairly treated with regard to the provision of transport subsidies in the city.
- Finally, as mentioned above, only a few studies have looked at the equity of transit fare policies. This type of analysis may help transport planners to evaluate whether fare policies on urban public transport meet their social objectives, and to determine to what extent transport subsidies promote social inclusion with regard to income.

Social efficiency of subsidy mechanisms for commuters

Subsidy policies on transport have been implemented on the basis of different premises, including addressing externalities, increasing the use of sustainable modes, or making transport more affordable to low-income individuals or to specific groups. Under the latter objective, a number of benefits for riding transit or vanpooling have been offered to employees in many different contexts such as USA —see for example Hamre and Buehler (2013), Canada—see for example Washbrook et al. (2006), New Zealand —see for example Scott et al. (2012) and The Netherlands—see for example Heinen et al. (2013).

These benefits —often referred to as ‘commuter benefits’— can be defined as any option or set of options which employers provide to employees, including benefits for driving (e.g., toll payments, subsidized parking), using public transportation (e.g., monthly passes, universal passes, or vouchers), and walking or cycling (e.g., financial incentives for bicycling or walking, or secure bike parking). Transit benefits program are considered to be advantageous for transit authorities (since they increase transit ridership and reduce costs associated with cash handling and individual fare transactions), as well as for employers and employees (generally, both of them reduce their contribution on income taxes).

Commuter benefits are aimed at influencing the travel behavior of workers, thus reducing the share of employees driving to work alone through various incentives, disincentives, or marketing tools (Dill and Wardell, 2007). In fact, there has been an increasing recognition that these options may effectively persuade and induce workers to change their transportation habits. Consequently, several evaluations have sought to explain the effect of employer-paid benefits such as free parking (Shoup and Willson, 1992; Hess, 2001) and free and discounted transit pricing on commute mode choice (Zhou and Schweitzer, 2011; Boyle, 2010).

Overall, transit benefits packages are implemented as transportation demand management (TDM) programs, and therefore they are basically geared towards improving the efficiency of travel demand. Some of these strategies are effective means of increasing transit ridership, reducing car dependence and related problems such as air pollution and traffic congestion, reducing employee parking demand and rising transport authority revenues. However, the impacts on employee travel behavior are not as well understood and little rigorous research has been conducted on the topic (Transit Cooperative Research Program, 2005).

One possible reason explaining the few studies available, is that Employer TDM programs are sometimes difficult to evaluate because they are diverse in scope and involve individual behavior patterns, which are complex and difficult to model (Dill and Wardell, 2007). In spite of this, some relevant but scarce studies exploring the impacts of commuter benefits addressed to public transport, private transport, walking and cycling can be found in the literature —see for instance Cass and Faulconbridge (2016); Habibian and Kermanshah (2013); Herzog et al. (2006) or Rotaris and Danielis (2015).

From a detailed review of the current literature, the following conclusions can be pointed out:

- Most of the studies only quantify ridership growth once transit benefits are applied, but they hardly ever study commuter benefits as a driver that may influence transport mode choice. In addition, to the best of the author's knowledge, no substantive study has focused on the vertical equity impact of these benefits. Equity should be also an important consideration from a

social standpoint in order to insure that all employees —particularly low-income and minority groups— receive equal treatment with regard to the provision of commuter benefits.

- Previous studies —with few exceptions, such as the one conducted by Hamre and Buehler (2014)— are based on surveys conducted to transit benefits recipients instead of wider revealed preference travel data from household surveys. These kinds of studies may introduce potential bias in the results. There is a need to adopt approaches which allow examine, through statistically significant models, to what extent individual characteristics, household attributes and, certainly, transport-related factors such as commuter benefits influence the willingness to switch or stay from driving alone. Through this type of analysis, it becomes possible to understand, e.g. how differences between wealthy and nonwealthy people appear to explain commuter modal variability when controlling for other potential explanatory factors.
- In line with the previous comment, some travel behavior analyses have explored the influence of the income effect in mode choice as part of the explanatory factors. Nevertheless, social and distributive analyses of modal split —particularly with respect to lower-income groups and neighbourhoods— are not well documented within the literature. Given their applicability in transport appraisal guidance or social justice analysis, exploring the links between social exclusion and transport mode choice is an important area for further research (Markovich and Lucas, 2011).
- Given the fact that most of studies on the commuter mode choice are not built on the basis of completely disaggregated surveys, they are not able to capture, simultaneously, the separate effect of benefits for driving, public transportation, and walking or cycling on commuter mode choice. As a result, these studies do not provide detailed information on shifts in travel behavior.
- Lastly, most previous studies in this field have included some ways to incorporate transit access as a variable explaining mode choice. Generally, this aspect has been introduced through either dummy variables indicating whether people live near or not to a transit station, or proxy variables based

on the number of transit stations located in the residential traffic analysis zone (Dill and Wardell, 2007; Hamre and Buehler, 2014). This analysis may be extended by conducting a more thorough approach for assessing accessibility.

In this context, the questions that arise from this point are:

RQ2: To what extent the TDM programs based on providing transportation subsidies and benefits to employees can incentivize changes in daily travel behavior? Are user's decisions on daily mode choice influenced by income levels?

In order to deeply explore the relationships between commuter benefits and mode choice, as well as income level and mode choice, it is particularly suitable to cover an interesting case in the international context in relation to the impact of transit benefits on employees' travel behavior: the States of New York (NY) and New Jersey (NJ) in the United States (US). They represent a case of particular interest because of the following reasons:

- Since American cities still have one of the highest motorization rates in the world, driving is the primary travel mode in most of them —89% of all trips, according to the findings from the National Household Travel Survey (US Department of Transportation, 2006).
- The evolution of employer TDM measures in the United States makes this case study relevant for debating over the effects of introducing transit benefits on employees' travel behavior. Despite the widespread implementation of transit and vanpool benefits all over the US, there is still only a limited evaluation of the influence that transit benefits offered to employees may have on their use of public transportation, neither is there in-depth quantitative assessment of its impact on commuter mode choice.
- The case is relevant when exploring the links between social exclusion and mode choice since a trend towards inequality can be observed when analyzing the income distribution within both states. At this point, a lower concentration of households at the high end of the earnings distribution is noticeable in both states as well as in the nation as a whole.

- Since there is a need to promote a more sustainable commuting pattern in major urban centers in the United States, commuter benefits in the New York and New Jersey Metropolitan Area—one of the most cited examples of commuter benefits—and their impacts on employee travel behavior becomes a case study of great interest in the international context.
- Furthermore, under the new law (effective from January, 2016), employers with 20 or more full-time employees have the obligation to offer commuter benefits to their workers. According to the Forbes Magazine (2016), it means that an estimated 450,000 more New York City-based employees will have access to these programs, in addition to the 700,000 employees who already participate in these types of programs.

1.2.2 Perceived fairness of transport policies: The case of road pricing

A strong relationship between equity and acceptability is generally assumed since the latter may reflect an overall sentiment of fairness towards a policy initiative. As Levinson (2010) argue, equity is an essential element among effectiveness, acceptability and implementability. For this reason, many scholars have suggested considering the fairness of the policy to be implemented as an approach for overcoming the public resistance (Grisolía et al., 2015; Jakobsson et al., 2000).

Regarding the transport sector, this is especially relevant in the case of road charging strategies, a transportation policy advocated by economists for decades (Pigou, 1912; Vickrey, 1955) and still representing one of the most debated topics for transportation planners and researchers.

As pointed out by Cao et al. (2014), the implementation of road pricing mechanisms has proven to be an effective instrument in achieving the objectives of congestion relief, environmental improvements and revenue generation to face public budget constraints. However, one of the major obstacles for its widespread implementation is its still scarce public acceptability (Kockelman et al., 2012). As previous works have evidenced, public attitudes towards road pricing are rather negative and often quite low—see for example Gaunt et al. (2007); Harsman et al. (2000); Link and Polak (2001); Luk and Chung (1997); Morris and Bird (2006) or Schade and Schlag (2001).

Numerous publications and academic research have examined attitudes towards road pricing strategies —see for example Jakobsson et al. (2000) and Jones (1998). At the European level, it is also noticeable the numerous projects launched by the European Commission within the so-called Framework Programmes (FP). Table 1.2 presents a descriptive summary of some the most relevant projects that have addressed the public acceptability towards the concept of road pricing within that context.

Table 1.2 Summary of European Projects for infrastructure pricing and its acceptance

Acronym	Full name	Objectives	Main Results
PRIMA 1999-2000	Pricing methodologies acceptance	Evaluate different design elements of interurban road pricing schemes in terms of feasibility and acceptance.	Guidelines for removing barriers to implementation. It concludes that public attitudes towards road pricing are rather negative.
OPTIMA 1995-1997	Optimisation of policies for transport integration in metropolitan areas	Assess the feasibility and acceptability of the implementation of different urban transport and land use strategies.	Identification of economically efficient and sustainable strategies such as low cost improvements to road capacity, improvements in public transport and increases in the cost of car use.
PATS 1999-2000	Pricing acceptability in the transport sector	Identify reasons behind the acceptance of new forms of transport pricing, and find ways of increasing their acceptability.	Acceptability of transport pricing may be more dependent on practical issues, convictions and beliefs than on economic variables (e.g. transparency in handling the revenues).
AFFORD 1998-1999	Acceptability of fiscal and financial measures and organizational requirements for demand management	Demonstrate that marginal social costs based on pricing measures are both efficient and feasible.	Despite pricing was perceived to be effective, empirical analysis shows that current acceptability is rather low. The factors that mostly influence the level of acceptability were social norms, expected personal outcome and perceived effectiveness of the instrument.
DESIRE 2000-2003	Design for interurban road pricing schemes in Europe	Practical assessment of the effectiveness of distance-based interurban road pricing in Europe (focusing on heavy vehicles).	A systematic review of previous research in order to agree on a comprehensive harmonisation of concepts and terms. In addition, it estimates the impacts of the application of tolls on freight transport.
FATIMA 1997-1998	Financial assistance for transport integration in metropolitan areas	Identify differences between urban transport strategies optimised using public funds and those requiring private funding.	Recommendations for the design of optimal transport strategies and the role of the private sector (e.g. distinction between peak and off-peak charges and fares, among others).
PRoGRESS 2000-2004	Pricing road use for greater responsibility, efficiency and sustainability in cities	Evaluate the acceptance and effectiveness of urban transport pricing schemes in achieving transport and social goals and raising revenue.	Some key recommendations: (i) present road pricing as part of a strategy, (ii) consider running trials as a first step, (iii) provide useful information on the scheme objectives, (iv) focus on traffic behaviour, rather than political issues.
EUROPrice 1997-1999	Energy efficiency of urban road pricing investigation in capitals of Europe	Assess the fuel saving potential of urban road pricing schemes in several European capital cities and to test public acceptability, interoperability and energy efficiency implications.	Road pricing pilot-actions and/or pricing effects modelling in the following european capital cities: Dublin, London, Athens and Budapest.

Source: Authors' elaboration based on DESIRE (2001); European Commission (2015); and MOBIDAYS (2010).

Among the previous studies, it is commonly agreed that gaining support toward road pricing constitutes one of the main policy objectives for a broader implementation of these schemes —see Fujii et al. (2004); Jakobsson et al. (2000); and Schade and Baum (2007). In this respect, some experiences such as Costa Rica —see Vassallo (2015)— or China —see Jones (1995)— testify that road pricing can rarely be imposed against the public will. However, the literature has shown that pricing is more acceptable: a) if the purpose and the benefits coming from this policy are clearly understood; b) if the objectives of the scheme meet public concerns such as environmental issues, and c) if revenues are spent in the transport sector —see for example Gaunt et al. (2007) and Odeck and Bråthen (2002). A reasonable allocation of revenues or the appropriate compensation to the losers is expected to increase the perceived sentiment of fairness.

There are a number of factors that may influence the acceptability towards road pricing such as socio-demographic characteristics, trip-related attributes, attitudinal variables, and other factors such as attributes of the pricing scheme (Steg et al., 2003). In this respect, the type of pricing scheme may play an important role in the issue of public acceptance. However, current evidence on the relationship between public acceptance and different charging schemes is inconclusive and has not been analyzed in detail (May et al., 2010; Jaensirisak et al., 2005). Despite of this fact, previous research works have shown that, in general, more complex schemes are likely to be less acceptable (Gómez et al., 2016; Zmud and Arce, 2008; Vrtic et al., 2007).

Similarly, the literature has not generally led to conclusive and coincident results about the influence of the income effect on users' attitudes. Some research works have not confirmed the relationship between the support for pricing options and the level of income (Dill and Weinstein, 2007; Rienstra et. al., 1999), while many others found that the higher the income, the more positive the users' attitudes towards toll roads (Odeck and Kjekreit, 2010).

Regarding the factors influencing public support to transport policies, equity arises as a central element for making road pricing politically and publicly acceptable (Oberholzer-Gee and Weck-Hannemann, 2002; Viegas, 2001). At this point, equity concerns are considered as one of the most relevant objections to

charging schemes (Levinson, 2010). This is due to the fact that transport pricing measures are mostly considered regressive since they tend to have (in relative terms) more burdensome effects on individuals with lower incomes, relative to those with higher incomes (Franklin, 2006). In this line, the analysis of social impacts and equity implications of road user fees has been mainly focused on the additional burdens coming from these measures. In general, previous contributions have suggested that the higher the level of income, the less important the additional burden from road pricing charges (PATS, 2001), thus interpreted pricing policies as regressive in terms of income distribution. For instance, the study conducted by Teubel (2000) in Dresden obtained the absolute and relative welfare losses or gains of a commuter caused by road pricing and found that the introduction of the scheme charges less-wealthy individuals relatively more than the rich.

However, as mentioned by Levinson (2010) in what is the most comprehensive literature review conducted on the equity effects of road pricing: whether road pricing is regressive or progressive depends on circumstances and the regressivity can be mitigated by certain strategies such as redistributing collected toll revenue. In fact, other research pieces have shown that pricing can be progressive rather than regressive— see for example Banister (2002); Eliasson and Mattsson (2006); or Steininger et al. (2007).

As can be seen, the literature review showed a significant body of research regarding public acceptability. However there are still many points to address. Firstly, there is no consensus in the literature about the influence of personal characteristics and attitudinal factors on users' acceptability, which is essential to provide good guidance for policy-makers. Indeed, the effect of road pricing on low-income travellers is unclear and the answer to the question of equity in tolling is indeterminate in general. Secondly, the fundamental issue of the influence of different road pricing schemes on acceptability has not received great attention in the academic literature, as recognized by Jaensirisak et al. (2005). Specifically there is a need to explore how the adoption of a different charging scheme may contribute to change users' acceptability for those road facilities already tolled. Thirdly, previous research works have been mainly focused on urban areas,

showing particular interest into the implementation of congestion charging systems (Dieplinger and Fürst, 2014; Hao et al., 2013), while large scale acceptability studies specifically focused on interurban roads are particularly limited (Schade, 2002).

Then, in the light of the previous considerations, the following research questions are established:

RQ3: What are the factors influencing public acceptability towards different road pricing schemes? Are perceptions of fairness towards road schemes determined by the level of income?

In this regard, it may be useful to explore acceptability towards alternative schemes for a toll network already in operation. This may contribute to the limited literature in this field by exploring perceptions towards different road pricing schemes, for those users already utilizing a charged road. At this point, the Spanish case —not studied in great detail before in this field— is an interesting case study given:

- Its importance in length, since it is one of the longest national tolled networks in the world, and
- Its historical evolution, since the current network is asymmetrically distributed throughout the territory.

Furthermore, it is worth mentioning that this case is also useful for a better understanding of the vertical equity of road pricing, since low-income travellers do not lack alternatives to undertake their trips. This is due to the fact that, in Spain, toll roads generally have a free parallel road competing with them within the same corridor.

1.3 The role of social impacts in transport decision-making

There is also a dilemma about the assessment of transport policies: whether it is really a matter for decision-making or it is more a part of an evaluation *ex post*. This fact has not yet been treated in detail yet in the literature, and it is possible to find both *ex-ante* assessments (appraisals) and *ex-post* assessments (evaluations)

of transport policies. Since the primary purpose of social and distributional assessments is to ensure that all people receive an equitable distribution of impacts throughout the lifetime of a given policy, it should start with the appraisal and decision-making, because, decision-makers have great influence on the future performance of the policy at this point. In other words, implementing social principles become more effective at the planning stage than as part of an ex-post evaluation. By contrast, evaluating the social impacts of an already existing policy can be useful to “recycle” best practices and procedures in future decisions, and thereby help ameliorate social exclusion by proposing measures to mitigate it.

In view of the above considerations, this section focuses specifically on the appraisal process of transport policies. Firstly, a discussion of the importance of social and distributional impacts within the sustainability framework is presented, along with an overview of the concept of sustainability —comprising economic, ecological and social aspects (sub-section 1.3.1). Secondly, the integration of social impacts into the state of the practice of transport policy appraisal and its priority —weight— versus other sustainability criteria is examined (sub-section 1.3.2).

1.3.1 The role of social impacts in the sustainability framework

Although there has been major progress in the assessment of social impacts of transport, equity considerations are still lacking in transport appraisal guides and practices (Thomopoulos et al., 2009). One of the main difficulties to undertake thorough ex-ante assessments relies in the fact that social impacts of transport have been underexposed in transport appraisal (Geurs et al., 2009). This may be due to a lack of understanding of the role of social impacts within transport decision-making as well as the difficulty of identifying and estimating them with precision.

Social impacts are an important dimension of sustainability, encompassing a holistic consideration of economic, social, and environmental aspects with a long-term perspective. A transport policy will be considered sustainable when it contributes to favour economic development and fulfill the transportation needs of the society in a manner consistent with natural laws and human values —including equity over generations. This allows concluding that the concept of sustainability

will not make sense without considering the complete triple bottom line view, then the relevance of social impacts arises at this point.

However, social impact appraisal frequently receives little attention in the literature, although these impacts —particularly the distribution of costs and benefits of a transport policy across population groups and regions— often receive much public and political attention in decision-making processes (Geurs et al., 2009). As these authors pointed out, one possible reason is that social impacts can take on many forms, some of which are particularly difficult to estimate with any precision. Furthermore, these methodologies have often been less well developed than economic and environmental assessment approaches. As an example, today there is no standardized method to evaluate social and distributional effects of transport interventions.

A study developed by the Evaluation Partnership and the Centre For European Policy Studies (TEP and CEPS, 2010) found some limitations that have to be addressed in order to set up an effective social assessment:

- The term ‘social impacts’ is potentially too broad and has not been well defined yet;
- The lack of appropriate tools to assess social impacts quantitatively is one of the most frequently cited challenges to effectively carry out social impact assessment. Most social assessments remain purely qualitative, and often very superficial.

However, as Forkenbrock et al. (2001) pointed out, there are a number of methodologies for assessing social and distributive effects associated to a transport intervention, including those elaborated by scholars — see for example Forkenbrock et al. (2001) and Sinha and Labi (2007). Based on this study, the authors confirmed that existing work analyzing the social and distributional effects of changes in the transportation system is limited, and that the profession is better equipped to assess economic effects than social effects.

Overall, transport projects and policies are appraised in practice through a number of tools or methodological frameworks that include the assessment of

social impacts to a greater or lesser extent. Current approaches can be broadly grouped into three main categories:

- The first group comprises traditional decision-making techniques and includes cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria decision analysis (MCDA), the social life-cycle assessment (SLCA), and others;
- The second group includes sustainability rating systems that grade and score the sustainability performance of transport projects, including the social aspects;
- The third group, more general, covers the frameworks, guidelines, as well as indicators and other developed approaches for the social assessment of transport schemes and policies. This category includes tools and methods such as risk analysis, geographic information systems (GIS) and comprehensive economic models.

Table 1.3 presents the main strengths and weaknesses of the most common used appraisal tools, after examining how they handle social and distributional impacts. Some references supporting the analysis are shown in the *reference* column included in the table. A more detailed description and evaluation of the appropriateness of available tools for assessing transport projects and policies according to the social principles is beyond the scope of this introduction. Interested readers are referred to European Commission (2014), Forkenbrock et al. (2001), and Markovich and Lucas (2011). These reports provide a comprehensive view of existing methods, tools, and techniques currently available for assessing the social and economic effects that may arise from a transportation project.

Table 1.3 Performance of current tools in the context of accounting for social impacts

Tool	Strengths	Weaknesses	References
Cost benefit analysis (CBA)	<ul style="list-style-type: none"> · A known and widely used technique to support decision-makers in appraising transport projects and policies. · It offers valuable support since it is a rigorous, transparent and formal appraisal tool. 	<ul style="list-style-type: none"> · The monetization is questionable for intangible items. · Limited considerations regarding distributional equity (tends to ignore the distribution of burdens and benefits). · The intertemporal aggregation is still contentious for non-market goods. 	<ul style="list-style-type: none"> · European Commission (2014) · Omura (2004) · Mackie and Preston (1998) · Niemeyer and Spash (2001)
Cost-effectiveness analysis (CEA)	<ul style="list-style-type: none"> · It is becoming more widely used in transport policy analysis, and allows decision-makers to take evidence-based decisions on comparing policy options. · It ensures that goals will be achieved at the least possible cost and the most efficient way. 	<ul style="list-style-type: none"> · Limited to identify the best policy option for achieving a single defined objective, then not suitable to evaluate a policy with variety of potential benefits. · The inclusion of social aspects has been marginal compared to the attention given to the economic and environmental dimensions. 	<ul style="list-style-type: none"> · Browne and Ryan (2011) · Kampman et al. (2006) · Labuschagne and Brent (2006)
Multi-criteria decision analysis (MCDA)	<ul style="list-style-type: none"> · It offers a number of advantages for policy and planning analysis, compared to conventional economic welfare techniques. · The possibility of simultaneously take into account criteria of different nature—including those difficult to monetize/quantify. 	<ul style="list-style-type: none"> · The assessment process tends to become highly subjective. · The complexity of identifying impacts to be included and its measurement method. · The process for obtaining the relative importance of different criteria (weights) might appear questionable. 	<ul style="list-style-type: none"> · Munda (1995) · Thomopoulos et al. (2009) · Sayers et al. (2003) · Browne and Ryan (2011)
Social life-cycle assessment (SLCA)	<ul style="list-style-type: none"> · Increasing interest for the standard inclusion of social aspects into the environmental life cycle assessment. 	<ul style="list-style-type: none"> · The inclusion of social aspects into the life-cycle assessment is still under progress. · SLCA methodologies are in an early stage of development where consensus building still has a long way to go. 	<ul style="list-style-type: none"> · Jørgensen et al. (2008) · Hauschild et al. (2008)
Rating systems	<ul style="list-style-type: none"> · They are a collection of best practices, useful for practitioners in incorporating economic, environmental and social principles together. · Provide guidance and constitute a good basis for setting credible social criteria of transport projects. 	<ul style="list-style-type: none"> · They lack transparency and objectiveness in the definition of criteria and selection of weightings, which are not based on standardized methods. · In practice, they are mostly focused on environmental issues related to construction processes and materials. 	<ul style="list-style-type: none"> · Lee et al. (2011) · Hirsch (2012)
Appraisal Guidelines*	<ul style="list-style-type: none"> · They represent best practice transport appraisal guidance, providing expert advice for transport policies with regards to sustainability. · Highly effective tools for identifying and quantifying sustainability impacts of transport projects and standardize the approach using detailed appraisal procedures. 	<ul style="list-style-type: none"> · Approaches targeted at the evaluation process rather than at the decision-making appraisal. · They do not provide mechanisms for comparing all multiple trade-offs among impacts. · The social and distributional impacts continue to be based mostly on a simple qualitative approach and little guidance on the evaluation of the distribution of impacts among population groups. 	<ul style="list-style-type: none"> · UK Department for Transport (2017) · Geurs et al. (2009)

*Appraisal guidelines included in this table refer to two of the most prominent guidelines available in Europe: (i) the UK Department of Transport analysis guidance—WebTAG, and (ii) the Scottish transport appraisal guidance—STAG.

From an overall standpoint, these tools are valuable for helping decision-makers meet social targets within their specific scope. However, as the *weaknesses* column evidences in Table 1.3, there is still room for improvement in the effectiveness of current assessment tools. The main limitation is the lack of standardized methods for evaluating the social and distributional effects of public policies. As mentioned by Sinha and Labi (2007) “compared to the most other types of transportation system impacts, social and cultural impacts is a relatively inexact science”.

As shown by the literature review, although there has been a growing interest in addressing the triple bottom line concept (which includes equity) in transport appraisals, the comprehensive sustainability appraisal of transport policies and interventions is still an unresolved matter. Particularly:

- The concept of sustainability is still far from being well-defined.
- There is currently no standardised or commonly agreed methodology offering a holistic consideration of economic, social and environmental aspects when appraising and evaluating transport interventions — see George (2001) and Stamford and Azapagic (2011).
- There is still room for improvement in the effectiveness of current tools for project appraisal. Since they are mostly biased towards either an environmental or an economic assessment, they fail to address sustainability thoroughly, being overly focused on certain dimensions of sustainability and having difficulties in including social and distributional impacts.
- As can be concluded from Table 1.3, there is a need to improve the potential role of social impacts in decision-making and to conduct research to improve the methodological soundness of social impact assessments (Geurs et al., 2009). Despite transport appraisals increasingly address the three components of sustainability, social and distributional impacts have remained relatively unexplored.

On the basis of these drawbacks, it seems that additional research for a more comprehensive framework on the topic of transport evaluation is essential. In

particular, the following research questions (RQ) are established with a special focus on the social dimension.

RQ4: Which are the sine qua non requirements for a tool to become appropriate for appraising sustainability according to the equity principles? Are available tools for assessing transport projects and policies appropriate according to the sustainability principles?

1.3.2 Incorporating social and distributional impacts in the appraisal of transport projects and policies

Once the role of social and distributional impacts in ex-ante assessments is understood, and in order to undertake a complete sustainability assessment, a new need arises for integrating them into the existing appraisal process of transport policies. To that end, it should be necessary to set the weights of different sustainability criteria (including the three dimensions of sustainability: social, economic and ecological) in order to measure their relative impact in a better way. Setting up clear trade-offs implies understanding the extent to which the worsening of a certain sustainability item might be offset by the improving of another one.

After the social impacts of a transport planning decision have been identified and quantified/qualified, they should be considered in transport appraisals, as a key part of the sustainable agenda. A central task of this process is to ensure that proper consideration of social and distributional impacts takes place within the sustainability assessment framework. To that end, the appraisal process should identify the importance of the social criteria (weight) in comparison to those criteria related to environmental or economic impacts.

With regards to the evaluation of the weights, it should be pointed out that despite the numerous sustainability tools available, none of them seems to be useful for determining the weights to rank different criteria in a thorough way. While there are positive characteristics associated with each tool, some practical issues remain unsolved, particularly regarding trading-off different sustainability dimensions. The tools mentioned above did not succeed in fulfilling the

requirement of using analytical and rigorous approaches for comparing all trade-offs among economic, environmental and social aspects, particularly:

- CBA has well-known limitations when converting non-economic values into monetary terms (Beria et al., 2012). Considerable research would be needed to place monetary values on non-market goods (such as travel-time savings, CO₂ emissions, road accidents or social impacts) —if it is possible at all. An arbitrary monetization of social and environmental impacts may lead to an erroneous assumption regarding the relative importance of these items versus others with market prices (such as infrastructure costs).
- In CEA, the objective of transport policies is defined in one single dimension, and therefore, it is not a suitable tool for evaluating different policy options with impacts in several dimensions. When measuring the performance of policy alternatives towards multiple objectives, the analysis is called weighted cost effectiveness or Multi-Criteria Analysis (Mackie et al., 2005). For its part, MCDA can introduce subjectivity when evaluating the weights selected to different criteria (Barfod et al., 2011; Beria et al., 2011)— in fact, the use of weights is the main unresolved matter of this methodology. Qualitative assessment and the imputation of value-laden weightings to assumptions may lead to subjective and non-transparent biasing —see Munda (2004) and White and Lee (2009).
- Similarly, rating systems and models lack transparency and objectiveness in the selection of criteria and weighting process (Lee et al., 2011). The selection of weightings are not based on standardized methods of performance measurement since they are mainly based on non-representative data instead of surveys which allow building statistically significant weighting exercises.
- Finally, despite the usefulness of appraisal guidelines for identifying and quantifying sustainability impacts of transport projects, they usually do not provide mechanisms for comparing all multiple trade-offs among impacts. In this respect, they represent a full account of impacts, including monetized, quantified and qualified ones, in form of ‘summary tables’, but they do not come up with a final aggregated value. Because of this drawback, the

selection process of the most suitable alternative may be based on subjective judgments. Since no weighting information is provided in these guidelines decision-makers must apply their own judgement when weighing the impacts to reach a final assessment of a proposal (Geurs et al., 2009).

In summary, until now “decision-aiding techniques do not overcome the problem associated with incomparable quantities” (Browne and Ryan, 2011). Despite the tension between ecological, social and economic perspectives on sustainability, very few studies can be found in the literature addressing the issue of valuing all these attributes in the same analysis. Here, it is worth mentioning a research work conducted by López (2007), who developed a methodology —based on the use of spatial impact analysis tools— for complementing traditional assessment methodologies of transport infrastructure plans integrating three different criteria: efficiency (network efficiency and cross-border integration), cohesion (regional cohesion and social cohesion) and environmental sustainability aspects (global warming and habitat fragmentation). Other examples in the literature include particular studies for determining the trade-off between two specific effects such as environmental care and long-term growth —see Gradus and Smulders (1993); capital accumulation and environmental quality—see Becker (1982); or trade-offs between two specific dimensions of sustainability such as economic growth and environmental quality —see Den Butter and Verbruggen (1994)— or environmental protection versus economic development —see Feiock and Stream (2001).

Given the fact that, as far as the author of this Thesis is aware, there are scarce previous studies considering the analysis of the relative importance of all the sustainability criteria in transport planning decisions —including social equity issues— and, recognizing the importance of weighting the impacts for a rigorous and objective assessment, a research gap can be identified. It has to do with the definition of a transparent approach for determining the relative impact of each sustainability item. For an appropriate sustainability assessment, it is necessary to determine priorities for sustainability items (called criteria weights) based on a standard, transparent and consistent methodology to properly embed economic,

environmental and social equity issues into the appraisal process. More specifically, the following research need is defined:

RQ5: How to effectively evaluate the trade-offs among social, economic and environmental aspects in transport projects and policies as appropriate matters for social concern?

In order to explore this issue, it should be useful to focus on one of the most common forms of appraisal of transport systems and infrastructure: the Multi-Criteria Decision Analysis (Bristow and Nellthorp, 2000), which is the most appropriate tool to adopt decisions based on an integrated sustainability approach (Hyard, 2012; Munda et al., 1998; Walker, 2010). Furthermore, one of the main problems of this widely used technique is precisely setting the weights to different criteria in a transparent and precise way. In that respect, studying the issue of criteria weightings through this technique may contribute to the literature by reducing the subjectivity and making the decision process more rational and accountable.

1.4 Objective and research questions of the Thesis

Based on the above considerations, the overarching objective of this Thesis is to review, assess and evaluate the social impacts of existing transportation policies and their potential equity consequences from the sustainability viewpoint. The results from this research can help policy-makers and practicing planners with regard to the promotion of more efficient and socially inclusive transport policies.

The four specific objectives of this Thesis are the following:

- (i) Obtain lessons about the incidence of different transportation policies (e.g. transport subsidies, transport benefits, and road pricing) on social inclusion, particularly on income distribution;
- (ii) Understand the three-dimensional concept of sustainability—including the most relevant tools for its assessment—and the role of social impacts within the sustainability framework;
- (iii) Explore the integration of social and distributional impacts into the existing appraisal process; and,

- (iv) Draw policy recommendations based on the analysis and findings from (i) to (iii) above, in order to provide useful and practical suggestions for local transport planners when evaluating policies, specifically in meeting social objectives.

As a starting point, the Thesis develops different analyses of transport policies as case studies —based on data availability—to give a broad overview of the effectiveness of these strategies in reaching lower-income people and their distributional effects. Subsequently, the research provides a comprehensive framework on the topic of transport appraisal, making visible the importance of the social dimension and still unresolved issues. Finally, the Thesis explores how to integrate the social impacts of a transport policy into the existing appraisal process by setting up clear trade-offs among the three dimensions of sustainability (social sustainability, economic growth and environmental quality).

In particular, this dissertation studied three different policy alternatives. In this regard, extreme policies options were selected: two usually progressive with respect to income —i.e those favoring disadvantaged people—and other generally typically assumed to be regressive —i.e those that specially burden disadvantaged groups.

Within the first category, two different policy interventions were chosen: (i) public transport fare subsidies and (ii) the provision of transport subsidies and benefits to commuters. In the second group, different road pricing strategies were considered. This policy was adopted to investigate the question of regressivity since the impact on low-income car owners is usually regressive —even though the regressiveness of road pricing depends on circumstances (Levinson, 2010). Therefore, particular attention was given to the role of income effects in (i) public transport use, (ii) the mode choice for commuting trips, and (iii) the public acceptability towards different pricing schemes.

To achieve these objectives, five specific questions stated above need to be answered. These are developed in different academic papers, namely:

RQ1: How to measure the social and distributional impacts of fares and subsidy policies in urban transport? Is it possible to implement transport subsidies with a progressive distribution of benefits?

Despite the widespread implementation of urban transport subsidies in many cities, there is still only a limited evaluation of the equity of these policies, and scarce quantitative assessment of their distributional incidence. Since only a few authors have looked at equity aspects of transit fare policies per se, this study adds evidence and contributes to fill this research gap in the literature. It will develop a feasible assessment methodology for measuring the social and distributional effects of a given public transport fare and subsidy policy. By exploring the equity implications of the mentioned policy, the aim of this research work is to determine whether it provides benefits to the people in most need, namely low-income groups.

This methodology will be tested in the City of Madrid (Spain), a suitable study area for this type of analysis. The expected contribution of this Thesis to the literature is to analyse whether transport subsidies in the city are related to income (vertical equity), and to provide a methodology to quantitatively evaluate the distributional effect of transit fare subsidy. As far as the authors are aware, there are no previous studies analyzing the public transport subsidy policy in Madrid at a disaggregated level.

RQ2: To what extent the TDM programs based on providing transportation subsidies and benefits to employees can incentivize changes in daily travel behavior? Are user's decisions on daily mode choice influenced by their income level?

An important TDM strategy has been providing transportation subsidies and benefits to employees including toll/mileage reimbursements, public transport payments, free car parking and incentives for walking and cycling such as the provision of showers, lockers and bike parking. However, few detailed research works have been conducted on the topic. Previous studies are mainly based on surveys conducted to transit benefits recipients instead of wider revealed preference travel data from regional household surveys, which allow building statistically significant models.

By recognizing the potential of commuter benefits to promote more sustainable transportation habits, it would be necessary to deeply analyse to what

extent these benefits can incentivize changes in daily travel behavior. In light with the main objective of this Thesis, it will also be essential to explore the relative importance of income on mode choice decisions. In this respect, a case study of great interest is selected: the New York and New Jersey Metropolitan Area. This is among the most populated and transit-intensive area in the US, not deeply studied before in the field of transit benefits. The results of this analysis will come up with useful policy implications regarding the promotion of sustainable transport behavior. This study is aimed at contributing to the literature in three ways. First, it provides further insight for a remarkable case in the international context. Second, it is expected to concurrently explore commuter benefits for driving as well as walking, cycling and public transportation, as factors influencing individual decisions to commute. To the author's knowledge, only few works analyzing this fact were reported in the literature. Finally, it will compare the effect of the benefits with other research previously conducted. This is expected to be particularly useful to contrast the results with the existing literature.

RQ3: What are the factors influencing public acceptability towards different road pricing schemes? Are perceptions of fairness towards road schemes determined by the level of income?

Despite the fact that there is a common consensus on the idea that inequity or perceived inequity may reduce public acceptability, the existing literature has evidenced that socioeconomic and transport-related factors are not generally conclusive to explain users' perceptions towards road pricing policies. Particularly for the analysis of social impacts and equity implications, there remains the question of whether road charging should be interpreted as a regressive or progressive policy in terms of income distribution, which is essential to provide good guidance for policy-makers.

Furthermore, there is a need to explore how the adoption of different charging schemes may contribute to change users' acceptability towards those road facilities already tolled. To that end, a feasible methodology will be developed in order to explore perceptions towards different road pricing schemes, for those users already using a charged road. This methodology will be applied to the Spanish toll network, an interesting case given (i) its high capacity network, one of

the longest in Europe, (ii) the marked asymmetry of the interurban high capacity network across regions, (iii) the peculiar fact that each toll road generally has a free parallel road. As far as the author is aware, this methodology has not been used yet to model the acceptability of alternative pricing strategies.

The results from this analysis can help policy-makers and practicing planners with regard to the promotion of more efficient, socially inclusive and publicly acceptable road pricing schemes.

RQ4: Which are the sine qua non requirements for a tool to become appropriate for appraising sustainability according to the equity principles? Are available tools for assessing transport projects and policies appropriate according to the sustainability principles?

As mentioned before, the reason for this research question is that although the concept of sustainability has gained increasing importance, the comprehensive sustainability appraisal of transport interventions is still an unresolved matter. The appropriateness of available tools for assessing transport projects and policies according to the sustainability principles has been barely studied before. To solve this problem a comprehensive review of the current assessment tools of sustainability applied to transport planning decisions will be conducted. This review will provide an explanatory and comparative analysis of the tools and methods in terms of their effectiveness to appraise sustainability, including the social dimension which is the main area of interest of this Thesis. The analysis is aimed at constituting a critical evaluation of the current state of the art to identify the limitations of existing approaches, point out new areas of research, and propose a sustainability appraisal agenda for the future.

On the basis of the literature reviewed above, it will be possible to identify the sine qua non requirements for a tool to become appropriate for appraising sustainability according to the equity principles, focused on applying progressive policy principles. To analyse these tools and methods, the author will review-reporting guidelines, frameworks and relevant academic studies.

RQ5: How to effectively evaluate the trade-offs among social, economic and environmental aspects in transport projects and policies as appropriate matters for social concern?

Until now, the Thesis has acknowledged the importance of implementing a suitable approach to the evaluation of social and distributional impacts of transport policies. However, there is a need for integrating this analysis into the appraisal process. By recognizing the complexity of this research need, we will be focus on a particular but important step to undertake a complete sustainability appraisal: the imputation of weights for social, economic and environmental aspects in order to measure their relative impact.

The question responses to the issue of putting economic, environmental and social aspects together. It has to do with the transparency of judgements and their influence on the final results on a certain sustainability assessment. In that respect, the Thesis will present a possible new methodology for an alternative weighting scheme addressing social equity issues in each context. It will be based on the multi-criteria decision analysis, which is the most appropriate tool to adopt decisions based on an integrated sustainability approach (Hyard, 2012; Munda et al., 1998; Walker, 2010).

The new and transparent method will effectively assist decision-makers in determining the criteria weightings for transport project appraisal. It is expected to have a number of advantages including its simplicity and comprehensibility and its flexibility and ability of replication (the results can be adapted to different real-world applications).

1.5 Research methodology and Thesis structure

The process to achieve the mentioned objectives and to answer the research questions has been structured into different stages. Figure 1.3 shows the interaction among the stages of the research. A short description is detailed in the following bullets:

Stage 1: Analysis of transportation policies as case studies

- Regarding the first transport policy to be analyzed (***transport fare and subsidy policy in the case of Madrid***): Literature review based on the social impacts of transport, especially equity impacts and development and application of a practical approach to evaluate the impact of fare subsidization on vertical equity using the latest disaggregated data from Madrid's Transportation Survey. This work will be culminated in a chapter of conclusions regarding the effects of public transport fare and subsidy policy. To produce aggregated value, a practical approach at the neighborhood level will be conducted for assessing the accessibility to public transport in Madrid (in order to incorporate this variable into the research). As far as the author is concerned, this is one of the few works exploring this issue at such a disaggregated level—jointly with those ones developed by Gutiérrez et al. (2011) and Gutiérrez et al. (2000). However, an extensive evaluation of the transit accessibility is beyond the scope of this research work. Hence, despite these results can be seen to be a good indicator of the overall accessibility in a given neighborhood, the proposed approach should be further improved —see Section 4.4.
- Regarding the second transport policy to be analyzed (***transportation subsidies and benefits to employees in the case of New York and New Jersey***): Literature review on the field of employer benefits programs. On the basis of individual data from a Regional Household Travel Survey (RHTS), the extent to what commute mode choice is influenced by commuter transportation benefits and other relevant socio-economic and transport-related variables will be investigated. A discrete choice approach will be adopted to analyze the impact of different types of commuter benefits on mode choice by comparing motorists with public transport users, pedestrians, and cyclists. The relative importance of additional explanatory variables such as car ownership, accessibility to public transport or income will also be explored. Finally, a set of conclusions will be established regarding these types of measures and their effectiveness to promote more sustainable commuting patterns. To produce aggregated value, a thorough approach is going to be

conducted for assessing accessibility to public transport in the region in order to incorporate this variable into the research. As far as the author is concerned, this is among the first works exploring this issue at such a disaggregated level. Nevertheless, an exhaustive evaluation of the transit accessibility in this Region is beyond the scope of this Thesis. Hence, the practical approach to be applied in this case should be further improved—see Section 4.4.

- Regarding the third transport policy to be analyzed (***acceptability towards Road pricing schemes in the case of Spain***): Literature review on road pricing, its acceptability and equity effects. Based on a nationwide survey conducted to toll road users in Spain, the research will develop several discrete choice models to analyse users' acceptability towards three alternative charging approaches: a surcharge to avoid congestion at any time (express toll lanes), a time-based (peak vs. off-peak) pricing approach, and a flat-fee (vignette). After gaining insight into how toll road users' acceptability might be improved, some policy recommendations as a means of implementing more effective and socially inclusive pricing policies will be established.

Stage 2: Understanding the role of social impacts in decision-making

- Regarding the role of social impacts within the sustainability framework: Review of the concept of sustainability followed by an examination of the literature regarding tools and appraisal methodologies for the ex-ante assessment of transport projects and policies, focused on the social dimension of sustainability. After the critical evaluation, identification of a number of conclusions, final reflections and recommendations for future research areas in this field.
- Regarding the incorporation of social impacts into the sustainability appraisal process: A new and transparent method for effectively assisting decision-makers in determining the criteria weightings for transport project appraisal will be proposed. The novelty of the method is the separate consideration of expert preferences and the objective characteristics of the criteria in the geographical and social context of the project. It has the advantage of allowing, for many road projects (selected example as a case study), the use of the same

consensus based on comparative judgments and preferences results obtained from the survey conducted in this stage.

Stage 3: Conclusions and further research

- Finally, conclusions on practice-oriented and policy recommendations will be drawn and areas for further research in the field will be identified. This stage will also provide a practical set of questions to consider when examining the equity implications of transport subsidies and pricing schemes.

Figure 1.3 Research stages and connection between research questions (RQ) and papers

Source: Author's elaboration

The research questions previously described were addressed through academic papers included in Chapters 2 and 3. The papers are referred to in the text by roman numerals I to V (see Section 1.6). These papers have been published in international journals included in the Journal Citation Report (JCR) index. Consequently, the Thesis is structured into the following 5 chapters containing the

research papers, as well as an introduction to the Thesis theme itself and a final chapter including recommendations, conclusions and further research.

- Chapter 1 is the present introduction, providing a conceptual framework from the study and summarizing the research gaps identified and the main objective of the research.
- Chapter 2 develops an analysis of social equity regarding three common transport planning policies: two related to the public transport fares and the provision of subsidies and the other related to the implementation of pricing strategies. With regards to the first type of policy intervention, it addresses the social and distributive impacts of fares and subsidy policies in urban transport through case studies and identifies the factors influencing daily travel behaviour (**Paper I** and **Paper II**). Furthermore, in connection with the second type of policy, this chapter also develops an analysis of the acceptability towards three different road pricing schemes. Particularly, it presents a policy case to determine the factors influencing public acceptability of different pricing schemes (**Paper III**).
- Chapter 3 provides a comprehensive framework for the topic of transport evaluation, analyses the concept of sustainability according to the equity principles and the current appraisal methods for its assessment (**Paper IV**). It also includes a possible methodology for the incorporation of social and distributional effects of a transport policy into the appraisal process. Particularly, it addresses the question of criteria weighting in a multi-criteria problem (**Paper V**).
- Based on the results of the previous chapters and papers, Chapter 4 is a summary of the main conclusions and contributions of the Thesis. It also includes some future research areas. Finally, Chapter 5 includes a compilation of all references used in the research.

1.6 List of original publications

This Thesis is based on the following papers that have been published in scientific peer-reviewed journals. As a result there is some overlap in the content between

the chapters (papers), which address those research questions previously identified.

The papers are referred in the text by Roman numerals I-V:

- I. **Bueno, P.C.**, Vassallo, J.M., and Herraiz, I. (2016). Social and Distributional Effects of Public Transport Fares and Subsidy Policies: Case of Madrid, Spain. *Transportation Research Record: Journal of the Transportation Research Board* 2544 47-54. doi: 10.3141/2544-06.
- II. **Bueno, P.C.**, Gómez, J, Peters, and Vassallo, J.M., (2017). Understanding the effects of transit benefits on employees' travel behavior: Evidence from the New York-New Jersey Region. *Transportation Research Part A: Policy and Practice* 99 1-13. doi:10.1016/j.tra.2017.02.009.
- III. **Bueno, P.C.**, Gómez, J, and Vassallo, J.M. (2017). Seeking Factors to Increase the Public's Acceptability of Road-Pricing Schemes: Case Study of Spain. *Transportation Research Record: Journal of the Transportation Research Board* 2606 9-17. doi: 10.3141/2606-02.
- IV. **Bueno, P.C.**, Vassallo, J.M., and Cheung, K. (2015). Sustainability Assessment of Transport Infrastructure Projects: a Review of Existing Tools and Methods. *Transport Reviews* 35(5) 622-649. doi: 10.1080/01441647.2015.1041435.
- V. **Bueno, P.C.**, and Vassallo, J.M. (2015). Setting the Weights of Sustainability Criteria for the Appraisal of Transport Projects. *Transport* 30(3) 298-306. doi: 10.3846/16484142.2015.1086890.

2. ANALYSIS OF TRANSPORTATION POLICIES AS CASE STUDIES

2.1 Overview

This chapter analyses the social impacts of three different policies within the transport planning context: two of them related to the public transport fares and the provision of subsidies, and the other related to the acceptability of alternative road pricing schemes. As mentioned in Chapter 1, particular attention is given to the role of income effects in (i) public transport use, (ii) the mode choice for commuting trips, and (iii) users' acceptability towards different pricing schemes.

2.1.1 Public transport fares and subsidy policies

With regards to the first type of policy intervention, this chapter addresses the social and distributive impacts of fares and subsidy policies in urban transport through the following two case studies:

The case of Madrid (Spain)

Despite the widespread implementation of urban transport subsidies in many cities, there is still only a limited evaluation of the equity of these policies, and scarce quantitative assessment of their distributional incidence. This paper (paper I) contributes to filling this gap by developing a practical approach for the evaluation of vertical equity impacts of public transport fares and subsidy policies, taking the City of Madrid (Spain) as case study given its high subsidization rate. A two-step methodology is adopted to conduct this analysis. First, two main indicators are proposed to measure the social impact of the “travel pass”, thus determining the effectiveness of the policy in reaching lower-income citizens. Second, using the latest disaggregated data from Madrid's Transportation Survey, a multiple regression model was performed to understand the factors that could explain the level of travel pass usage in the city. Particular attention is paid to the

role of income effects in public transport use, and the implications of that role in the final equity results.

As far as the author is aware, this is the first analysis of the social impacts of the transport subsidy policy in Madrid. The case represents an interesting opportunity for evaluating whether the transport fare policy effectively meets social objectives, and to determine to what extent these subsidies have promoted social inclusion with regard to income.

The case of New York and New Jersey (US)

Implementing effective travel demand management measures provides an opportunity to reduce transport dependence on the private car. There is growing acknowledgement that the strategy of implementing transit benefits may boost transit ridership and reduce personal vehicle use. This research (paper II) contributes to the understanding of this issue by examining the relationship between commuter benefits and mode choice for commuting trips in the States of New York and New Jersey (US). Based on individual data from the Regional Household Travel Survey conducted by the New York Metropolitan Transportation Council and North Jersey Transportation Planning Authority, a multinomial logit model was adopted to identify the extent to which transport benefits to employees—including public transport-related, private transport-related and benefits for walking and cycling—promote changes in commuters' modal split. Particular attention is paid to the income variable as a potential key factor affecting mode choice and its influence in the social justice analysis.

As far as the author is aware, this is among the few studies using revealed preference travel data from regional household surveys to analyse the impact of transportation subsidies and benefits on travel behavior. Moreover, given the fact that the model is built on the basis of a completely disaggregated survey, this study is able to simultaneously capture—as few contributions have done before—the separate effect of benefits for driving, public transportation, and walking or cycling on commuter mode choice. This metropolitan area represents an interesting case study for exploring the determinants of travel mode choice, since it is among the

most populated areas and having the highest transit usage rate within the United States.

Both case studies (the case of Madrid and the case of New York and New Jersey) paid particular attention to transit accessibility, as a social indicator and as a variable influencing transit ridership. Each one of them measured this variable at the same level of the model built: at the neighborhood level for the case of Madrid, and at the individual level for the case of New York-New Jersey. In the case of Madrid, accessibility to public transport was studied by analyzing the service area (SA) of each facility, using locally accepted walking distances to transit stations: 1,200 meters for commuter rail stations, 600 meters for underground rail stations and 300 meters for urban and interurban bus stations, according to the Sustainable Urban Mobility Plan of the Madrid Center District (Madrid City Hall, 2013). After the SAs around all the transport stations on the network street lines were computed, the accessibility to public transport for each neighborhood was obtained as the ratio of service areas (including all the stations influencing that neighborhood) to the total neighborhood area.

For the case of New York-New Jersey, public transport accessibility was obtained by creating different buffers around the existing public transport network (subway and rail lines), taking as a reference the accepted walking distances to transit stations applied in the case of Madrid: a 600 meters buffer was created for subway lines and a 1,200 meters buffer for rail lines. Due to the lack of detailed geographic information available for bus routes, accessibility to bus services was measured based on a proxy indicator at the county level, calculated as the number of bus stations per county divided by the county area. Finally, households were classified as 'accessible to public transport' if their corresponding census tracts centroids were situated within a buffer or were located within a county where the number of stations per area is above the average value obtained for the rest of the counties.

2.1.2 Perceived fairness of transport policies: acceptability towards road pricing

With regards to the second type of policy intervention, this chapter also examines whether it is possible to apply a road pricing scheme both acceptable and effective through the following case study:

The case of the Spanish toll network

Although several studies have addressed public acceptability of road pricing, little evidence can be found regarding the effects of different pricing strategies. Particularly, exploring acceptability towards alternative schemes for a toll network already in operation is an issue to be tackled. Furthermore, the existing literature has evidenced that individual income level is not generally conclusive to explain users' perceptions towards toll roads. This paper (paper III) is aimed at contributing to the limited literature in this field by exploring perceptions towards different road pricing schemes, for those users already using a charged road, with a particular emphasis on income as a potential explanatory variable to determine users' support for any particular pricing scheme. Based on a nationwide survey conducted to toll road users in Spain, the research develops several binomial logit models to analyse users' acceptability towards three alternative charging approaches: a surcharge to avoid congestion at any time (express toll lanes), a time-based (peak vs. off-peak) pricing approach, and a flat-fee (vignette). The results from this analysis can alert policy-makers and practicing planners with regard to the promotion of more efficient, socially inclusive and publicly acceptable road pricing schemes.

As far as the author is aware, this is among the few studies on public acceptability carried out based on a nationwide survey conducted to real users of a toll motorway network. Since toll roads in Spain generally have a free parallel road, the case study is of particular interest when exploring equity implications of road pricing.

2.2 Academic Papers

This chapter includes three papers that have been published as:

- I. **Bueno, P.C., Vassallo, J.M., and Herraiz, I. (2016).** Social and Distributional Effects of Public Transport Fares and Subsidy Policies: Case of Madrid, Spain. *Transportation Research Record: Journal of the Transportation Research Board* 2544 47-54. doi: 10.3141/2544-06¹.
- II. **Bueno, P.C., Gómez, J, Peters, and Vassallo, J.M., (2017).** Understanding the effects of transit benefits on employees' travel behavior: Evidence from the New York-New Jersey Region. *Transportation Research Part A: Policy and Practice* 99 1-13. doi:10.1016/j.tra.2017.02.009.
- III. **Bueno, P.C., Gómez, J, and Vassallo, J.M.** Seeking Factors to Increase the Public's Acceptability of Road-Pricing Schemes: Case Study of Spain. *Transportation Research Record: Journal of the Transportation Research Board* 2606 9-17. doi: 10.3141/2606-02.

The overall scheme of the papers included in this chapter is shown in Figures 2.1, 2.2 and 2.3, respectively:

Figure 2.1 Paper I scheme

¹ Erratum in this paper. In Figure 1(b) for 'Extrusion represents population density' read 'Extrusion represents population', page 59.

Figure 2.2 Paper II scheme

Figure 2.3 Paper III scheme

Finally, the three papers are presented below in the order they are previously mentioned:

Social and Distributional Effects of Public Transport Fares and Subsidy Policies

Case of Madrid, Spain

Paola Carolina Bueno Cadena, Jose Manuel Vassallo, Israel Herraiz, and Manuel Loro

Despite the widespread implementation of urban transport subsidies in many cities, there are still only a limited evaluation of the equity of these policies and scarce quantitative assessment of their distributional incidence. This research contributes to filling this gap by developing a practical approach to evaluate the impact of fare subsidization on vertical equity. This paper implements a two-step methodology. First, two main indicators were developed to measure the social impact of the travel pass, a highly subsidized fare, to determine the effectiveness of the policy in reaching lower-income citizens. Second, by using the latest disaggregated data from a transportation survey, in Madrid, Spain, a multiple regression model revealed that travel pass usage (TPU) depended mainly on income level and accessibility to public transport. The results show that the accessibility level has a positive effect on the TPU indicator, whereas income level has a negative influence. Because income level is shown to play the most significant role in influencing public transport use, the subsidy policy associated with the travel pass in the city can be considered progressive, since it effectively targets economically disadvantaged groups. This fact suggests that subsidies for public transport in Madrid tend to favor vertical equity.

Despite the increasing interest in equity issues within the concept of sustainability, scholars agree that social impacts and their distributional effects have traditionally received less attention than economic and environmental aspects. One of the drawbacks of including social impacts in the evaluation of public policies is that there is considerable uncertainty as to what a social impact is, how to measure it, and how to evaluate its distributional effects and equity issues (1). Frequently, “transport projects are implemented by using methods such as Cost-Benefit Analysis which makes extensive use of financial costs and benefits without considering social impacts of the project at a disaggregate level” (2). There are today very few standardized methods for evaluating the social and distributional effects of public policies. Knowledge is fragmented across a large number of different disciplines and, consequently, the concept of equity is addressed in the literature from different perspectives.

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Transportation Research Record: Journal of the Transportation Research Board, No. 2544, Transportation Research Board, Washington, D.C., 2016, pp. 47–54.
DOI: 10.3141/2544-06

Much less is known about the consequences of transport policies on equity. The literature on transport policies mainly focuses on economic and environmental rather than social and distributional impacts. As Nuworsoo et al. observed, only a few authors have looked at equity aspects of transit fare policies per se (3). Equity considerations associated with fare policies and the distributional incidence of subsidies have been subjected to very little detailed analysis, as the common perception is that subsidies always have progressive distribution effects (4). Although equity is often the key component in debates on how to allocate public resources, the social and distributional dimensions of public transport subsidies have drawn significantly less attention in the literature (5).

This paper presents a thorough assessment of the social and distributional effects of the public transport fare and subsidy policy in the city of Madrid, Spain. The research is based on a two-step methodology. First, two quantitative indicators formulated from Madrid’s Transport Survey are defined and evaluated. Second, this information is used to calibrate a multiple regression model to study the variables explaining the use of the travel pass. By exploring the equity implications of the travel pass approach, the aim is to determine whether this policy provides benefits to the people in most need, namely low-income groups. The results show that the accessibility level has a positive effect on travel pass usage (TPU), whereas income level has a negative influence. Because income level is shown to play the most significant role in influencing public transport use, the subsidy policy associated with the travel pass in the city can be considered progressive, since it effectively targets economically disadvantaged groups. This fact suggests that subsidies for public transport in Madrid tend to favor vertical equity.

This article summarizes current knowledge on the social impacts of transport, especially equity impacts, and presents the characteristics of the city of Madrid and its mobility. The next section outlines the research approach for addressing the concept of social justice in relation to the most highly subsidized fare in Madrid: the travel pass. The results of the evaluation of Madrid’s fare policy are then discussed and, finally, conclusions and recommendations for additional research in the field of transport equity are presented.

LITERATURE REVIEW: EQUITY IMPLICATIONS OF TRANSIT FARE POLICIES

“Equity refers to the distribution of impacts—benefits and costs—among members of the society and whether this distribution is considered appropriate” (6). Equity is closely related to the concept of

fairness. For a policy to be considered equitable, it should distribute its costs and benefits in a fair way across society (7).

Although the concept of equity is a major premise of transport subsidy policies, the social and distributive dimensions of urban transport subsidies have received scarce attention in the literature. According to Serebrisky et al., despite the many subsidy policies adopted for urban public transport, “there are virtually no quantitative assessments of their distributional incidence, making it impossible to determine if these policies are pro-poor” (5).

Although there are few studies on the distributional incidence of transport subsidy policies, a number of methodological approaches have been developed to analyze the equity effects of urban transport subsidies. Nuworsoo et al. analyzed the five alternative fare proposals for the Alameda–Contra Costa Transit District in California, by paying particular attention to the impact on certain riders (gender, income group, and race) (3). The research acknowledges that certain of the riders’ characteristics (such as income, age, and trip purpose) make them more sensitive than others to price changes. The research conducted by Bureau and Glachant, using disaggregated data from the Global Transport Survey, evaluates the distributional effects of alternative urban public transport scenarios in the Paris Region (fare reduction and increase in the speed of public transport) (8). These authors found that the changes were progressive and that low-income populations perceived more benefits from fare reductions than from increases in public transport speed.

There are different opinions and results with regard to the progressiveness of targeting subsidies to the poor. Some researchers have shown that the effect of transit subsidies redistribute income from high-income to low-income classes (9, 10), while other authors have concluded that transport subsidies show either a neutral or regressive distributive impact (5, 11).

The case of Spain is of particular interest: first, because urban public transport in Spanish cities is highly subsidized (12); second, the public sector is currently facing budget cuts; and third, only a few studies have looked at the equity of transit fare policies. For instance, the redistribution effects of urban transport subsidies at the municipal level throughout the country were analyzed by Asensio et al., who calibrated a model that took into account expenditure on urban public transport (12). From calculations of Gini indexes in different municipalities, these researchers concluded that in general terms urban public transport subsidies in Spain were progressive and had a positive redistributive effect.

In Madrid, there is very little analysis of the distributional incidence of public transport subsidies. There are some studies that examine how users respond to changes in prices and service characteristics in the Madrid metropolitan area (13) and evaluate the impact on revenue with the introduction of the travel pass (14). By estimating demand equations and elasticities and quantifying explanatory variables for the significant rise in public transportation use, it was found “that despite succeeding in reversing the declining patronage trend of public transportation in Madrid, the adoption of these transportation policies tended to require an increasing financial support that was not always available” (14).

A broad analysis of urban public transport policy funding in Madrid looked at the evolution of public transport subsidies between 1995 and 2005 and their relationship with equity aspects (4). On the basis of a simple correlation analysis between the use of the travel pass and income per capita by geographical zone, the authors found that, in the city of Madrid, the lower the income level was, the higher the use of the travel pass was. However, Vassallo et al. pointed out that in the outer zones of the metropolitan area the correlation between the level of income and use of travel passes was almost nonexistent (4).

The contribution of this paper to the literature is that it analyzes whether categorical transport subsidies in the city (preferential fares for groups such as senior citizens and young people) are related to income and provides a methodology to quantitatively evaluate the distributional effect of transit fare subsidy. A further difference with earlier works is that the analysis is not restricted to income and social class at the metropolitan level or the municipal level in the Madrid metropolitan area. As far as the authors are aware, there are no previous studies analyzing public transport subsidy policy at a disaggregated level, such as by neighborhoods.

For the purpose of this paper, the term “subsidy” with regard to a monthly pass should not be interpreted as part of programs in which employers provide benefits for employees (e.g., transit pass reimbursements) but as a discount involved in a monthly travel pass in and of itself.

CHARACTERISTICS OF THE CITY OF MADRID AND ITS MOBILITY

City of Madrid: Overview of Income Distribution

More than 6 million inhabitants live in the Madrid metropolitan area, which comprises 179 municipalities. About 50% of the population lives in the city of Madrid, in an area of 607 km². According to the National Institute of Statistics, the average population density in the city is 5,390 inhabitants per square kilometer. The distribution of residential areas and employment centers gives rise to an urban structure that follows a predominantly monocentric model, with radial trips from satellite settlements to the city center. This structure makes Madrid well suited to public transportation use. Currently, as the 2004 Transport Survey reveals, “there are 6,670,000 motorized trips every working day—48% served by public transport and 52% by car” (Monzón and Guerrero, 15).

The city is split into 21 districts, which are further subdivided into 128 neighborhoods and 2,412 census sections. Unlike the trend in some of the world’s cities, the districts and neighborhoods located in the center of Madrid are wealthier than the average for the city. Furthermore, the income distribution within each neighborhood is fairly homogeneous. In other words, low- and high-income neighborhoods do not overlap, and the distribution is not highly skewed. Average income can therefore be seen to be a good indicator of the overall income in a given neighborhood.

Public Transport in Madrid

The public transport system in the Madrid metropolitan area consists of four modes, two of which are typically urban (underground rail system and urban buses), while the other two are predominantly metropolitan modes (commuter rail and interurban buses). All the transport modes are integrated into a public authority called Consorcio Regional de Transportes de Madrid (CRTM) (Madrid Regional Transport Consortium) in charge of coordinating modes and fares.

Besides the typical single and multiride (10-trip) tickets, there is a travel pass available in Madrid to promote use of public transport. The travel pass is a monthly flat fare suitable only for frequent users and represents a considerable implicit subsidy. Vassallo et al. report that, on average, travel pass users pay 35.5% less per trip than do users of typical single and multiride tickets (4). This pass is valid for 1 month on all public transport modes inside a certain ring. Travel

pass holders can make unlimited trips inside the ring zone associated with that travel pass. There are three types of transit passes, including a regular travel pass and two special kinds of travel passes that address potentially vulnerable groups: a travel pass for young people (younger than age 23 years) and a travel pass for senior citizens (65 years and older). In 2011, young people paid 35% less and seniors 77% less than for a regular monthly travel pass.

Since the adoption in 1987 of an integrated fare approach in Madrid, essentially based on a monthly and annual travel pass, there have been no studies aimed at quantifying the redistributive effects of subsidization at a disaggregated level, such as at the neighborhood or household level. It is worth noting that the implementation of the travel pass in Madrid can be considered a success with respect to promoting public transport usage because it has increased the number of trips by frequent users and the likelihood of attracting new ones.

However, the travel pass has had negative consequences on financial sustainability as the coverage ratio (ratio of revenues from users to operation costs) of the public transport system in Madrid has decreased steadily over the years, leading to the need for progressive increases in the amount of public subsidies.

All of the above factors highlight Madrid as a suitable study area for this type of analysis. It is crucial to evaluate whether the fare policy is effectively meeting its social objective and to determine to what extent these subsidies have promoted social inclusion with regard to income.

PUBLIC TRANSPORT SUBSIDY POLICY IN MADRID: METHODOLOGY TO EVALUATE VERTICAL EQUITY

According to Delbosc and Currie,

there are two general categories of transportation equity: horizontal and vertical equity. Horizontal equity (fairness or egalitarianism) is concerned with providing equal resources to individuals or groups considered equal in ability. It avoids favoring one individual or group over another, and services are provided equally regardless of their need or ability. Vertical equity (social justice, environmental justice or social inclusion) is concerned with distributing resources among individuals of different abilities and needs. Vertical equity favors groups based on social class or specific needs in order to make up for overall societal inequalities. (16)

While both dimensions of equity can contribute to the analysis, this paper focuses on the vertical equity implications of transportation subsidy policies applied to the case study of Madrid, as there is little quantitative analysis of their distributional incidence on different income groups. This section defines the methodology that was designed to obtain the results and explains the databases used for the analysis.

Data Collection

Every 8 years the Madrid transport authority (CRTM) conducts a mobility survey in the Madrid metropolitan area that provides travel data and travel trends over time. The last survey available at the time of writing was conducted in 2004. Because there are no more recent data (the 2012 survey was canceled because of a shortage of funds), disaggregated data from the 2004 Transport Survey were used in this study. This survey enabled the authors to design a set of indicators to measure the distributional impacts at the neighborhood level (individual data are not available).

The *Madrid Statistical Yearbook* was used to obtain information about the characteristics of the population in each neighborhood and to study the relationship between TPU per neighborhood and the variables characterizing each one (17). In addition, income per capita data were used from the Madrid Region Statistical Institute, available at the census section level. The CRTM provided data on public transport fares, subsidies, and accessibility for each neighborhood.

Given the fact that some of these variables only have a yearly record (i.e., travel data and income levels), this study relies on cross-sectional data. Consequently, all data from the *Madrid Statistical Yearbook*, Madrid Region Statistical Institute, and CRTM used for this analysis are from 2004. Therefore, the results are limited by the period considered and do not allow an analysis over time. Unfortunately, the lack of more recent data in Madrid makes an up-to-date analysis not possible.

Finally, the results of this research are also constrained by the aggregate nature of the data, which are collected at the neighborhood level. Accuracy would be improved by using data from a completely disaggregated survey that captures more precise individual characteristics and preferences. Unfortunately, this information is not yet available in Madrid.

Some Previous Calculations: Accessibility to Public Transport in Madrid

Accessibility is often used as a social indicator (18–21). Geurs and van Wee claim that social equity impacts can be evaluated if the accessibility measure is spatially differentiated and disaggregated (18); the authors therefore decided to look more closely at accessibility to public transport in Madrid to incorporate this variable into the present research (see the section on variables that might explain the use of the travel pass).

The approaches for measuring accessibility often include the application of geographical information systems. This research applied an approach based on the integration of existing geographical information systems and a detailed city street map to measure accessibility to transit services in different neighborhoods in Madrid. This research is the first work to explore this issue at such a disaggregated level.

Accessibility to public transport in Madrid was studied by analyzing the service area of each facility (underground rail, commuter rail, urban and interurban bus) within each neighborhood in the city. Service areas were calculated as irregular polygons depicted by using locally accepted walking distances to the transit stations, according to a Madrid City Hall plan (22). After the service areas around all the transport stations on the network street lines were computed, the accessibility to public transport for each neighborhood was obtained as the ratio of service areas (including all the stations influencing that neighborhood) to the total neighborhood area.

A statistical analysis was conducted that aimed to analyze the distribution of the accessibility values previously calculated. It was concluded that this distribution was heterogeneous and slightly skewed toward low values.

Methodology for Assessing Vertical Equity Impacts

Following the research objectives, a methodology was developed to evaluate the impact of fare subsidies on vertical equity in Madrid. Two steps were defined: the development of indicators to measure the role

of public transportation on social equity and the study of TPU through potential explanatory variables.

Indicators to Evaluate the Distributional Impacts of Public Transport Fare Policy in Madrid

To develop these indicators, it is first necessary to select the type of equity to evaluate and the method of categorizing people. This research was based on vertical equity and categorized people by income class (lower-income areas). The study opted to prioritize the economic needs of potentially vulnerable groups over other needs to evaluate whether the subsidy policy is progressive with respect to income per capita.

Indicators were chosen with the following characteristics: easy to explain, reliable, specific, representative, and easy to validate. Two quantitative indicators were developed by monitoring the effectiveness of travel pass policy in favoring disadvantaged groups. The following list shows the indicators and how they should behave to promote vertical equity with regard to income and social class:

- TPU percentage per neighborhood. The TPU indicator is an indirect measurement of transport affordability. Vertical equity would mean that a significantly higher percentage of the population in the poorest neighborhoods would benefit from the travel pass compared with that in the wealthiest neighborhoods.
- Average user cost per trip for travel pass users across Madrid neighborhoods (ACT). The ACT indicator shows whether lower-income people would be expected to pay less per trip than would nonvulnerable groups.

Variables That Might Explain the Use of the Travel Pass

A linear regression model was designed and fitted to explain the use of the travel pass and evaluate the distribution of transport subsidy benefits among different income groups in Madrid. A model was calibrated to estimate the relationship between a dependent variable (the number of people who buy the travel pass per neighborhood) and some explanatory variables that are assumed to influence TPU.

To conduct this statistical analysis, a database panel was built with 128 observations corresponding to the 128 neighborhoods in the Madrid metropolitan area. A model was set up to predict the use of the travel pass in each neighborhood by testing the following independent variables that characterize each of the 128 neighborhoods:

- Income per capita;
- Neighborhood area;
- Total population and potential population (defined below) for the regular pass, young people's pass, and senior travel pass;
- Percentages of population with high, medium-high, medium, medium-low, and low socioeconomic levels;
- Motorization;
- Number of people with different educational levels: illiterate, no studies, first grade or secondary education, high school, basic or higher professional training, diploma courses, bachelor's degree, and doctoral studies;
- Employed, unemployed, active population, inactive population (women and men);
- Housing price per square meter; and
- Public transport accessibility.

Since multicollinearity is a traditional problem in regression analysis and to avoid erroneous inferences from possible relationships between predictor variables, collinearity was examined between all the independent variables through the correlation matrix. If there is multicollinearity between two predictor variables, then the correlation coefficient between these variables will be nearer to 1.0. If there is a high correlation between two variables, one variable is excluded from consideration.

Multiple regression analysis was then applied to predict TPU. By constructing the full model with all the predictor variables obtained after the detection of multicollinearity, the full model R^2 -value was obtained. The significance of the model's coefficients was also tested so as to discard variables with no influence on the dependent variable. After researchers started with a full model and eliminated variables according to this test, a final model was obtained in which all the coefficients were significantly different from zero. Different models were run until the optimum was found with respect to the multiple correlation coefficient R , the residual standard error, and a test of significance for R . On the basis of the results, a final examination was made of the actual signs of the linear coefficients and they were compared with their predictable signs.

The cross-validation technique was used to detect and prevent overfitting. On the basis of a 10-fold cross-validation test, it was estimated how accurately the predictive final model would perform in practice. Finally, following econometric practice, the elasticities of independent variables in the use of the travel pass were interpreted.

ANALYSIS AND FINDINGS

This section shows the results of the indicators used to evaluate the impact of TPU on vertical equity across different neighborhoods. For the TPU indicator, the results are displayed on a map showing the indicators for the 128 neighborhoods in the city of Madrid. The neighborhoods were split into three income levels: low income (up to €10,310 per capita); medium income (between €10,310 and €14,700); and high income (between €14,700 and €31,218) (€1.00 = US\$1.24 in 2004) (Figure 1). In addition, Figure 1 includes information about the population and the population densities for the 128 neighborhoods in the city.

Indicators to Evaluate the Distributional Impacts of Public Transport Fare Policy in Madrid

TPU Percentage per Neighborhood

The first indicator measures the percentage of the population using the travel pass in each neighborhood. Within each neighborhood, the potential population (P_{pi}) of travel pass users was calculated by adding the potential population for the regular pass, young people's pass, and senior travel pass. As explained before, the criteria for obtaining a special travel pass depend on age, as established by the CRTM. For example, the potential population for the young people's travel pass is defined as individuals younger than age 23 years living in the neighborhood, and 65 years and older for the senior travel pass. The group of regular travel pass users is made up of individuals between the ages of 23 and 64 years.

The TPU indicator was calculated through the following ratio. The numerator of the equation was obtained from the 2004 Trans-

FIGURE 1 Neighborhood characteristics: (a) income level and (b) TPU percentage (numbers in parentheses indicate number of Madrid neighborhoods in each category).

port Survey. The denominator is the sum of potential population for all types of travel pass per neighborhood.

$$TPU_i(\%) = \frac{\text{residents of neighborhood } i \text{ who actually use the travel pass}}{P_{pi}} \quad (1)$$

General TPU values per neighborhood are shown in Figure 1. According to this indicator, there is some evidence that subsidies contribute to promoting social equity in the city, as the TPU percentage appears to be higher in the disadvantaged neighborhoods of Madrid. On the basis of the calculations of this indicator, it was found that 88% of the neighborhoods with a high TPU percentage are low-income areas. The highest TPU percentages occur in disadvantaged neighborhoods such as Campamento (TPU = 34%), Justicia (TPU = 33%), and La Chopera (TPU = 31%).

These results support the hypothesis that the travel pass is vertically equitable, because the highest percentages of this indicator are distributed among economically disadvantaged neighborhoods. Given that the travel pass is the most highly subsidized fare in Madrid, this public transport policy provides the greatest benefit to lower-income groups.

Average User Cost per Travel Pass Trip Across Madrid Neighborhoods

The average user cost per travel pass trip is designed to determine whether people using the travel pass in low-income neighborhoods

are more subsidized than people using the travel pass in high-income neighborhoods. This methodology was applied separately for each type of travel pass user (regular pass, young people's pass and senior pass) to obtain the subsidy effect for each group. On the basis of the number of residents per neighborhood who actually use the travel pass and the fares for each type of travel pass, the amount of money they spent on transportation per month (AMI_i) was calculated. The transportation survey was used to obtain the number of monthly trips made with each type of travel pass per neighborhood and then the average user cost per trip (ACT_i) per neighborhood and type of travel pass was calculated as follows:

$$ACT_i \text{ RTP}(\text{€}) = \frac{AMI_i \text{ RTP}}{TMT_i \text{ RTP}} \quad (2)$$

$$ACT_i \text{ YTP}(\text{€}) = \frac{AMI_i \text{ YTP}}{TMT_i \text{ YTP}} \quad (3)$$

$$ACT_i \text{ STP}(\text{€}) = \frac{AMI_i \text{ STP}}{TMT_i \text{ STP}} \quad (4)$$

where

$ACT_i \text{ RTP}$ = average user cost per trip for residents of neighborhood i using a regular travel pass,

$ACT_i \text{ YTP}$ = average user cost per trip for residents of neighborhood i using a young people's travel pass,

$ACT_i \text{ STP}$ = average user cost per trip for residents of neighborhood i using a senior travel pass,

AMI_i RTP = amount of money spent on transportation per month by residents of neighborhood i using regular travel passes,

AMI_i YTP = amount of money spent on transportation per month by residents of neighborhood i using young people's travel passes,

AMI_i STP = amount of money spent on transportation per month by residents of neighborhood i using senior travel passes,

TMT_i RTP = total monthly trips by regular travel pass users living in neighborhood i ,

TMT_i YTP = total monthly trips by young people's travel pass users living in neighborhood i , and

TMT_i STP = total monthly trips by senior travel pass users living in neighborhood i .

To be vertically equitable, the ACT ratio should be lower in disadvantaged neighborhoods, meaning that travel pass users from poorer neighborhoods are more highly subsidized per trip than those from richer neighborhoods. However, results for the ACT ratio suggest a fairly equal treatment of all users (regardless of their income levels), which is strictly speaking not vertically equitable with respect to income. Subsidies for travel pass users do not distinguish between low- and high-income neighborhoods. High-income travel pass users pay on average €0.47 per trip with the regular travel pass, €0.33 per trip with the young people's travel pass, and €0.13 per trip with the senior travel pass. Lower-income users pay similar amounts for a trip made with the regular pass and young people's travel pass, whereas they pay €0.14 per trip with the senior travel pass.

However, there are clear differences between the average user costs per trip for regular passes, young people's passes and senior travel passes. The user cost per trip is €0.47 with a regular travel pass, €0.33 with a young people's travel pass, and €0.13 with a senior travel pass. This amount shows an equitable distribution of benefits and costs among minority groups such as young people and seniors.

The ACT indicator shows that the subsidies for travel pass users cannot be claimed to support vertical equity because they are equally distributed across neighborhoods. Nevertheless, because residents of low-income neighborhoods have a higher TPU level than those of richer neighborhoods (shown by the TPU indicator), the poorest neighborhoods still receive a higher subsidy than the richest.

A more comprehensive equity evaluation is needed to understand the causes that could explain the level of TPU in a given neighborhood. The next section shows how significant explanatory variables can be found by fitting a model.

What Variables May Explain TPU?

This section aims to identify the variables that explain the use of the travel pass across neighborhoods. A multiple regression model was used in which all the colinear variables within the set of selected variables were removed to assess whether the regression parameters were significant. If they were, the results were interpreted with respect to vertical equity.

Before calibrating the model, an evaluation was made as to whether multicollinearity was present in the data. As the linear model was correlated between the logarithms of all the variables, the correlation matrix was obtained for the logarithms of all the independent vari-

ables. After the correlation matrix was inspected, it was decided to remove the following variables because they were highly correlated with the rest of the variables (shown in parentheses) and did not provide any further information to the linear model:

- Potential populations for the regular pass, young people's pass, and senior travel pass (very highly correlated with overall population);
- Percentages of population with high, medium-high, medium, medium-low, and low socioeconomic status (highly correlated with population);
- Motorization (very highly correlated with population and number of people with different educational levels);
- Number of people with different educational levels (highly correlated with available income);
- Employed population, unemployed population, active population, and inactive population—women and men (highly correlated with population); and
- Housing price per square meter (correlated with available income).

In summary, from all the possible groups of noncollinear variables, the set of income, area, population, and accessibility was selected. As has been widely discussed in social research studies (6, 18, 23, 24), these variables were considered in the analysis to provide an adequate explanation of public transport use from an equity standpoint. Population and area were included as control variables. Because of its nature, public transportation use is probably highly influenced by income; a low income may contribute to disadvantages with regard to transportation. Finally, the heterogeneity found in public transportation coverage in different areas of the city suggests that accessibility may also play a key role in explaining public transportation demand.

After the colinear variables were removed, a multiple regression model was calibrated with the variable "number of travel passes acquired by people from a certain neighborhood" as the dependent variable. It was necessary to transform the set of variables before fitting the model since their relationship was unlikely to be linear. The Box-Cox transformation for linear models was used (25), which suggested using a logarithmic transformation. The correlation matrix explained in the previous paragraph was also performed with logarithmic transformations.

Once the transformed variables were obtained, a linear model was calibrated by using multiple regression. In this model, not all the variables had coefficients significantly different from zero. The linear model was repeated, removing the nonsignificant neighborhood area variable, and a model was finally calibrated on the basis of three endogenous variables: income per capita in each neighborhood, population, and accessibility. The correlation coefficient was strong (multiple $R^2 = .733$; adjusted $R^2 = .7265$; and p -value near zero). The results show that the use of the travel pass in Madrid is very well explained by only these three independent variables: income per capita in the neighborhood, total population, and the level of public transport accessibility (Table 1).

The final model shows a good overall level of fit and all the regression parameters were significant predictors (two of the variables at the 99% confidence level and the other at 90%), so there is strong statistical evidence supporting these relationships. Table 1 also shows the comparison between the signs expected and obtained for the regressions. All the signs were in line with the expected results. For instance, as was hypothesized, a negative sign was found for the variable "income

TABLE 1 Model Results

Independent Variable per Neighborhood	Coefficient of Elasticity	SE	Sign Expected	Sign Obtained	<i>p</i> -Value
Income level	−0.68	0.16	−	−	$p \sim 0^{***}$
Population	1.04	0.10	+	+	$p \sim 0^{***}$
Accessibility	0.30	0.12	+	+	$p \sim 0^*$

NOTE: SE = standard error.

***99% confidence level; *90% confidence level.

level,” meaning that higher levels of neighborhood income are related to lower use of the travel pass. The same applies to “accessibility,” with a positive coefficient in this case.

Finally, the predictive equation can be expressed as follows:

$$\log(\text{TPU}_i) = 2.94 - 0.68 \log \text{income}_i + 1.04 \log \text{population}_i + 0.30 \log \text{accessibility}_i \quad (5)$$

where

TPU_i = number of travel pass users in neighborhood i ,

income_i = income per capita in neighborhood i ,

population_i = total population in neighborhood i , and

accessibility_i = public transport accessibility in neighborhood i .

Since the predictive equation was estimated by using a logarithmic transformation for all the variables (including the dependent variable), the estimated coefficient can be interpreted as the elasticity. In this functional form, from the double log equation (Equation 5), −0.68, 1.04, and 0.30 are the elasticity coefficients for the income level, population, and accessibility variables, respectively. This result means that, other things being equal, a 10% increase in income level will generate a 6.8% decrease in TPU level per neighborhood, whereas a 10% increase in accessibility will generate a 3.0% increase.

Finally, the internal validity of the model was tested by means of a 10-fold cross-validation method. The neighborhoods were divided

into two sets: a training set and a test set. The training set contains 90% of the neighborhoods and was used to fit the linear model. The model was then applied to the test set (i.e., 10% of the remaining neighborhoods). Then the mean squared relative error (MSRE) of the prediction of the test set was evaluated. This procedure was repeated 5,000 times, with randomly selected training and test sets. The median error for this simulation was 4.5%. The average error was 31.3% with a standard deviation of 69.2%. The error distribution is highly skewed, which explains the difference between the median and average values. Most of the simulations had a very low MSRE value, but in some specific cases the MSRE value was very high. Figure 2 shows a box plot of the errors of this simulation with 5,000 random sets. Most of the models had an MSRE value of lower than 5%. This test is further evidence that this model can accurately predict TPU levels.

To summarize, it was found that the use of the travel pass in Madrid is fairly well explained by variables such as accessibility to public transport and income level. The level of accessibility has a positive effect on TPU levels, whereas income level has a negative influence. In other words, the use of the travel pass and its subsidy benefits increase when the average income per capita in the neighborhood decreases. Moreover, the elasticity values provide evidence that public transport use in Madrid is more sensitive to income variations than to accessibility. These results confirm that public transport subsidies in Madrid tend to be progressive with respect to income. Consequently, the current subsidy policy in regard to TPU in Madrid can be claimed to benefit lower-income areas.

FIGURE 2 Cross-validation results.

CONCLUSIONS

This research highlights some interesting conclusions about the effect of public transport fare and subsidy policy in Madrid on vertical equity. The TPU indicator confirms that people in poorer neighborhoods use travel passes much more often than do people in richer areas and thus obtain greater benefit from public subsidies. The results are categorical enough to confirm that public transport subsidies give special consideration to poor neighborhoods compared with wealthy ones. This indicator reveals that the travel pass subsidy policy satisfactorily targets the least wealthy people. However, the ACT indicator shows that travel pass users' cost per trip varies slightly across neighborhoods and that travel pass users in the lowest-income neighborhoods pay the same amount per trip as in high-income neighborhoods.

The multiple regression model clearly explains TPU with respect to three variables: population, accessibility, and income level. The results show that income level plays the most significant role in influencing public transport use. The lower the income level of the neighborhood, the greater is the use of the travel pass. When two neighborhoods in Madrid with the same standards of accessibility were compared, it was found that people in the poorer neighborhoods used the travel pass more than did people in the wealthier neighborhoods. These results support the claim that the subsidy policy in Madrid is progressive, since it establishes a fairness of treatment between individuals with different income levels. This finding means that vertical equity principles are fulfilled insofar as the transport policy favors economically disadvantaged groups.

Since there is very little analysis of the distributional incidence of public transport subsidies in the city of Madrid, local transport planners should take advantage of these findings to evaluate the effectiveness of the policy in reaching lower-income citizens. This analysis can also alert policy makers, practicing planners, scholars, and citizens in other contexts on the need to determine the progressiveness of targeting subsidies to the poor.

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Understanding the effects of transit benefits on employees' travel behavior: Evidence from the New York-New Jersey region

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ABSTRACT

Implementing effective travel demand management measures provides an opportunity to reduce transport dependence on the private car. There is growing acknowledgement that the strategy of implementing transit benefits may boost transit ridership and reduce personal vehicle use. This research contributes to the understanding of this issue by examining the relationship between commuter benefits and mode choice for commuting trips in the states of New York and New Jersey (US). Based on individual data from the Regional Household Travel Survey conducted by the New York Metropolitan Transportation Council and North Jersey Transportation Planning Authority, we adopted a multinomial logit model to identify the extent to which transport benefits to employees – including public transport-related, private transport-related and benefits for walking and cycling – promote changes in commuters' modal split. The analysis shows that commuter benefits play a significant role in explaining observed travel patterns. Benefit programs that pay for auto expenses (e.g. toll payments, mileage reimbursement, free parking) are negatively correlated with transit, biking, and walking, while employer-funded benefit programs for transit passes and bike reimbursements increase their respective mode shares. This result confirms that promoting these types of measures is an effective policy to encourage the use of public transport modes, thus increasing efficiency and sustainability in daily mobility patterns.

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1. Introduction

Since their first implementation in the 1970s, transportation demand management (TDM) programs have been used as policy mechanisms to tackle transportation-related problems such as air pollution or traffic congestion. In its broadest sense, they include a wide range of measures that are geared towards improving the efficiency of travel demand. As pointed out by Meyer (1999), TDM programs can be regarded as either actions that are implemented at specific sites, or strategies that are implemented at an area-wide level. In this paper, we focus on the first dimension of these policy tools: TDM programs at employer worksites.

Employer benefits programs—often referred to as 'commuter benefits'—are aimed at reducing the share of employees driving to work alone through various incentives, disincentives, or marketing tools (Dill and Wardell, 2007). In its broader

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sense, commuter benefits can be defined as any option or set of options which employers provided to employees aimed at influencing their travel behavior, including benefits for driving (e.g., toll payments, subsidized parking), using public transportation (e.g., monthly passes, universal passes, or vouchers), and walking or cycling (e.g., financial incentives for bicycling or walking, or secure bike parking).

Ever since these benefits were put into effect, there has been an increasing recognition that these options may effectively persuade and induce workers to change their transportation habits. Consequently, several evaluations have sought to explain the effect of employer-paid benefits such as free parking (Hess, 2001; Shoup and Willson, 1992) and free and discounted transit pricing on commute mode choice (Boyle, 2010; Zhou and Schweitzer, 2011).

However, as pointed out by the [Transit Cooperative Research Program \(2005\)](#), “the impacts on employee travel behavior are not as well understood and little rigorous research has been conducted on the topic at a national scale”. In addition, although commuter benefit packages are supposed to influence mode choice decisions, some authors have acknowledged that only few contributions on commuter mode choice concurrently include variables measuring benefits for driving, public transportation, walking, and cycling (Hamre and Buehler, 2014). Furthermore, according to the authors themselves, the relationship between commuter benefits and the likelihood to walk and cycle has been scarcely explored until very recently.

By recognizing the potential of commuter benefits to promote more sustainable transportation habits, this paper investigates the links between them and modal selection for commuting trips in the states of New York (NY) and New Jersey (NJ) in the US. Particularly, this research is aimed at determining to what extent employee benefits can incentivize changes in daily travel behavior. This study contributes to the literature in three ways. First, it covers an interesting case in the international context given that it is among the most populated and transit-intensive areas in the US, not studied in great detail before. In this respect, the results of this paper come up with useful policy implications regarding the promotion of sustainable transport behavior. Second, to our knowledge, this is among the few works concurrently exploring commuter benefits for driving as well as walking, cycling and public transportation, as factors influencing individual decisions to commute by using revealed preference data via a household travel survey. Finally, it comparatively analyses the effect of the benefits with other research previously conducted. This is particularly useful to contrast our results with the existing literature.

The document is structured as follows. Section 2 provides a literature review on the topic, concluding with some research gaps, and outlines also the expected contributions of the present work. Section 3 briefly summarizes the main socioeconomic characteristics and mobility patterns for the states of NY and NJ. Section 4 describes the methodology adopted to model individuals' choices for commuting trips, and shows the RHTS survey and the explanatory variables considered for the analysis. Finally, Section 5 presents and discusses the results, and establishes a set of conclusions and recommendations for additional research in this field.

2. Literature review

Ever since sustainability emerged as a key priority in transportation planning, there has been growing interest in promoting sustainable transportation policies. Consequently, several travel demand management measures have been proposed in many different contexts—a complete overview at this point can be found in Loukopoulos (2007). Some of these strategies are sure means of changing travel related choices. As acknowledged by Garling et al. (2002), they lie from those measures that discourage car use to those policies encouraging the use of alternative modes. The latter are often called pull measures—i.e. improving public transport, improving infrastructure for cycling and walking or increasing the level of public transport subsidies—while the former are generally referred to as push measures—i.e. restricting parking availability, taxation on cars and fuel, decreasing speed limits, implementing road pricing mechanisms.

An important TDM strategy has been providing transportation subsidies and benefits to employees including toll/mileage reimbursements, public transport payments, free car parking and incentives for walking and cycling such as the provision of showers, lockers and bike parking. The literature review in this section will be mainly focused on these benefits as potential determinants of transport mode choice. Furthermore, we point out some useful insights of recent developments and mention some gaps found in the literature.

Employer TDM programs are sometimes difficult to evaluate because they are diverse in scope and involve individual behavior patterns, which are complex and difficult to model (Dill and Wardell, 2007). Overall, commuter benefits have been examined by using surveys as part of programs evaluation and a variety of statistics reported after or before introducing commuter benefits. For example, Herzog et al. (2006) conducted a survey of firms acknowledged as best workplaces for commuters in the metropolitan areas of Denver (Colorado), Houston (Texas), San Francisco (California) and Washington, DC. The study was aimed at determining the differences between the commuting patterns of individuals who receive employee commuter benefits and those who do not. This relevant research concluded that employees being offered public transportation benefits are significantly less likely to drive alone.

Another important contribution exploring the influence of transit benefits offered to employees was conducted under the [Transit Cooperative Research Program \(2005\)](#). The study was based on surveys focused solely on people who receive a transit benefit, surveys applied before and after the implementation of transit benefits or surveys to commuters in general. Overall, the results from this study suggested that transportation benefits for employees can produce an increase in transit use in some circumstances as well as an increase in new transit riders.

Practical studies focused on the effects of different employer-based TDM programs are too numerous to be completely reviewed here. [Table 1](#) presents a descriptive summary of some of the most relevant and latest studies evaluating the impact of commuter benefits addressed to public transport, private transport, walking and cycling on travel choices. In order to limit the present review to a manageable scope, we present only two examples per kind of benefit. Many other examples aimed at understanding the role of transportation demand management policies on commuters are found in the literature (see for instance [Cass and Faulconbridge, 2016](#); [Habibian and Kermanshah, 2013](#); [Rotaris and Danielis, 2015](#)).

Previous transit benefits assessments suggest a shift to more sustainable transport modes (bicycling, walking and public transport) for commuting trips as a consequence of the implementation of employer transit benefits. However, as mentioned by [Zhou and Schweitzer \(2011\)](#), most of these studies are focused on relatively homogeneous groups of people such as university students. In addition, as pointed out by [Hamre and Buehler \(2014\)](#), few contributions on commuters mode choice jointly include benefits for driving, public transportation, and walking or cycling. Finally, most of these studies only quantify ridership growth once benefits are applied, but they hardly ever study commuter benefits as a driver that may influence transport mode choice.

Despite the increasing attention devoted to the study of the impact of commuter benefits by transportation researchers, the current literature has certain gaps that have motivated this research:

- First, previous studies – with few exceptions, such as the one conducted by [Hamre and Buehler \(2014\)](#) for the case of Washington – are based on surveys conducted to transit benefits recipients instead of wider revealed preference travel data from regional household surveys. In our study, the sample presents higher variability because respondents of the household survey were not limited to those individuals receiving a transport benefit, thus reducing potential bias in the results. The approach adopted here allowed us to examine throughout a statistically significant model, to what extent individual characteristics, household attributes and, certainly, transport-related factors such as commuter benefits influence the willingness to switch or stay from driving alone. Moreover, given the fact that the model is built on the basis of a completely disaggregated survey, this study is able to capture, simultaneously, the separate effect of benefits for driving, public transportation, and walking or cycling on commuter mode choice. As a result, the model provides more detailed information on shifts in travel behavior.
- Second, the analysis developed in this research explicitly considers the influence that residence location may have on employees' mode choice. At this point, it is necessary to estimate context-specific effects by accounting for the spatial clustering of individuals within the whole area under analysis. Particularly, we may expect that commuters living in the urban center—better served by transit services—may show different mobility patterns when compared to those living in inner suburbs. The model hence is able to capture whether the variability of the dependent variable—commuter mode choice—is attributable to individual circumstances, or is a result of the group effect—the county of residence within the NY/NJ metropolitan area. To that end, the multinomial logit model developed in this paper was complemented with a multilevel model extension.
- Lastly, most previous studies in this field have included some ways to incorporate transit access as a variable explaining mode choice. Generally, this aspect was introduced through either dummy variables indicating whether people live near or not to a transit station, or proxy variables based on the number of transit stations located in the residential traffic analysis zone ([Dill and Wardell, 2007](#); [Hamre and Buehler, 2014](#)). In this research, we extend this analysis by conducting a more thorough approach for assessing accessibility. This involves the integration of existing geographical information systems and a detailed city street map.

3. The case of New York and New Jersey

American cities represent a case of particular interest when exploring the determinants of travel mode choice. In order to develop this analysis, we have selected two regions of particular interest: the states of New York (NY) and New Jersey (NJ), which are among the most populated areas within the United States. Below, a brief summary of the main characteristics of these regions is presented, with an emphasis on population, income distribution and some mobility patterns.

The population of NY and NJ states is dynamic and growing. Data from the 2010 Census reveal that more than 19 million inhabitants live in the NY metropolitan area while the New Jersey State has a total population of around 8 million inhabitants. According to the 2013 American Community Survey, the State of NJ is the second-wealthiest state within the nation, while NY State remains in the 18th position. When analyzing the income distribution of both states, the essential finding is their similarity with the national distribution, thus a trend towards inequality can be observed. At this point, a lower concentration of households at the high end of the earnings distribution is noticeable in both states as well as in the nation as a whole.

An aspect that deserves particular attention in this context is the relationship between the level of income and vehicle ownership. Typically, higher-income households have higher vehicle ownership rates. According to the New York Metropolitan Transportation Council and the North Jersey Transportation Planning Authority, 48% of the New Yorkers and New Jerseyans having one car per household belong to the wealthiest households. In contrast, only 14% of car owners belong to low income households. Indeed, a 74% of households having two or more registered motor vehicles relates to the higher income levels registered, while this rate only reaches 4% for the households in the lowest income levels. This analysis suggests that,

Table 1

Overview of previous studies.

Author	Context	Title	Main characteristics and results
Letarte et al. (2016)	Canada	The Impacts of Universal Bus Pass on University Student Travel Behavior	<ul style="list-style-type: none"> • Origin-destination surveys before and after the implementation of the benefit. • Programs implemented had the expected results of increasing the public transit share and decreasing the car share. However, the walk share to campus decreased importantly.
Zhou and Schweitzer (2011)	USA	Getting Drivers to Switch: Transit Price and Service Quality among Commuters	<ul style="list-style-type: none"> • Based on two surveys. 568 respondents. • Try-transit and fare-free programs followed with discounted passes are likely to get some drivers to switch mode.
Washbrook et al. (2006)	Canada	Estimating commuter mode choice: A discrete choice analysis of the impact of road pricing and parking charges	<ul style="list-style-type: none"> • Based on a stated preference method. 650 respondents. • Results suggest that policy makers interested in reducing auto travel should create financial disincentives for auto use while improving the supply of alternative travel modes.
Scott et al. (2012)	New Zealand	Company cars and fringe benefit tax: understanding the impacts on strategic transport targets	<ul style="list-style-type: none"> • Based on travel plans. 5770 employees were examined. • his research indicates that employees who receive significant parking subsidies are more likely to drive than use alternative modes of transport.
Heinen et al. (2013)	The Netherlands	The effect of work-related factors on the bicycle commute mode choice in the Netherlands	<ul style="list-style-type: none"> • Based on a survey with over 4000 respondents. • Results indicate that an individual's working situation increase the likelihood of being a commuter cyclist (the presence of bicycle storage inside; having access to clothes changing facilities, etc.).
Hamre and Buehler (2013)	USA	Role of Commuter Benefits in Shaping Decision to Walk, Cycle, or Ride Transit to Work in Washington, DC, Region	<ul style="list-style-type: none"> • Data about full-time workers originate from the Washington, DC Household Travel Survey. 4630 respondents. • Results indicate that free car parking is significantly associated with lower levels of commuting by public transport as well as less walking and cycling to work. In contrast, benefits for walking and cycling are associated with higher levels of walking and cycling to work, as well as public transport usage.

at least in the case under study, the higher the household income the higher the car ownership rate, and thereby vehicle property may be capturing the income effect at a certain point.

The public transport system in the State of NY mainly consists of three modes: subway, bus and commuter trains. Despite New York has the highest transit usage rate in the United States, many communities are underserved by public transit—especially for many of New Yorkers who live outside Manhattan. On the other hand, the public transport system in the State of New Jersey consists of three main modes (commuter rail, bus and light rail), completed by a number of ferry services. According to the [New Jersey Department of Transportation \(2008\)](#), almost one in every ten workers in New Jersey uses public transit to get to work, twice the national average.

Another aspect that deserves consideration is related to the accessibility to public transport. As [Peters and Kramer \(2012\)](#) reported, good quality public transport is not universal in this region. For the case of New York City, they concluded that the outer boroughs are relatively underserved by mass transit relative to Manhattan. In particular, 99% of persons living in Manhattan are within half a mile of train stations. By contrast, other boroughs such as Staten Island or Queens reported significant lower percentages of accessibility (31% and 52%, respectively). Despite the importance of this topic, studies specifically focused on accessibility are particularly limited in these contexts and, consequently, it has not been thoroughly defined. We therefore decided to look more closely at transportation accessibility in order to later incorporate this variable into our research (see Section 4). Our analysis on this matter is in line with previous studies. Particularly, we found a huge difference in the accessibility to the subway, rail and bus system together for houses located in different counties. For example, 100% of the Manhattan residents have acceptable walking distances for transit services, while in other areas this percentage falls in the range of 20–30%, such as in Monmouth-Ocean, Hunterdon-Sussex-Warren and Mercer.

Finally, since there is a need to promote a more sustainable commuting pattern in major urban centers in the United States, commuter benefits in the New York and New Jersey metropolitan area and their impacts on employee travel behavior becomes a case study of great interest in the international context. Furthermore, under the new law (effective from January 2016), employers with 20 or more full-time employees have the obligation to offer commuter benefits to their workers. According to the [Forbes Magazine \(2016\)](#), it means that an estimated 450,000 more New York City-based employees will have access to these programs, in addition to the 700,000 employees who already participate in these types of programs.

4. Data sources, variables and model development

In order to explore the effects of transit benefits on employee travel behavior in the NY and the NJ region, we established a multinomial logit model based on data from the 2010–2011 Regional Household Survey (RHTS). The survey is representative of the region and requested participants to complete diary records of their daily travel over a 24-h period for each household member. All households within the counties constituting the NY/NJ metropolitan area were eligible for inclusion in the survey. In total, 18,965 households (43,558 persons) completed travel diaries. As previously done in the literature (Buehler, 2012; Hamre and Buehler, 2014; Dill and Wardell, 2007), our research focuses on commuters ($n = 21,771$ persons).

The survey is particularly useful for studying the relationship between commuter benefits and individual's commute mode choice. It collected information on the provision of commuter benefits which can be grouped into: (i) public transport-related (public transport fares reimbursement), (ii) private transport-related (toll payment, mileage reimbursement, free parking available for the employee at the working place, provision of company cars or take-home vehicles, etc.), or (iii) soft transport modes-related (secure bike parking, workplace showers and lockers or shared-use paths).

The variables initially included in the modelling approach are shown in Table 2. The dependent variable refers to the commuter's reported usual mode to get to work (driving, public transport, walking, and cycling). All available options have been grouped into these four categories. Firstly, private transportation includes car, motorcycle and taxi, the latter having the same characteristics from a transportation point of view (motorized door-to-door service, used by a single or small group of passengers). By contrast, public transportation includes shared passenger transportation services, such as subway, local/-express buses, light rail, etc. Finally, walking and cycling comprise non-motorized door-to-door options, typically for short distances. In those cases where more than one type of transport mode has been used, only the one covering the higher share of the total trip distance has been considered in the analysis.

The explanatory variables comprise attributes at both the individual and household levels (see Table 2). Individual characteristics include gender, age, race, work location, travel time to work, etc. Within this group, the key variable of interest regards to the transportation benefits/subsidies provided by the employer. The second group of variables is related to household characteristics, such as the household income, the household structure or the household vehicle size. Within this group of variables, it was considered necessary to incorporate the accessibility to public transport as a potential key explanatory variable of mode choice. To that end, we defined a new variable indicating the household accessibility to public transport services (bus, subway and rail lines). While this is still a limited measure due to the lack of detailed geographic information for bus routes, it is a good proxy of transit access and it is expected to be positively correlated with public transport use. The details regarding how we obtained this variable are reported in Table 2. Finally, we incorporated the variable *county grouping level* to capture specific issues dependent on the location of residence, e.g. the commuter lives in the urban core or in inner suburbs of the NY/NJ region. For instance, this variable may capture that residents of the urban core are likely to be provided with better public transport services. In addition, households located in NYC are wealthier than the average for the state and maybe more aware of pedestrians and cyclist.

Regarding the descriptive statistics of the sample, a balanced proportion of men (51.1%) and women (48.8%) were surveyed, with a higher presence of people aged between 35 and 54 (47.2%). We observed the income typically lying above \$75,000, and a vast majority of driving license holders (91.6%) and white ethnicity people (76.4%). Due to the nature of the database, it is also noticeable that the majority of respondents are full-time employed (73.3%). According to the sample, representative of the region, more commuters drive to work (61.3%) than use public transportation (21.9%). In addition, 23.8% reported to receive benefits including toll payment or reimbursement, public transit payment or reimbursement, free parking or reimbursement or secure bike parking, among others. Finally, the majority of respondents (87.5%) reported the availability of a car in their household. Some variability is also found in other explanatory variables such as the work location, household size or household structure. Further information about the descriptive statistics of explanatory variables included in this research can be found in Table 2.

As mentioned before, the research adopts a multinomial logit model (MNL) in order to explore the influence of transit benefits programs on employee travel behavior. The model can also be useful to examine other explanatory factors potentially affecting commuters' mode choice. Particularly, respondents reported in the RHTS survey the transport mode they chose for commuting purposes. As mentioned above, these answers were grouped into four different categories (public transit, private transport, walking and cycling), and represented the dependent variable of the multinomial choice specification. In this respect, the MNL approach adopted in this research represents an appropriate framework to explore and explain choice processes comprising more than two alternatives (Ben-Akiva, 1985).

A detailed description of the multinomial logit model is beyond the scope of this paper, and the reader is referred to Ben-Akiva and Bierlaire (1999), Ben-Akiva (1985), and Ortúzar and Willumsen (2011), among others. The original formulation of the logit model is derived from the utility maximizing behavior, assuming that decision makers are utility maximizers. Then, according to the economic theory, the individual will choose the option with the highest utility, each one determined by a number of explanatory parameters related to both personal attributes of the individual (I) and other characteristics of the household itself (H). The utility (U_{nj}) gained by individual n for choosing alternative j can be written as:

$$U_{nj} = f(I_{nj}, H_{nj}) \quad (1)$$

Table 2

Descriptive statistics for the independent variables.

Variable		Categories	Respondents	% Sample	
Dependent variable					
Mode of transport to work		Private transportation	13,338	61.3%	
		Public transportation	4764	21.9%	
		Walk	839	3.8%	
		Cycle	107	0.5%	
		Missing values (MV) ^a	2723	12.5%	
Explanatory variables					
Individual characteristics	Gender	Male—base reference (BC)	11,133	51.1%	
		Female	10,624	48.8%	
	Age	MV	14	0.1%	
		Under 24 years (BC)	1335	6.1%	
		From 24 to 34 years	2701	12.4%	
		From 35 to 54 years	10,262	47.2%	
		From 55 to 64 years	5704	26.2%	
		Above 64 years	1434	6.5%	
		MV	335	1.5%	
	Driver's license status	Positive	19,962	91.6%	
		Negative (BC)	1786	8.3%	
	Race/ethnicity	MV	23	0.1%	
		White (BC)	16,622	76.4%	
		Non-white ^b	4755	21.8%	
	Life cycle status	MV	394	1.8%	
		Full-time employed (BC)	16,086	73.3%	
		Part-time employed	5481	24.9%	
		MV	204	1.8%	
	Work location	Fixed (BC)	17,107	78.6%	
		Varies	4664	21.4%	
	Employer transportation benefits	Do not use any subsidies (BC)	13,601	62.5%	
		Private vehicle-related	3604	16.5%	
		Public transport-related	1350	6.2%	
		Bike-related	43	0.2%	
		Other	189	0.9%	
	Typical travel time in minutes ^c	MV	2984	13.7%	
		Non-categorical variable	Mean: 35.98	Sd: 29.05	
		Number of person trips per day ^c	Non-categorical variable	Mean: 3.64	Sd: 2.54
	Household characteristics	Residence type	Single-family (BC)	14,622	67.2%
			Other	7129	32.8%
			MV	20	0.0%
		Household income	Under \$14,999 (BC)	580	2.7%
From 15,000 to \$29,999			1373	6.3%	
From \$30,000 to \$74,999			5688	26.2%	
From \$75,000 to \$99,999			3139	14.4%	
Above \$100,000			9631	44.2%	
MV			1360	6.2%	
Household size		1 member (BC)	3350	15.4%	
		2 or more members	18,421	84.6%	
Household vehicle size		No vehicle (BC)	2728	12.5%	
		1 or more vehicles	19,043	87.5%	
Household structure		Above 2 Workers with Child(s) (BC)	4815	22.1%	
		Above 2 Workers no Children	9375	43.1%	
		1 Worker with Child(s)	1574	7.2%	
		1 Worker no Children	6007	27.6%	
Public transport accessibility ^d		Not accessible(BC)	6373	29.3%	
		Accessible	15,398	70.7%	
County grouping level		Manhattan (BC)	1688	7.8%	
		Other NYC	4222	19.4%	
		Long Island	3021	13.9%	
		Mid-Hudson	1761	8.1%	
		Mid-Hudson (other)	1007	4.6%	
		Bergen Passaic	1835	8.4%	
		Essex-Hudson union	2745	12.6%	
		Middlesex-Morris-Somerset	2231	10.3%	
		Monmouth-Ocean	1566	7.2%	

Table 2 (continued)

Variable	Categories	Respondents	% Sample
	Hunterdon-Sussex-Warren	1270	5.8%
	Mercer	425	1.9%

^a This variable has a substantial number of cases with missing values, corresponding to the answers recorded as 'don't know' or 'refuse to answer'. We also added those cases with transport modes that cannot be classified as public transport or private car.

^b This category includes: African American, Black, Asian, American Indian, Alaskan Native, Pacific Islander, Multiracial and Hispanic/Mexican.

^c The mean and the standard deviation are presented as descriptive statistics for non-categorical variables.

^d This variable was obtained by using Geographic Information System (GIS) techniques. Particularly, we created different buffers around the existing public transport network (subway and rail lines). We used a 600 m buffer for subway lines and a 1200 m buffer for rail lines. Due to the lack of detailed geographic information available for bus routes, accessibility to bus services was measured based on a proxy indicator at the county level, calculated as number of bus stations per county divided by the county area. Finally, households were classified as 'accessible to public transport' if their corresponding census tracts centroids were situated within a buffer or were located within a county where the number of stations per area is above the average value obtained for the rest of the counties.

Then, the utility obtained by the decision maker from alternative j can be divided into two additive parts as follows:

$$U_{nj} = V_{nj} + \varepsilon_{nj} = \beta_j X_{nj} + \varepsilon_{nj} \quad (2)$$

The average utility (V_{nj}) is made up of explanatory variables known by the researcher while ε_{nj} are the disturbances or random components associated with the choice option. X_{nj} is a vector of observed variables relating to alternative j that define individual or household characteristics such as age, race, level of income or travel time. β_j is a vector of coefficients to be estimated (Louviere et al., 2010).

As explained by Ben-Akiva (1985), the probability that respondent n will choose alternative j can be expressed as shown in Eq. (3). According to Train (2009), the multinomial choice is a simple extension of logit models for binary responses. With respect to the choice between different transportation mode alternatives, the multinomial logit regression model is thus given by the following equation, where $P(Y_n = j)$ equals the probability that the individual with characteristic x_n chooses the j th category of the dependent mode choice variable.

$$P(Y_n = j) = \frac{e^{V_{nj}}}{\sum_j e^{V_{nj}}} = \frac{e^{\beta_j X_n}}{\sum_{j=1}^J e^{\beta_j X_n}} \quad \text{for } j = 1, \dots, J \quad (3)$$

Then, the MNL models the odds¹ of each category relative to a baseline category as a function of covariates (Kohansal and Firoozzare, 2013). Regarding the interpretation of the results, the β coefficient indicates that for a unitary increase in a certain explanatory variable X_i , the odds ratio in favor of happening $Y = 1$ increases by e^{β_i} .

In addition, we calculated the marginal effects (MEs) of the explanatory factors of the model, interpreted differently depending on whether the explanatory variable is continuous or categorical. For categorical variables, the MEs show the difference in the predicted probabilities for cases in one category relative to the reference category (e.g., white respondent instead of non-white respondent). On the other hand, MEs for continuous variables measure the instantaneous rate of change. Finally, we used the cross-validation technique to detect and prevent over-fitting. Based on a 10-fold cross-validation test, we estimated how accurately our predictive final model would perform in practice. To that end, we divided the data into two sets: a training set and a test set. The training set contains 90% of the sample, and was used to fit the multinomial model. The model was then applied to the test set (i.e. 10% of the remaining respondents). We then evaluated the accuracy of the prediction on the test set by means of a variable that counts the number of times the model correctly predicts the transport mode chosen by each individual. This procedure was repeated 5000 times, with randomly selected training and test sets.

As a complementary approach to the inclusion of the dummy variable *county grouping level* (see Section 4), we decided to explore in more detail potential differences in mode choice across geographic counties of residence. As this analysis represents an extension reinforcing the developed model, we applied the standard multilevel binary logit analysis based on random coefficients (Leew et al., 2008). In this sense, we account for potential correlation among responses due to hierarchical structures in the data, corresponding in our case to the county-group of residence. As in every multilevel approach, a significant random intercept with regard to the county of residence indicates correlation among responses from same clusters.

5. Results

This section summarizes the main findings from the multinomial logit regression analysis conducted to examine the impact of transit benefits on commuters' travel behavior. Before calibrating the model, we conducted some tests aimed at identifying potential multicollinearity problems between the explanatory variables included in the model, concluding no significant interactions. Regarding the goodness of fit of the estimated results, the model presents a pseudo R-square coefficient

¹ As defined by Bhadra (2010), the odds is the ratio of the probability that the event of interest occurs to the probability that it does not.

of 0.54, which may be considered satisfactory for logit specifications according to Hensher and Bradley (1993). This result is comparable to the fit accuracy achieved in similar studies (see for instance Buehler, 2012; Dill and Weinstein, 2007; Thrane, 2015). In addition, the signs of the regression coefficients and their statistical and practical significance are in line with the expected results.

Final results coming from the modelling analysis are shown in Table 3. It should be noted that only those coefficients resulting statistically significant with 90%, 95% and 99% confidence intervals are displayed. Hence, explanatory variables included in Table 2 but not listed in Table 3 (i.e. gender, residence type, household structure, age, among others) were finally excluded out of the final model as being non-statistically significant (p -value > 0.10) because they showed irrelevant influence on the overall model results. As commonly done for logit models analysis, slope coefficients of explanatory variables (β_j) are evaluated according to a twofold criterion: (i) the sign of the coefficient and (ii) its magnitude.

The results confirm that commuters' mode choice is influenced by both individual and household characteristics. Among individual characteristics, providing *transport benefits* was found among the most significant determinants of commuters' mode choice. In this respect, receiving subsidies that encourage private transport use (*private vehicle-related*) is found to be strongly negatively related to the likelihood of commuting by using public transport, walking or cycling. For instance, benefits such as toll payments, mileage reimbursements or free parking decrease the likelihood to commute by public transport over private car by 82%. This result is similar to the finding in Peters et al. (2011) with respect to toll payment by employers and the frequency of use of toll facilities. Moreover, we have found that private vehicle benefits are associated with a significant decrease in the probability of choosing alternative modes such as walking (−57%) or cycling (−60%) over driving, which reveals the importance of commuter benefits for promoting more sustainable options for short distances. In sum, employer-paid benefits for driving do not seem to effectively promote more sustainable commuting patterns pursued by TDM objectives.

In contrast, employer programs promoting the acquisition of public transport monthly passes, universal passes, vouchers or reimbursements significantly encourage employees to switch from drive-alone commuting. Commuters provided with public transportation benefits are about 9 times more likely to ride public transport than to drive alone and 3 times more likely to change their travel behavior towards walking or cycling. Therefore, incentives offered by employers have a great influence on employees' choices, making it more convenient to e.g. ride transit to work than drive a car. It is worth mentioning that our analysis identified *public transport-related* subsidies as the primary determinant in explaining public transport choices, if we exclude the location of the county of residence within the NY/NJ area.

Finally, bike benefits are strongly correlated with an increased likelihood of commuting by bicycle. Compared to individuals receiving no subsidies, individuals with cyclist showers, lockers, or bike parking at work are 50 times more likely to commute by bicycle. In fact, *bike-related benefits* were identified as the most important factor explaining the decision of cycling to work (over all other explanatory variables listed in Table 2). Nevertheless, the effect of bike-related benefits is expected to be significant mainly for short distances. Additionally, we should point out that the bike share for the area under study still remains rather low (0.5% in the sample).

In summary, the modelling results confirm that the provision of transport benefits to employees such as trip-end facilities for cycling at work, free car parking, incentives for private car use and public transportation reimbursements, can strongly influence commuters' choices. In this respect, employer benefits should be acknowledged as a key component to be included and properly drawn when designing a sustainable transport policy package for daily mobility. However, it is worth to keep in mind that potential self-selection has not been explored in this study, which might leads to an overestimation of the importance of these benefits in the model—see van Wee (2009).

Based on the above results, we claim that, at least for commute mode choice, the conditioning influence of receiving subsidies prevails over other individual variables. In the following paragraphs, we present the main conclusions that can be drawn regarding the additional control variables which resulted statistically significant in the analysis (see Table 3).

Regarding the *driver's license status*, it can be concluded that individuals having a driving license are less likely to ride public transport ($=e^{-1.933}$) and less likely to cycling ($=e^{-1.527}$) or walking ($=e^{-1.819}$) to get to work than individuals without it, keeping the rest of variables constant. Furthermore, other individual variables are also related to commute mode choice, but their influence is less strong in practice. For instance, those workers who are *part-time employed* and whose *work location* varied, have a lower chance of commuting by public transport. The latter result may be an indication of the relationship between public transport and the regularity of the trips. Moreover, we found that white (Anglos) people are significantly more likely to commute by using private transport as compared to other races and ethnicities. Conversely, non-white people were also associated with reduced odds for walking and cycling to work. Furthermore, coefficient results for *person trips* and *travel time* variables pointed in the expected directions. An increase in the number of trips generates a decrease in public transit usage, as it becomes less flexible to easily reach multiple destinations. Likewise, an increase in the travel time typically increases the probability of using the public transport system – e.g. commuting by train when living far away from the NY/NJ metropolitan area – and decrease the probability of walking to get to work, especially for long-distance trips.

Results also suggest that household characteristics do also play a significant role in explaining travel behavior. In that respect, the commuting mode choice was found to be mostly determined by *car ownership*. Having one or more vehicles greatly decreases the probability to commute by public transport (−96%), walking (−95%) and cycling (−97%) when compared to the reference case (choosing private transport).

On the other hand, a statistically significant influence cannot be concluded from this analysis for the *income* variable. Differences between wealthy and poor residents within NY and NJ do not appear to explain commuter modal variability when

Table 3

Summary of Model Results for commuters' mode choice (base case: private transport).

Variables		Public transport (j = 1)		Walk (j = 2)		Cycle (j = 3)	
		β_j	p-value	β_j	p-value	β_j	p-value
Individual characteristics	<i>Driver's license status</i>						
	Negative (BC)						
	Positive	−1.933	0.000***	−1.819	0.000***	−1.527	0.000***
	<i>Race/ethnicity</i>						
	White (BC)						
	Non-white	0.237	0.000***	−0.148	0.149	−0.765	0.007**
	<i>Life cycle status</i>						
	Full-time employed (BC)						
	Part-time employed	−0.303	0.000***	0.167	0.140	−0.297	0.384
	<i>Work location</i>						
	Fixed (BC)						
	Varies	−0.268	0.003***	−0.123	0.424	0.365	0.292
	<i>Employer transportation benefits</i>						
	Do not use any subsidies (BC)						
	Private vehicle-related	−1.748	0.000***	−0.847	0.000***	−0.921	0.026**
	Public transport-related	2.157	0.000***	1.198	0.000***	1.096	0.006***
Household characteristics	Bike-related	0.105	0.887	−0.713	0.570	3.942	0.000***
	Other	1.952	0.000***	0.702	0.286	1.201	0.273
	Typical travel time in minutes	0.050	0.000***	−0.084	0.000***	−0.000	0.886
	Number of person trips per day	−0.095	0.000***	−0.010	0.561	0.029	0.357
	<i>Car ownership</i>						
	No vehicle (BC)						
	1 or more vehicles	−3.258	0.000***	−2.871	0.000***	−3.401	0.000***
	<i>Public transport accessibility</i>						
	Not accessible (BC)						
	Accessible	0.820	0.000***	0.672	0.001***	0.337	0.867
	<i>County grouping level</i>						
	Manhattan (BC)						
	Other NYC	−1.472	0.000***	−1.975	0.000***	−1.611	0.000***
	Long Island	−3.431	0.000***	−3.838	0.000***	−3.584	0.000***
	Mid-Hudson	−2.545	0.000***	−3.531	0.000***	−4.036	0.000***
	Mid-Hudson (other)	−4.219	0.000***	−3.680	0.000***	−3.790	0.000***
	Bergen Passaic	−2.893	0.000***	−3.890	0.000***	−4.269	0.000***
	Essex-Hudson union	−2.174	0.000***	−2.897	0.000***	−2.851	0.000***
	Middlesex-Morris-Somerset	−3.819	0.000***	−4.568	0.000***	−2.555	0.000***
	Monmouth-Ocean	−3.777	0.000***	−3.591	0.000***	−3.503	0.000***
	Hunterdon-Sussex-Warren	−6.324	0.000***	−3.692	0.000***	−3.302	0.000***
	Mercer	−3.045	0.000***	−3.289	0.000***	−1.663	0.024**

Base outcome driving (private transport).

Log likelihood −5471.27.

Pseudo R2 0.548.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

controlling for other potential explanatory factors. This result is in line with other papers found in the literature (Buehler, 2011; Hamre and Buehler, 2014; Lipps and Kunert, 2005; Schwanen and Mokhtarian, 2005). This finding could be explained by the fact that vehicle ownership may be capturing somehow the income effect. This assumption is supported by the relationship previously observed between the level of income and vehicle ownership in NY and NJ (see Section 3). At this point, it may happen that mode choice decisions in this area may be mostly influenced by other explanatory variables such as car ownership, in contrast to a limited effect of the income level. In fact, income may well be a catchall bucket for other economic variables that were omitted from the model, and with a well specified model the impact of income may be muted as other variables that directly impact demand may take the explanatory power away from a very gross metric of households ability to command goods (income).

Accessibility to public transport has also evidenced to be a relevant factor when explaining commuters' mode choices. Particularly, individuals living in areas close to public transport facilities are about 127% more likely to commute by bus, subway or rail, compared to people with poor accessibility to the public transport network. Indeed, transit access is also associated with a greater likelihood of walking and cycling to work. This later result may be due to the fact that transit stations are interpreted by respondents as possible facilities for integrating bicycles (bike sharing stations or bike parking at rail stations and bus stops, as well as bike racks on buses and short-term rental bikes). These findings provide evidence that the level of *public transport accessibility* in NY and NJ plays a significant role in determining public transport use, and promoting

a more sustainable mobility in high-dense metropolitan areas. This is important from a planning perspective—as the access to good quality public transport is not universal in this region—, also applicable to other American cities. Therefore strategic expansions of the transit networks may have significant impacts on mode choice over time.

The influence of the explanatory factors can also be interpreted by taking into account the marginal effects in predicted probabilities. The main results obtained from this analysis are shown in Table 4. Among all the variables modelled, it is worth mentioning the case of *transport benefits*, *public transport accessibility*, and *car ownership*; since—as explained above—were found to have a greater impact on travel mode choice decisions compared to other personal and household characteristics. According to the results, setting all variables at their means reveals that if the employer transportation benefit changes from *no subsidies* to *private vehicle-related subsidies*, the probability of driving increases by 12% while the probability for public transport use decreases in the same proportion. By contrast, a change towards *public transport-related subsidies* reduces the probability of driving by 16% and increases the likelihood for riding public transport by 15%. Moreover, encouraging bike commuting through *bike-related* transportation benefits slightly increases the probability of cycling to work (+2%).

Similar findings for marginal effects were obtained for the variables *public transport accessibility* and *car ownership*. In case of owning *one or more vehicles*, the probability of choosing the private transport alternative increases by 40%. However, in this case, the probabilities for riding transit (−28%), walking (−10%), and cycling (−2%) are strongly reduced. Conversely, having household *accessibility to public transport* slightly increases the probability of choosing transit modes (5%) and, to some extent, reduces the predicted probability for the cases of driving to work (−6%). Further information about the marginal effects reported for other explanatory variables included in this research can be found in Table 4.

Finally, we analyze the influence of residence location on commuters' mode choice within the area under study. Estimation results show that residents of inner suburbs of the NY/NJ region are associated with a decreased likelihood of riding public transportation, walking, and cycling to work (see Table 3, variable *county grouping level*). This suggests that people living in Manhattan commute more often by public transport and soft transport modes than residents of inner suburbs. This result may be a consequence of having higher transit access and/or living closer to their workplaces. To a lower extent, it seems to be also the case of the Essex-Hudson area, since it is fairly provided with public transport services. By contrast, outer regions such as Hunterdon-Sussex-Warren or other Mid-Hudson, with a poorer accessibility by transit modes, show higher percentages of individuals commuting by private car. This analysis was confirmed by exploring differences in mode choice across counties of residence through a multilevel specification, a suitable econometric technique for exploring geographic differences from the sample. Through this process, we found the standard deviation of random intercepts for regions to be highly significant ($p\text{-value} = 0.001$). This fact evidences that, from a practical point of view, there are significant differences among counties of residence regarding the mode choice. Results for random coefficients obtained for every county-grouping can be found in Annex 1. They confirm that individuals living in Manhattan show the highest use of public transport services. By contrast, residents of the counties Hunterdon-Sussex-Warren reported significant lower transit ridership levels. As can be seen, this result is strongly consistent with previous analysis based on the dummy variables included in the original multinomial model (see Table 3).

Table 4
Marginal effects.

Variables	Private transport dy/dx	Public transport dy/dx	Walk dy/dx	Cycle dy/dx
<i>Driver's license status</i>				
Positive	0.204***	−0.148***	−0.053***	−0.003
<i>Race/ethnicity</i>				
Non-white	−0.011**	0.022***	−0.007**	−0.004***
<i>Life cycle status</i>				
Part-time employed	0.016**	−0.024***	−0.008**	−0.001
<i>Work location</i>				
Varies	0.017**	−0.019***	−0.001	0.003
Typical travel time	−0.001***	0.004***	−0.003***	−0.001**
<i>Employer transportation benefits</i>				
Private vehicle-related	0.127***	−0.121***	−0.006	0.001
Public transport-related	−0.159***	0.148***	0.127	−0.001
Bike-related	−0.001**	0.010***	−0.030	0.021***
Other	−0.138***	0.138***	−0.001	0.001
Person trips	0.006***	−0.007***	0.001	0.001**
<i>Car ownership</i>				
1 or more vehicles	0.396***	−0.280***	−0.096***	−0.021**
<i>Public transport accessibility</i>				
Accessible	−0.061***	0.053***	0.010*	−0.001

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

As a final point, as explained in Section 4, we tested the internal validity of the model by means of a 10-fold cross-validation method. According to this simulation analysis with 5000 random sets, we found that on average the model correctly predicts 84% of the transport mode choices made by individuals in the sample. This test is further evidence that our model can accurately predict travel behavior.

6. Comparative analysis of the results and limitations

The results from the multinomial logistic regression presented above suggest a significant association between commuter benefits and transportation mode choice. This conclusion is consistent with relationships reported in most other studies found in the literature. There are however, some different findings across studies due to the effect sizes of the benefits. As pointed out by [Transit Cooperative Research Program \(2005\)](#), the results may vary, from cases with very minor impact to cases in which transit ridership more than doubled.

Although most studies suggest that commuters receiving private vehicle-related subsidies are less likely to use public transport, the magnitude of this effect slightly varies across case studies. As explained before, benefits such as toll payments, mileage reimbursements or free parking were found to greatly discourage public transportation use (82%). This finding is similar to that reported by [Hamre and Buehler \(2014\)](#), who found car benefits related to a 90% decrease in the probability to choose public transportation than private car.

Moreover, private vehicle benefits are typically found in the literature to discourage cycling to work. For example, [Buehler \(2013\)](#) found that car facilities such as free parking at the workplace are associated with a lower likelihood for cycling to work (odds ratio of 0.303). In our analysis, these benefits are associated with similar magnitudes of decrease in the odds ratio in favor of other alternative modes such as walking (odds ratio of 0.43) or cycling (odds ratio of 0.39). Then, our findings are also consistent at this point with previous works, such as [Buehler \(2013\)](#) or [Shoup \(2005\)](#). It is worth mentioning that the level of influence of these kind of benefits on the possibility of cycling to work does not considerably vary among the studies.

Likewise, we found that commuters being offered public transportation benefits are about 9 times more likely to take public transportation than to drive and 3 times more likely to choose walking or cycling over driving. Other research such as [Hamre and Buehler \(2014\)](#) obtained comparable results, particularly the effect sizes (11 times more likely for riding transit and 2 times more likely for walking and cycling). However, our study found higher influence of bike benefits on the choice between cycling and driving (odds of 51.5) when compared to other effect sizes reported in the literature—for example [Hamre and Buehler \(2014\)](#) or [Buehler \(2013\)](#). This difference may be interpreted on the basis of the small sample size of bike benefits recipients for the area under study.

Divergences found in this section might be explained by the unique nature of each case study and also by the differences in the methodology applied in the various studies mentioned before, including sample characteristics, the type of survey and the model development. Furthermore, findings may be not replicated in our context of study since we analyzed a very transit-intensive and large metropolitan area that may be not necessarily representative of other U.S. cities and regions.

Finally, several aspects for further research arise from the results and limitations of this paper. Firstly, additional efforts are needed to extend the current multilevel analysis in order to estimate more accurately how much of the variability observed in the mode choice variable is attributable to individual variables, and how much may correspond to a group effect (geographic area of residence). Future contributions should attempt to refine this analysis by adopting more complex econometric specifications such as multilevel multinomial logistic regression models. Secondly, additional research should delve more deeply into how self-selection may help to a better understanding of travel behavior. At this respect, more complex models such as structural equations modelling could be developed in order to address the potential self-selection bias effect on the results. Thirdly, the quality and quantity of the benefits provided should be examined in greater detail, particularly the influence of changes in the magnitude of benefits on mode choice. Additionally, since our research considered only the main mode in a multimodal trip, future studies should also explore the relationship between commuter benefits and the combination of several modes for origin-destination relationships.

7. Summary and conclusion

This study is aimed at exploring the effects of transport benefits programs on commuter travel behavior in the regions of New York and New Jersey. It addresses the question of whether packages that offer benefits for driving as well as walking, cycling, and using public transportation effectively promote sustainable travel behaviors. On the basis of individual data from the 2010–2011 Regional Household Travel Survey (RHTS), we have investigated to what extent commute mode choice is influenced by commuter transportation benefits and other relevant socio-economic and transport-related variables. To that end, we have developed a multinomial logit model to analyze the impact of different types of commuter benefits on mode choice by comparing motorists with public transport users, pedestrians, and cyclists. We also explored the relative importance of additional explanatory variables such as car ownership, accessibility to public transport or income. The analysis yielded some interesting conclusions.

The first conclusion regards the strong and significant relationship observed between commuter benefits and transportation mode choice. This result is important insofar as policy efforts are directed towards reducing car dependency in the US. Since benefits for public transportation are strongly associated with an increased likelihood to ride public transportation,

walk and cycle to work; our research provides insight to claim that these benefits may be an effective means to make public transport and soft modes more attractive to commuters, thus increasing efficiency and sustainability. Results of this analysis indicate that benefits such as public transport monthly passes, universal passes, vouchers or reimbursements constitute the most significant determinant for explaining the decision to ride transit.

At the same time, we found out that the provision of private transport-related benefits, such as free car parking or toll/mileage reimbursement, is strongly associated with a low likelihood to choose public transportation and soft modes for commuting trips. This finding confirms that, as expected, employer-paid benefits for driving do not contribute to promote sustainability objectives. Furthermore, bike-related benefits were found among the factors mostly influencing bicycle commuting. It means that trip-end facilities for cycling at work play a key role in determining the likelihood of bike commuting, at least for short distances.

Then, increasing employer benefits to make public transport and soft modes alternatives more attractive, while reducing private vehicle benefits at the same time, may be an effective means of changing travel-related choices, particularly in metropolitan areas. Results of this analysis indicate that a comprehensive package of policies seems to be more effective than implementing them alone. Some level of pull measures—incentives for changing car use to non-automobile travel modes—along with push measures—decreasing benefits for automobile users—may have larger impacts on travel behavior.

The second conclusion is that modal choice is the result of a whole range of factors that are interrelated to a greater or lesser extent. For that reason, we also studied additional control variables regarding the characteristics of the trip maker as well as other household-related attributes potentially determining the choice of transport mode. On the basis of the results of this research we conclude that individuals with driver licenses and easy access to a car are less likely to commute by public transport, walking and cycling. By contrast, commuters living in areas close to public transport facilities have a higher chance of commuting by bus/subway/rail services. On the other hand, explanatory variables such as household income level were not found statistically significant to explain individuals' decision for this case study.

Although there are many factors that affect employee travel behavior, the present study supports earlier findings that present transit benefits as a key driver of the mode choice adopted. As a consequence, we claim the need for implementing proactive policies that promote alternative and sustainable modes combined with policies that make car use less attractive. Through e.g. transit benefits programs, decision-makers can easily influence commuters travel behavior, whereas controlling other determinants such as car use (e.g. towards road charging, gasoline taxation, car purchase policies) may be more difficult to implement or may result in negative public attitudes.

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Appendix A. Random coefficients obtained through a multilevel model for the county groups

County grouping level	Mean
Manhattan (BC)	3.081
Other NYC	1.639
Long Island	−0.385
Mid-Hudson	0.581
Mid-Hudson (other)	−1.193
Bergen Passaic	0.252
Essex-Hudson union	0.929
Middlesex-Morris-Somerset	−0.794
Monmouth-Ocean	−0.781
Hunterdon-Sussex-Warren	−3.331
Mercer	0.094

95% confidence interval: 1.036–2.472.

Std. error 0.355.

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Seeking Factors to Increase the Public's Acceptability of Road-Pricing Schemes

Case Study of Spain

Paola Carolina Bueno, Juan Gomez, and Jose Manuel Vassallo

User acceptability has become a critical issue for the successful implementation of transport pricing measures and policies. Although several studies have addressed the public acceptability of road pricing, little evidence can be found of the effects of pricing strategies. The acceptability of alternative schemes for a toll network already in operation is an issue to be tackled. This paper contributes to the limited literature in this field by exploring perceptions toward road-pricing schemes among toll road users. On the basis of a nationwide survey of toll road users in Spain, the study developed several binomial logit models to analyze user acceptability of three approaches: express toll lanes, a time-based pricing approach, and a flat fee (vignette) system. The results show notable differences in user acceptability by the type of charging scheme proposed. Express toll lanes were more acceptable by travelers who perceived greater benefits from saving travel time. The acceptability of time-based approaches (peak versus off-peak) decreased for users who felt forced to use the toll road, whereas this was not an aspect that significantly influenced users' support for flat fee schemes. In addition, a flat fee strategy was more acceptable for long-distance trips and truck drivers who regularly used the toll facilities. The results from this analysis can inform policy makers and planners for the promotion of more efficient, socially inclusive, and publicly acceptable road-pricing schemes.

Road charging remains one of the most debated topics for transportation planners and researchers. Given that road charging encourages users to pay for the external costs they produce, it has been a transportation policy advocated by economists for decades. In practice, the implementation of road-pricing mechanisms has proven to be an effective instrument in achieving the objectives of congestion relief, environmental improvements, and revenue generation in the face of public budget constraints.

Congestion-charging schemes have been implemented in urban environments, such as Singapore (1975), Oslo (1990), London (2003), and Stockholm (2006), among others. Pricing schemes have been implemented in metropolitan and interurban contexts worldwide, under the approach of toll road concessions, generally managed by private operators, or, especially for European countries, tolling schemes adopted by national authorities as a funding source and a way to promote efficient road mobility in interurban contexts.

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One of the major obstacles to the widespread implementation of road charging is its still scarce public acceptability (1). Previous research has clearly shown that public acceptability of such measures is low, with considerable public resistance to road pricing in Europe and beyond, as was evidenced by Link and Polak (2). Nevertheless, public opposition to charging policies is not inevitable, as was pointed out by Jaensirisak et al. (3). For instance, spending road revenues on public transport or setting an understandable and reasonable pricing purpose may contribute to minimizing opposition to road charges and increasing their political acceptability.

Acceptability of road-pricing schemes is determined by several factors, which can be broadly classified into three main categories. The first group comprises socioeconomic characteristics, such as income, age, gender, and labor status, among others. The second category includes some trip-related attributes, such as trip purpose or frequency. The third group covers attitudinal factors specific to individuals, including perceptions and beliefs about road pricing, as well as context-specific variables.

In the extensive literature on road-pricing acceptability, some important issues have not yet received the attention they deserve. A key issue is the extent to which the type of pricing scheme applied may influence user acceptability toward tolling. The current evidence on the relationship between acceptance and various charge schemes is inconclusive and has not been analyzed in detail (3, 4).

This study aimed to gain insight into how toll road user acceptability might be improved, and establish some policy recommendations for implementing more effective pricing policies. The study explored differences in user acceptability of alternative charging systems to be potentially implemented: a surcharge to avoid congestion at any time (express toll lanes), a time-based (peak versus off-peak) pricing approach, and a flat fee (vignette) system. The results of this study are also useful for identifying user market segments, as well as targeting effective messages to specific groups at the time of the implementation of the proposed pricing systems.

The study analyzed users' perceptions through stated-preference choices from real users of the toll network, as was done by Gomez et al. (5) for Spain, and Odeck and Bråthen (6) for Norway. However, as far as the authors are aware, this methodology has not been used to model the acceptability of alternative pricing strategies. The analysis was carried out based on a nationwide survey of users of the toll motorway network in Spain. As other authors have done (7, 8), the information was obtained from drivers who use the toll road mainly for work purposes (commuting and work trips paid by the user). This group was selected because it is more captive of the road than leisure drivers are.

This paper provides a literature review on the topic and briefly describes the case study analyzed: the toll road network in Spain.

It then outlines the methodology adopted for the research, and presents the survey and explanatory variables that were considered for the analysis. Finally, the paper discusses the results and provides conclusions and policy recommendations.

LITERATURE REVIEW

Acceptability of Road Pricing

Many books and academic papers have examined attitudes toward road-pricing strategies [e.g., Jakobsson et al. (9); Noordegraaf et al. (10)]. Among previous studies exploring the phenomenon of public acceptance, it was commonly agreed that gaining support for road pricing constitutes one of the main policy objectives toward a broader implementation of these schemes, as was found by Jakobsson et al. (9) and Schade and Baum (11).

Acceptability of road charging has been formally evaluated in different ways. These include, among others, full-scale trials, as developed in Stockholm, and referendums, as in the case of Edinburgh or Sidney. Studies of the acceptability of road pricing have covered many contexts. These studies include real cases such as Stockholm and Milan and hypothetical implementations such as London and Leeds in the United Kingdom, and New York and Virginia in the United States. As noted by Grisolia et al. (12), the recent literature has shown growing interest in the issue of acceptability by the general public and politicians, generally aimed at extracting lessons from previous charging implementations [e.g., Odeck and Bråthen (6); Noordegraaf et al. (10)]. Furthermore, many contributions have focused on public opinion toward the concept of pricing, as in Li and Hensher (13) and Fürst and Dieplinger (14).

The following list presents the main conclusions that can be drawn from a detailed review of previous contributions dealing with attitudes toward road pricing, to identify the gap in the literature that motivated this research.

- Most of the previous studies acknowledged that public support for transport pricing measures and policies is often quite low (15), with citizens generally opposed to this type of measure [e.g., Harsman et al. (16)].

- Acceptability is not predetermined and may be influenced by, and hence can be changed through, a variety of attitudinal, empirical, and political persuasions (17). The literature has shown that pricing is more acceptable (a) if the purpose and benefits of the policy are clearly understood; (b) if the objectives of the scheme address public concerns, such as environmental issues; and (c) if revenues are spent in the transport sector [e.g., Odeck and Bråthen (6); Gaunt et al. (15)]. Some policies, such as reasonable allocation of revenues or appropriate compensation to the losers, are expected to increase the perceived sentiment of fairness.

- The type of pricing scheme may influence the level of acceptability. However, the current evidence on the relationship between public acceptance and various charging schemes is not conclusive. As acknowledged by May et al. (4), some authors have found little difference between the acceptability of cordon, distance, and delay-based charges (18), while other analyses have demonstrated that there are large differences in acceptability, depending on the characteristics of the charging system (19). In general, previous research has shown that more complex schemes are likely to be less acceptable (20, 21). All the research studies mentioned have explored public acceptability of the hypothetical implementation of different types of road-pricing

schemes. By contrast, there is a need to analyze the effects of public acceptability based on the point of view of those individuals who are already charged for using roads.

- Several factors may influence the acceptability of road pricing. In general, these factors can be grouped into sociodemographic characteristics, trip-related attributes, attitudinal variables, and other factors such as attributes of the pricing scheme. For example, some studies have found that car drivers show lower acceptability compared with public transport users (22), while other authors have identified the region of residence as one of the most significant determinants of the acceptability of road pricing (20). Furthermore, some contributions have pointed out that socioeconomic factors may have a somewhat lesser impact on acceptability than attitudinal factors have (3, 18, 23).

- Current evidence of the influence of socioeconomic or transport-related factors (age, income, trip purpose, and so forth) on perceptions toward road pricing was not conclusive at the time of this study. For instance, some empirical studies have found a positive relationship between age and acceptance (23), while others have found no significant relationship (24) or even a negative correlation (3). Some authors have found that women support road pricing more strongly than men do (24), while the opposite occurs in the case of Edinburgh (25). Gehlert et al. (26) also provided examples of socioeconomic differences in public acceptability of road pricing.

- Analysis of the social impacts and equity implications has focused on the additional burdens of road-pricing measures. Some studies have suggested that the higher is the level of income, the less important is the additional burden from road-pricing charges (27). However, some other research has not confirmed the relationship between the support for pricing options and the level of income (19), or interpreted road charging as a regressive policy in income distribution (7).

- The literature review showed a significant body of research on public acceptability. However, there are still many points to be addressed. First, the fundamental issue of the influence of different road-pricing schemes on acceptability has not received great attention in the academic literature, as was recognized by Jaensirisak et al. (3). There is a need to explore how the adoption of a different charging scheme may contribute to changing user acceptability for road facilities that are already tolled. Second, previous research mainly focused on urban areas, showing particular interest in the implementation of congestion-charging systems (28, 29), while large-scale acceptability studies that focused on interurban roads were particularly limited (30). Finally, there has been no consensus in the literature on the influence of personal characteristics and attitudinal factors on user acceptability, which is essential to provide good guidance for policy makers.

Spain's Toll Road Network

In the early 1970s, tolls were introduced in Spain with the objective of developing high-quality road projects in a period of scarce budgetary resources (31). Spain's high-capacity network has a total of 16,583 km, one of the longest in Europe. The network is made up of toll and free high-capacity roads. The toll road concessions represent 18.2% of the high-capacity network currently in operation (32). A detailed description of the evolution of Spain's toll road network was beyond the scope of this study. Interested readers are referred to Gomez et al. (5). However, to understand the context of the stated preference survey, it is necessary to give some information about the toll road system in Spain.

Spain's national toll road network is made up of two types of tolled infrastructure: tunnels, representing only around 1%, and interurban road stretches of tolled motorways, the vast majority of the toll network (99%). Toll rates are established depending on the distance traveled, according to a euro/km rate regulated by the contract for each concession. Nevertheless, a wide range of variation of rates is found throughout the network. Current toll rates for light vehicles fall in the range of 0.07 to 0.10 euro/km. By contrast, a fixed toll is charged for crossing tunnels. In unitary values, toll rates for light vehicles in this type of infrastructure are quite expensive, from 0.143 euro/km (Eje Aeropuerto tunnel) to 0.49 euro/km (Artxanda tunnels). Furthermore, tolls vary across vehicle types, with toll rates applied to heavy vehicles being around 50% higher than those for light vehicles.

The rate per kilometer usually does not vary by the hour of the day or seasonally. Only some toll roads apply a somewhat flexible toll scheme, according to which different charges are paid at peak and off-peak times. This is the case of certain toll roads in the region of Madrid (Radials 2, 3, 4, and 5), one bypass in the region of Valencia (Circunvalación de Alicante), and one tunnel in Catalonia (Túnel de Vallvidrera). Toll operators for these roads offer discounts during off-peak hours, ranging between 50% and 90% for light and heavy vehicles. By contrast, most of the toll motorways, around 63% of the toll network in operation, provide discounts for frequent users.

Given the historical evolution of the country's toll policy, the current network is asymmetrically distributed throughout the territory [Gomez et al. (5) provide more details]. Although a significant percentage of the high-capacity network is tolled in certain regions, other areas have free high-quality roads. In addition, toll roads in Spain always have a free parallel road available serving the same corridor. Generally, the alternative road is a conventional (two-lane) road, and therefore of lower quality. Nevertheless, some of the toll roads have a free high-capacity road competing with them, with similar physical and design characteristics, as in the region of Madrid.

METHODOLOGY

Data Sources and Variables

The study aimed to explore users' perceptions toward various road-pricing schemes, given that a toll network is already in operation. To that end, a nationwide survey was conducted in Spain's toll network, to collect users' perceptions toward the implementation of three hypothetical road-pricing schemes to be potentially implemented in the current toll network. This research focused on individuals who used the toll roads mainly for working purposes, since, to a large extent, this group of road users had fewer options to modify their travel behavior after a change in the pricing scheme has been implemented. Overall, 1,176 real users (frequent and occasional) reported their perceptions. According to Ben-Akiva (33), the sample size can be considered representative enough for a stated-preference survey.

The survey considered the following pricing schemes to explore respondents' perceptions:

- A surcharge to avoid congestion at any time (express toll lanes). Users were asked to indicate their general perception toward a scheme that gives everyone the option of paying a supplementary fee to access a separate free-flow travel lane, or remaining in the existing lanes. Although express toll lanes are dynamically priced facilities, the survey participants were asked about the case of paying a fixed

surcharge, irrespective of demand. It was decided to ask about this simplified base case, since in Spain there has been no previous experience with variably priced managed lanes.

- Time-based (peak versus off-peak) pricing scheme. The survey asked the respondents their opinions about applying different toll rates (euro/km) within the same day or seasonally. With this system, all drivers pay higher charges during peak hours and lower rates during off-peak hours.

- Flat fee—charging (vignette) system. Finally, respondents were asked whether they were willing to pay a monthly flat fee, regardless of the mileage driven in the toll network and the period of time in which they use the toll road infrastructure. In this case, the people who were surveyed were told that the amount of the monthly flat fee would be similar to the amount they were currently paying for use of the road each month.

The responses to these schemes, grouped into two categories (positive and negative toward the change), made up the dependent variable of the binary choice models aimed at analyzing users' perceptions. In the end, three models were calibrated to explore attitudes toward the three schemes that were proposed.

The explanatory variables in the model comprise socioeconomic characteristics, trip-related attributes, and attitudinal variables (Table 1). The socioeconomic characteristics include gender, age, income, and region of residence. The latter variable was included because of its importance in explaining differences in users' attitudes and willingness to pay that were caused by the asymmetrical distribution of the toll network throughout Spain, as was pointed out by Gomez et al. (5). The second group of variables refers to personal trip-related attributes, such as the type of user (frequency), type of vehicle, and type of trip usually made (urban or metropolitan, long distance, and so forth). The third group of variables is comprised of attitudinal factors, including behavioral reactions and users' perceptions about the toll facility they currently use, such as its quality, effectiveness in helping them save time, and so forth. This group also captured whether drivers felt more or less captive to use the toll road, which may have been influenced by the alternative modes or routes available to each user.

Data collected from the survey were complemented with information related to the attributes of the existing toll facility. Within this group of variables, an explanatory factor was incorporated to control whether existing toll facilities already applied a time-based charge or established discounts for frequent users. Furthermore, given that toll highways in Spain always have a free alternative serving the same corridor, the study included the quality of the free parallel road—whether it was a conventional (two-lane) or high-capacity road—and the quality of the toll road as potential explanatory factors to explain drivers' perceptions. Since the quality of the toll road was not directly measurable, it was decided to incorporate it as a latent variable in the modeling approach, as detailed in Table 1.

Because most of the explanatory variables were categorical, a base case (BC) was selected as a reference to identify potential differences in user acceptability (Table 1). For example, for age, the study chose younger than 24 years as the BC. This choice allowed the study to measure whether user acceptability in the other age categories was statistically significant compared with the reference case.

The sample had a balanced distribution of respondents across regions, with a higher presence of people ages 35 to 49 years (46.5%). Income was typically between €20,000 and €30,000; the majority were frequent toll road users (82.1%), and most were car drivers (80.6%). Over half the respondents felt forced to use toll roads

TABLE 1 Summary of Variables Included in the Study

Variable	Category	Respondents	Sample (%)
Dependent			
Perceptions toward the implementation of			
Model 1: Surcharge to avoid congestion at any time (express toll lanes)	Accept	641	54.5
	Reject	532	45.2
	MV	3	0.3
Model 2: Time-based (peak versus off-peak) scheme	Accept	257	21.9
	Reject	917	78.0
	MV	2	0.2
Model 3: Flat-fee (vignette) system	Accept	640	54.4
	Reject	535	45.5
	MV	1	0.1
Explanatory			
Socioeconomic characteristics			
Gender	Male (BC)	749	63.7
	Female	427	36.3
Age	Under 24 years (BC)	62	5.3
	24–34 years	233	19.8
	35–49 years	547	46.5
	50–64 years	302	25.7
	Above 64 years	32	2.7
Income	Under 20,000 euro (BC)	237	20.2
	From 20,000 to 30,000 euro	323	27.5
	From 30,000 to 50,000 euro	165	14.0
	Above 50,000 euro	50	4.3
Region	MV	401	34.1
	Catalonia (BC)	271	23.0
	Madrid	229	19.5
	Valencia	247	21.0
	Galicia	196	16.7
	Basque Country	233	19.8
Trip-related attributes			
Type of user	Occasional (BC)	210	17.9
	Frequent	966	82.1
Type of vehicle	Car (BC)	948	80.6
	Van	121	10.3
	Truck	94	8.0
	Motorcycle	5	0.4
	Bus	7	0.6
	Other	1	0.1
Type of trip	Urban–metropolitan trip (BC)	257	21.9
	Interurban trip	594	50.5
	Long distance	325	27.6
Attitudinal factors			
Quality of the toll road facility ^a		Mean: –0.022	SD: 1.03
Forced to use the toll road ^b	Not forced (BC)	457	38.9
	Forced	719	61.1
Qualitative willingness to pay ^c	Low (BC)	426	36.2
	Medium	383	32.6
	High	362	30.8
	MV	5	0.4
Perception of the cost of the toll road ^d	Cheap (BC)	11	0.9
	Expensive	997	84.8
	Reasonable	168	14.3
Perception of the contribution of the toll road to save time ^e	Positive (BC)	961	81.7
	Negative	34	2.9
	Sometimes positive, sometime negative	181	15.4

(continued)

TABLE 1 (continued) Summary of Variables Included in the Study

Variable	Category	Respondents	Sample (%)
Other			
Existing time-based charge ^f		Mean: 97%	SD: 10.2
Existing discount for frequent users ^g	No (BC)	649	55.2
	Yes	527	44.8
Quality of the free alternative road ^h	Conventional road (BC)	945	80.4
	Highway	231	19.6

NOTE: MV = missing values; BC = base case.

^aThe variable was treated as a latent variable. It comes from the users' perception of the speed, security, general quality, and available services of the toll road facility.

^bThis variable was derived from the following question: Are you forced, or have you been forced, to use toll roads?

^cTo build this variable, the survey asked respondents to choose between different hypothetical situations of qualitative willingness to pay (QWTP). A high QWTP means that the driver is willing to use toll roads by paying whatever is needed; a medium QWTP means that the user is willing to pay a certain amount of money; and a low QWTP means that the respondent is willing to pay a small amount of money.

^dTo build this variable, the survey asked the following question: Do you think the toll fees you pay are cheap, expensive, or reasonable?

^eThe car drivers were asked whether they perceived the toll facility as an effective means for saving travel time.

^fThis variable represents the percentage of the full fee (peak tariff) that users pay compared with off-peak usage. The value 100% means there is no existing time-based change scheme in this toll road (peak tariff = off-peak tariff).

^gThis variable identifies which toll facilities currently provide discounts for frequent users or not.

^hDepending on the toll road used, the study classified the free parallel road available in the corridor as a highway or a conventional road, assuming the quality to be high when the free parallel road happened to be a highway.

(61.1%). This does not mean that toll road users had no other option, since toll highways in Spain always have a free alternative available, although it is of much lower quality in most cases. Finally, the majority of the respondents perceived that the current toll rates applied in the toll network were expensive. However, their attitude toward the effectiveness of toll roads in contributing to save travel time was mostly positive (81.7%). Some variability was found in the other explanatory variables. Table 1 provides further information on the descriptive statistics of the explanatory variables included in the study.

Binary Logit Models

The study calibrated three binary logit models to determine the factors that influence commuters' acceptability of the three pricing schemes proposed. Binary choice models were derived from utility-maximizing theory, according to which decision makers are utility maximizers. The individual chooses, among all the options available, the alternative measuring her or his utility, which can be determined by several explanatory variables. The study considered four types of parameters determining individuals' choices within the modeling approach: socioeconomic characteristics of the individual (S), trip-related attributes (T), attitudinal factors (A), and other variables related to the road facility (O). The utility (U_{ik}) gained by individual i from choosing alternative k can be written as shown in Equation 1:

$$U_{ik} = f(S_i, T_{ik}, A_{ik}, O_i) \quad (1)$$

Recalling that U_{ik} is considered a random variable, it can be divided into two additive parts (Equation 2):

$$U_{ik} = \sum_j V_{ik} + \varepsilon_{ik} = \sum_j \beta_j X_{ik} + \varepsilon_{ik} = \lambda_S S_i + \gamma_T T_{ik} + \alpha_A A_{ik} + \mu_O O_i + \varepsilon_{ik} \quad (2)$$

where

V_{ik} = systematic or representative components of utility;

ε_{ik} = disturbances or error components associated with the choice option;

X_{ik} = vector of explanatory variables that defines S , T , A , O ; and

β_j = vector of coefficients to be estimated (34).

Economic theory assumes that individual k will choose the option with the highest utility. As explained by Ben-Akiva (33), in the general form of a binary choice model, the probability that respondent k will choose alternative i , P_i , can be expressed as follows:

$$P_i = \frac{e^{V_{ik}}}{\sum_j e^{V_{ij}}} \quad (3)$$

The binary logit approach predicts the so-called logit of the odds ratio, L_i , given multiple explanatory variables X_i (35). The specification that the study finally adopted has the classical form of a binary logit model:

$$L_i = \ln \frac{P_i}{1 - P_i} = \alpha + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k \quad (4)$$

As a consequence of this linearization process, the interpretation of the β_k coefficients is different from that of standard linear regression models. The slope coefficient suggests that for a unit increase in a certain explanatory variable X_k , the weighted log of the odds in favor of a certain alternative ($Y = 1$) increases by e^{β_k} . More appealingly, for a unitary increase in a certain explanatory variable X_k , the odds ratio in favor of $Y = 1$ happening increases by e^{β_k} .

A more detailed description of binary choice models is beyond the scope of this paper. Further details are provided in Ben-Akiva (33) and Ortúzar and Willumsen (36).

RESULTS

This section summarizes the main findings of the analysis conducted in this research. The study developed different discrete choice models to estimate the probability of supporting certain road-pricing schemes. The analysis modeled user acceptability toward changing the current pricing scheme of toll roads, in which a constant per kilometer toll was applied, for three hypothetical alternatives: a surcharge to avoid congestion at any time, an express toll lane (Model 1); a time-based peak versus off-peak scheme (Model 2); and a flat fee—charging (vignette) system (Model 3). Before the calibration process, tests were conducted aimed at identifying potential multicollinearity problems among the explanatory variables, and showed no significant interactions.

The final results of the modeling analysis are shown in Table 2. The table contains some effects that are not significant at the 95% confidence level (p -value $> .05$), but were kept in the model since they were nearly significant in at least one of the three models estimated. The omitted variables, with no significant effects in all three models, are income and the categorical variable showing whether the existing toll roads already apply a time-based toll scheme (the existing time-based charge variable). The modeling results for these variables are not discussed since there is no statistically significant evidence of explanatory effects. As is commonly done for logit model analysis, the slope coefficients of the explanatory variables (β_k) are evaluated according to a twofold criterion: (a) the sign of the coefficient, and (b) its magnitude.

The results of Model 1 provide evidence that acceptability toward the implementation of an express toll lane is significantly lower when the user perceives that the toll road is not that useful for saving travel time (coefficient -0.784). The model reflects that users do not want to pay more if charging is not an efficient solution for saving travel time. The support for the express lane—charging system also varies significantly across age and gender, keeping the rest of the variables constant. However, this scheme seems to be more acceptable to frequent users (coefficient 0.290), and is somewhat positively influenced by the quality of the toll road facility (coefficient 0.10). These findings are likely because people are more willing to pay more when the quality of the toll road is better. Finally, the acceptability of this approach is also influenced by regional factors. As was pointed out by Gomez et al. (37), regional differences in users' attitudes may be influenced by an asymmetrical distribution of toll infrastructure facilities across the regions in a country. For the case of Spain, the authors analyzed in detail the impact of regionalism on users' perceptions. This study found that users from Madrid are more willing to tolerate an express toll lane (coefficient 0.457), likely because they are more aware of congestion than people in other regions are. Consequently, a change in the current pricing scheme in Madrid was possibly not perceived as a burden, but a supplementary option that would potentially be useful when the free alternative becomes congested.

In line with the first model, the results for Model 2—exploring acceptability toward a time-based (peak versus off-peak) pricing scheme—reveal that socioeconomic characteristics influence users' perceptions toward this pricing strategy only to a minor extent. By contrast, transport-related attributes play a more important role in explaining user acceptability. The time-based system becomes less acceptable for individuals who feel forced to use the toll road, since this variable is found to be negatively related (coefficient -0.414) to the probability of supporting this charging scheme. This result may be explained by the fact that respondents who were not provided with a free quality alternative perceived charges at peak times as

a potential additional burden, so they wanted to avoid an extra fee. The study also found a notable increase in the acceptability results if the toll road used by the respondent was of good quality (coefficient 0.145). Among the personal and socioeconomic attributes, no significant differences were found throughout the subgroups for region, type of user (trip frequency), age, type of vehicle, or type of trip. Furthermore, a significantly more negative attitude toward different charges at peak and off-peak times was observed in the case of females (coefficient -0.539). This finding is in line with previous results on gender referred to in the literature (25). However, there are no consistent conclusions concerning the influence of gender in the general acceptability of road pricing. Finally, it was surprising that past experiences with existing time-based strategies did not significantly influence users' attitudes. It may have been that the interpretation of what a time-based pricing scheme exactly implies varied widely across individuals.

The results from Model 3 reveal that attitudinal factors have a strong influence on users' perceptions toward a flat fee (vignette) scheme. As could be expected, perceiving the current toll to be expensive or reasonable might be strongly associated with support for this pricing strategy (coefficients 0.933 and 0.170 , respectively). Unlike the results obtained with the previous models, a flat fee system would be more acceptable for captive users (coefficient 0.183), that is, those who feel more obliged to use the toll network. These results indicate that a toll road pass may be interpreted by respondents as a possibility for driving higher mileage without an extra payment, so it seems to be perceived as a potential way to save money. Moreover, as has been pointed out in the literature, people prefer to know how much the charge will be before traveling (38). Further, other trip-related attributes can influence the acceptability of road pricing. Within this group of variables is the case of truck drivers, who are also frequent users of the toll road network. The results of this model show that truck drivers are 2.5 ($= e^{0.921}$) times more likely to support a flat fee system than car users are, keeping the other variables constant (Table 2). Model 3 also finds that perceptions toward the vignette scheme become more positive as the length of the trip increases. Users who make long-distance trips are two ($= e^{0.701}$) times more likely to support a flat tariff option compared with users who make short trips. Finally, the flat fee scheme was found to be more acceptable by individuals who use toll facilities without existing discounts, although a statistically significant influence cannot be concluded from this analysis (p -value $= .079$). Overall, the acceptability of this approach becomes higher when users expect to save money with its implementation.

From the three cases studied, specific significant determinants of acceptability can be found for each pricing scheme. As generally found in the literature on the acceptability of road pricing, it can be claimed that attitudinal factors have greater explanatory power compared with socioeconomic variables. A statistically significant influence cannot be concluded from this analysis for the income variable. Differences between wealthy and poor drivers do not appear to explain the variability in their acceptability of road-pricing schemes. This result is in line with other papers found in the literature, such as Jaensirisak et al. (3) and Dill and Weinstein (19).

For the goodness of fit of the estimated results, the models obtained rho-squared values between $.063$ and $.097$, which may be considered acceptable for logit specifications according to Hensher and Bradley (39). Furthermore, the signs of the regression coefficients and their statistical and practical significance are in line with the expected results.

TABLE 2 Summary of Model Results

Variable	Model 1: Express Toll Lane		Model 2: Time Based		Model 3: Flat Fee (vignette)	
	Coefficient	p-Value	Coefficient	p-Value	Coefficient	p-Value
Socioeconomic Characteristics						
Gender						
Male (BC)						
Female	−0.184	.157	−0.539	.002	−0.298	.031
Age						
Under 24 years (BC)						
24–34 years	−0.519	.101	−0.013	.976	−0.313	.378
35–49 years	−0.818	.007	−0.056	.892	−0.509	.138
50–64 years	−0.519	.098	0.021	.961	−0.810	.023
Above 64 years	−0.238	.630	−1.003	.157	−0.435	.450
Region						
Catalonia (BC)						
Madrid	0.457	.044	−0.420	.146	0.261	.280
Valencia	0.243	.191	−0.492	.041	0.205	.334
Galicia	0.191	.340	−0.053	.830	0.010	.962
Basque Country	0.194	.309	0.061	.793	0.135	.503
Trip-Related Attributes						
Type of user						
Occasional (BC)						
Frequent	0.290	.073	−0.020	.920	0.354	.082
Type of vehicle						
Car (BC)						
Van	0.033	.871	−0.325	.206	−0.033	.874
Truck	0.042	.861	−0.512	.102	0.921	.001
Motorcycle	−0.259	.781	0.327	.729	0.557	.635
Bus	1.773	.109	−1.971	.398	0.764	.375
Type of trip						
Urban trip (BC)						
Interurban trip	0.378	.020	0.222	.287	0.334	.046
Long distance	0.281	.138	0.123	.626	0.701	.001
Attitudinal Factors						
Quality of the TR	0.100	.121	0.145	.079	0.087	.174
Forced to use the TR						
Not forced (BC)						
Forced	0.010	.938	−0.414	.009	0.183	.176
Qualitative willingness to pay						
Low (BC)						
Medium	−0.156	.293	−0.516	.005	−0.010	.950
High	−0.070	.645	−0.456	.013	0.068	.663
Perception of the TR cost						
Cheap (BC)						
Expensive	−0.184	.784	−0.374	.611	0.933	.195
Reasonable	0.238	.727	0.182	.807	1.170	.110
Perception of the time savings						
Positive (BC)						
Negative	−0.784	.046	−0.028	.953	−0.399	.309
Sometimes	−0.390	.027	−0.307	.188	−0.227	.210
Other Variables						
Existing discount for frequent users						
No (BC)						
Yes	0.117	.552	−0.046	.844	−0.352	.079
Quality of the free alternative						
Conventional road (BC)						
Highway	0.009	.967	0.121	.656	0.305	.157
Intercept	0.902		−0.367		−1.237	
−2 log likelihood	1,528.30		1,136.25		1,493.94	
ρ^2	.063		.083		.097	

NOTE: BC = base case; TR = toll road.

CONCLUSIONS AND POLICY RECOMMENDATIONS

This research explored the acceptability of the hypothetical implementation of three highly differentiated road-pricing schemes, for individuals already being charged for the use of roads. Based on individual data from a nationwide survey of road users of the toll network in Spain, three binomial logit models were developed to analyze the relative importance of different explanatory variables related to (a) personal socioeconomic characteristics, such as age, gender, and household income; (b) trip-related attributes, such as usual trips undertaken or type of vehicle; and (c) personal attitudes about toll facilities, such as the perceived effectiveness of toll roads in reducing travel time. The analysis yielded some interesting conclusions.

The first conclusion is that user acceptability of the different proposed strategies—a surcharge to avoid congestion at any time (express toll lanes), time-based (peak versus off-peak) pricing, and a flat fee charge—is influenced by various factors, so a common trend cannot be determined. The research provided evidence that users' perceptions and conditionings vary noticeably with the type of charging scheme proposed. For instance, for the case of express toll lanes, the perceived effectiveness of the toll facility in contributing to saving travel time prevails over other individual variables. However, feeling forced to use the toll road plays a significant role in explaining levels of acceptability in the case of time-based (peak versus off-peak) pricing schemes. Finally, the type of vehicle driven and the type of trip usually made were the most important factors explaining acceptability of a flat fee scheme.

The second conclusion is that support for alternative pricing options does not seem to be related to income. By contrast, attitudinal factors were found to have a greater impact on acceptability compared with personal socioeconomic characteristics. These findings are largely consistent with the literature. However, in certain cases, users' perceptions may be influenced by individual characteristics such as gender and region of residence. In any case, the influence of socioeconomic variables on users' perceptions—especially those that have not generally led to conclusive and coincident results, such as age, gender, and income—needs to be explored more deeply.

The third conclusion is that real users of a toll network seem to have different perceptions of the three alternative pricing schemes. The survey respondents related a time-based (peak versus off-peak) charge to a higher burden to be borne, and saw a flat fee charge as a potential way to save money. As users feel obliged to use the toll road, they are less prone to accept a time-based (peak versus off-peak) scheme, but more favorable to a flat fee system. This result means that respondents who feel that they are captive users—those who in practice do not have an alternative option for their daily travel—accept or reject a scheme depending on its ability to achieve substantial cost savings. In this sense, the outcomes of this research are useful for crafting the schemes proposed or the messages directed to specific groups of opponents and even proponents, as well as for predicting the future behavior of users.

Based on the findings of this study, some policy recommendations might be addressed to decision makers:

- The first important aspect to be considered for user acceptability is the type of road-pricing strategy to be implemented. Hence, reactions to price changes are expected to be much stronger and more negative for schemes associated with greater variability (time-, distance-, or delay-based charging mechanisms) than for fixed charge

systems. Therefore, policy makers should pursue options that are technically feasible, transparent, and easy to understand.

- The premise that the acceptability of each scheme is influenced by factors of a different nature is a necessary precondition for an acceptable pricing scheme. A proper understanding of these differences can help planners to enhance acceptability for each specific type of pricing mechanism.

- Transport planners and decision makers should be aware of the differences in public support for road-pricing schemes before and after their implementation. In the case of a pricing scheme that is to be implemented, providing the public with detailed information about its objectives and potential impacts is essential to guarantee the success of road pricing, given that individuals do not have past experiences on which to base their opinion.

- The fact that attitudinal factors explain acceptability better than socioeconomic variables do constitutes another important factor that provides useful insight for transportation professionals. Understanding attitudes, as well as the reasons behind them, seems to be a crucial aspect for predicting social behavior and reactions toward new transport pricing schemes.

From the results presented in this paper, some aspects can be pointed out for further research. Because the analysis only considered work trips, future studies should attempt to extend the analysis by exploring other trip purposes. In addition, potential differences in acceptability across groups of respondents, that is, users and non-users of toll roads, should be analyzed in greater detail by adopting more suitable econometric specifications, such as multilevel models. Finally, additional research should delve more deeply into how people react to different levels of charges within the same pricing scheme. For example, this paper raised the general issue of different pricing systems but did not examine variations in the acceptability of different fee scenarios.

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3. THE ROLE OF SOCIAL IMPACTS IN DECISION-MAKING

3.1 Overview

This chapter provides a comprehensive framework on the topic of transport evaluation, making visible the importance of social dimension and exploring the role of social equity in the sustainability appraisal of transportation policies and planning practices. It also explores the integration of social impacts into the state of the practice of transport policy appraisal, as well as its importance —weight— compared to other sustainability criteria.

3.1.1 The role of social impacts within the sustainability framework

This research work discusses the importance of social and distributional impacts within the sustainability framework, along with an overview of the concept of sustainability. It also presents a review of the current assessment tools for the ex-ante assessment of transport projects and policies. The preliminary part of the paper (paper IV) is an explanatory and comparative analysis of the tools and methods in terms of their effectiveness to appraise sustainability according to the equity principles. It comprises (i) traditional decision-making techniques including cost-benefit analysis (CBA), multi-criteria decision analysis (MCDA), life-cycle assessment (LCA), and social life-cycle assessment (SLCA); (ii) sustainability rating systems; and (iii) the frameworks, guidelines and models used to perform the sustainability appraisal and evaluate transport policies and interventions in general. The analysis is a critical evaluation of the current state of the art to identify the limitations of existing approaches, point out new areas of research, and propose a sustainability appraisal agenda for the future.

On the basis of the literature reviewed, it was possible to identify the sine qua non requirements for a tool to become appropriate for appraising sustainability from a social perspective. The paper compares the various techniques and methods described with regard to those essential requirements, to identify the

most significant research needs that should be tackled to improve the sustainability appraisal of transport planning decisions.

3.1.2 Incorporating social and distributional effects into the appraisal process

The second part of this chapter explores the integration of social impacts into the sustainability appraisal process based on the Multi-Criteria Decision Analysis (MCDA) and provides insights for an alternative weighting scheme addressing social equity issues in different contexts.

Although the MCDA has made progress towards appraising and measuring the performance of sustainable transport projects, it still has important issues that need to be addressed such as the problem associated with incomparable quantities, the inherent subjective qualitative assessment, the complexity of identifying impacts to be included and its measurement method, and the corresponding weights. The issue of trading-off different sustainability criteria is the main unresolved matter of this method. This problem may lead to lack of accuracy in the decision-making process. This chapter presents a new methodology to set the weights of the sustainability criteria used in the MCDA in order to reduce subjectivity and imprecision. In the paper (paper V), criteria weights are obtained based on both expert preferences and the importance that the criteria have in the geographical and social context where the project is developed or the policy is implemented. This novel methodology is applied to a real case study to quantify sustainable practices associated with the design and construction of a new roadway in Spain. The result can be adapted to different real-world applications. It also has the advantage of allowing, for many road projects, the use of the same consensus-based comparative judgments and preferences results obtained from the survey conducted in this research.

This article is also a response to one of the most important research needs identified in paper IV: ***the need to define a transparent approach for determining the relative impact of each sustainability item***. For an appropriate sustainability assessment, it is necessary to determine priorities for sustainability items (called criteria weights) based on a standard, transparent and consistent methodology. As of today there are no standardized methods for evaluating the

trade-offs among social, economic, and environmental aspects in transport projects and policies, decision-makers typically fail in setting the weightings in a transparent and precise way.

3.2 Academic Papers

This chapter includes two papers that have been published as:

- IV. **Bueno, P.C., Vassallo, J.M., and Cheung, K.** Sustainability Assessment of Transport Infrastructure Projects: a Review of Existing Tools and Methods. *Transport Reviews* 35(5) 622-649. doi: 10.1080/01441647.2015.1041435.
- V. **Bueno, P.C., and Vassallo, J.M.** Setting the Weights of Sustainability Criteria for the Appraisal of Transport Projects. *Transport* 30(3) 298-306. doi: 10.3846/16484142.2015.1086890.

The overall scheme of the papers included in this chapter is shown in Figures 3.1 and 3.2, respectively:

Figure 3.1 Paper IV scheme

Figure 3.2 Paper V scheme

Finally, the two papers are presented below in the order they are previously mentioned:

Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods

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ABSTRACT Attempts to integrate sustainability in the decision-making process for transport infrastructure projects continue to gain momentum. A number of tools and methodological frameworks are available — such as rating systems, traditional decision-making techniques, checklists, and different evaluation frameworks and models. While these tools are highly valuable, some practical issues remain unsolved. There is also a need for more standardized tools to appraise the sustainability of transport projects. This paper is a presentation of a review on the current assessment tools of sustainability applied to transport infrastructure projects. The preliminary part of the paper is an explanatory and comparative analysis of the tools and methods in terms of their effectiveness to appraise sustainability. The analysis is a critical evaluation of the current state of the art to identify the limitations of existing approaches, point out new areas of research, and propose a sustainability appraisal agenda for the future.

1. Introduction

Since the emergence of the concept of sustainability as an international priority in the 1980s and 1990s, there has been a growing interest in some aspects regarding infrastructure sustainability. Some authors concede that while the concept of sustainability is now better understood in certain contexts, it is still far from being well defined. However, there appears to be a general consensus on the need to achieve economic and social development and protect the environment.

Although there are many approaches aimed at assessing the socio-economic and environmental feasibility of infrastructure projects, there is currently no standardized or commonly agreed methodology offering a reliable measurement of sustainability when appraising and evaluating transport projects over their life cycle — see George (2001) and Stamford and Azapagic (2011). The available literature on sustainable infrastructure — see Dasgupta and Tam (2005), Gilmour, Blackwood, Banks and Wilson (2011), Tsai and Chang (2012) — signals that policy-makers are in need of practical tools and techniques to assess sustainability

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in all the life stages of infrastructure projects. Decision-making processes require comprehensive and reliable appraisal methods.

Current approaches for project appraisal can be broadly grouped into three main categories. The first comprises traditional decision-making techniques and include cost–benefit analysis (CBA), multi-criteria decision analysis (MCDA), life-cycle assessment (LCA), social life-cycle assessment (SLCA), and others. The second includes sustainability rating systems that grade and score infrastructure projects depending on their sustainability performance; and the third covers the frameworks, guidelines, and models used to perform the sustainability appraisal and evaluate infrastructure assets.

From an overall standpoint, these tools are highly valuable for helping decision-makers meet some of their sustainability targets within their specific scope. However, there is still room for improvement in the effectiveness of current assessment tools. Their main weaknesses are that they are biased towards either an environmental or an economic assessment, they fail to address sustainability thoroughly, and are overly focused on certain stages of the project life cycle.

Although traditionally accepted techniques such as CBA, MCDA, and LCA — among others — offer valuable support for assessing transport projects, they do not fully address all the components of sustainability (economic, social, and environmental). For example, CBA has still serious problems in evaluating incommensurable goods, whereas MCDA can introduce subjectivity when evaluating the weights selected to rank different criteria. Rating systems and models are useful to rank and compare projects, but focus mainly on environmental aspects and on the construction stage of the project. Despite the usefulness of rating systems, the frameworks, and models are not designed to assist planners in the decision-making processes when selecting the most suitable design for sustainability.

This research is a review of existing tools and methods related to sustainability assessment of transport infrastructure projects. Our primary goal was to identify and evaluate the appropriateness of available tools for assessing transport infrastructure projects according to the sustainability principles. This research work is not an attempt to validate whether current assessment tools are good by themselves. Rather, the specific objectives of this research are: first, to evaluate the performance of appraisal tools when measuring sustainability; second, to provide a comparative review of the different characteristics, scope, application, and methodological constraints of these tools and methods; and third, to identify challenges to improve the sustainability assessment of transport projects in the future. To this end, a wide overview is given of the state of the art for measuring sustainability. Finally, we propose five major research needs to improve the appraisal of sustainability in dealing with transport projects.

The paper is structured as follows. In Section 2, after the introduction, there is a review of the concept of sustainability followed by an examination of the literature regarding tools and appraisal methodologies for sustainability assessment of transport infrastructure projects. To this end, we follow a systematic approach aimed at identifying key aspects that are not being incorporated into the current methods and sustainability assessment practice. On the basis of the literature review, in this section we outline five major challenges to improve sustainability appraisal of transport projects and examine how these challenges can be implemented in practice. Finally, Section 3 of the paper includes a set of

conclusions, final reflections, and recommendations for future research areas in this field.

2. Literature Review

2.1. Sustainability: General Concept and Definitions

The concept of sustainability was launched in 1972 at the United Nations (UN) Conference on the Human Environment held in Stockholm, which was the first international symposium called to discuss exclusively environmental issues. The Brundtland Commission subsequently produced the most widely used of all the definitions of sustainable development: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland World Commission on Environment and Development, 1987, p.1). These were followed by other high-ranking conferences and events in association with the UN. The progressive evolution of these conferences reveals “a shift in the political debate from a primary emphasis on environmental issues, through a shared focus on environmental, social and economic development” (Paul, 2008, p. 579).

Several definitions of sustainability can be found in the literature, although most focus on specific fields, such as economy, ecology, and the environment (Gilmour et al., 2011; Parkin, Sommer, & Uren, 2003; Radermacher, 1999). Since each discipline has its own explanation and semantic features, definitions tend to differ and “not a single reference presented a feasible definition of sustainable development which could incorporate all aspects of the concept commission’s report under investigation, and provide no ideal understanding of this concept” (Ciegis, Ramanauskiene, & Martinkus, 2009, p. 30). However, while there may be a debate about the universal definition of sustainability, there are some commonly agreed principles when considering actions to promote sustainable transportation — see, for example, National Cooperative Highway Research Program-NCHRP (2011).

Sustainable development is still seen as a complex issue that defies definition for practical purposes. According to Gilmour et al. (2011), “it is generally accepted that the real challenge lies in understanding how to put it into practice: that is, to operationalize sustainability” (p. 16). Sustainable construction is defined as a building process that incorporates the basic principles of sustainable development (Chaharbaghi & Willis, 1999; Parkin, 2000). These processes should comply with the objectives of environmental responsibility, social awareness, and economic profitability (Shelbourn et al., 2006).

2.2. Assessing Sustainability of Transport Projects

As stated above, there is no common understanding of what constitutes sustainability in real-life projects, both as a concept and in a practical sense. This section provides a definition of sustainability of transport projects and also explores the means whereby sustainability can be addressed in assessment.

For the purpose of this paper, a transport project will be considered “sustainable” when it contributes to favour economic development and fulfil the transportation needs of the society in a manner consistent with natural laws and human values. Beyond this definition, we believe that there are two other essential

points to take into account when dealing with sustainability. First, the fact that the measure of sustainability is sensitive to the economic, social, and environmental context where the project is located. And second, a proper definition of “sustainable transport projects” must include the whole life cycle; from conception through construction, operation, maintenance, and the recycling/reuse stage.

The last mentioned element of the sustainability concept, based on the Brundtland definition and other academic references — see, for example, Munasinghe, Sunkel, and Miguel (2001), Sijtsma (2006) — reinforces the adoption of a “long-term approach” for the purpose of sustainability assessment. Hence, impacts to be considered for transport projects might be related to the construction (e.g. investment costs of the project, generally comprising land acquisition, design/legal/administration and construction costs); maintenance (e.g. air pollution costs covering short-term air quality effects caused by maintenance activities); operation of the facility (e.g. vehicle operating cost, including fixed costs, and operating costs); and the recycling/reuse stage (e.g. energy consumed by using fuel and electric power in the process of transporting and recycling).

On the other hand, there is also a dilemma about the purpose of sustainability: whether it is really a matter for decision-making or it is more a part of an evaluation *ex post*. In the literature this fact has not yet been treated in detail yet. However, some authors have acknowledged that it is good to consider sustainability at the planning stage. For example, Reid, Davis, and Bevan (2012) admitted that “the opportunities to incorporate sustainability vary and eventually diminish as a project moves through the project life cycle”. Tsai and Chang (2012) in their turn pointed out that “Great potential reductions in operations’ sustainable impacts could be made if sustainability is considered early in planning and design”.

As a consequence, we can claim that the primary purpose of sustainability assessment should start with the appraisal and decision-making, because, at this point, decision-makers have great influence on the future sustainability performance of the project. In other words, implementing sustainability principles become more effective at the planning stage than as part of an *ex-post* evaluation. However, verifying the sustainability of an already existing project can be useful to “recycle” best practices and procedures in future projects, due to the retrospective character it implies. Despite sustainability should be necessarily part of a primarily an *ex ante* assessment, it can also be used for other purposes. Figure 1 explores the means whereby sustainability can be used in assessment and clarifies how its role fits with the decision-making and the implementation processes of an infrastructure project (Anderson & Muench, 2013; Cundrič, Kern, & Rajkovič, 2008; Dasgupta & Tam, 2005; Gambatese & Rajendran, 2005; Gühnemann, Laird & Pearman, 2012; Lee, Edil, Benson & Tinjum, 2011; Ugwu, Kumaraswamy, Wong, & Ng, 2006).

2.3. *Current Methods and Techniques for the Assessment of Transport Infrastructure Projects. How do they Address Sustainability?*

Transport infrastructure projects are appraised in practice through a number of tools or methodological frameworks that include the concept of sustainability to a greater or lesser extent. These methods and tools encompass the traditional

	ex-ante sustainability evaluation	ex-post sustainability evaluation
Corresponding project lifecycle stage
Sustainability is part of	The appraisal and the decision-making process	The monitoring process, for evaluation purposes
Sustainability aims at	Supporting the selection of the alternative option that maximizes beneficial outcomes on all dimensions of sustainability	Quantifying sustainable practices associated with the construction and maintenance processes. In these stages, sustainability can be used to certify and monitor transport projects
Means by which sustainability can be used: A ROAD PROJECT EXAMPLE	A process where sustainability is used to provide guidance on appraisal and decision-making: (i) After identifying project impacts, calculate the global sustainability evaluation of each alternative, for example using a multi-criteria approach (ii) Obtain the ranking order of alternatives and select the alternative with the highest sustainability performance	Sustainability as a monitoring tool can be used in different processes to: (i) Evaluate the project against original objectives that it was designed for (ii) Assess, compare and award the existing road, depending on its performance against relevant sustainability criteria previously defined, for example by a rating system for roads (e.g. Greenroads, GreenLITES) (iii) Improve current practices in roadway construction and do more than the minimum requirements (iv) Suggest best practices and procedures in future road projects, due to the retrospective character it implies
Practical application examples	Gühnemann et al. (2012); Cundrič, Kern, & Rajković (2008); Ugwu, Kumaraswamy, Wong, & Ng (2006); Dasgupta & Tam (2005)	Lee, J., Edil, T., Benson, C., & Tinjum, J. (2011); Gambatese & Rajendran, (2005); Anderson & Muench (2013)

Figure 1. Sustainability as an ex ante/ex post tool.

methodologies as well as a number of current sustainability tools. We classify the current tools and methods in the following way:

- (1) *Project appraisal methods for decision-making.* In this paper we focus on CBA and multi-criteria approaches. Despite the fact that some of these tools were not initially designed for sustainability assessment, we consider them in the analysis because they are until now the most commonly used techniques for decision-making processes in transport project appraisal, and they are evolving towards the introduction of sustainability aspects.
- (2) *Techniques for assessing environmental/social impacts.* Approaches to assess the environmental and social impacts of transport project options that are evaluated here include: the LCA and the SLCA. Although these techniques address mostly environmental or social topics, we took them into account since they are often combined with other tools for a complete sustainability assessment.
- (3) *Sustainability assessment methodologies, including rating systems and frameworks and appraisal guidelines.* The analysis includes sustainability self-evaluation tools developed for civil infrastructure in general (such as the Civil Engineering Environmental Quality and Assessment Scheme — CEEQUAL, the infrastructure rating and recognition system developed by the Zofnass Program for Sustainable Infrastructure and the Institute for Sus-

tainable Infrastructure — Envision™ and the Leadership in Energy and Environmental Design Rating System for Neighborhood Development — LEED®) as well as rating systems focused on roads (e.g. the voluntary rating system developed by the University of Washington and CH2M HILL — Greenroads™, and, the Green Leadership in Transportation Environmental Sustainability rating program — GreenLITES). In addition, we also included in the analysis frameworks and appraisal guidelines for sustainability assessment of infrastructure projects.

Current transport-related sustainability methods and techniques are introduced in the following sections from a sustainability perspective. By highlighting their strengths and weaknesses, our aim is to examine how they work and identify whether existing tools provide a suitable framework to integrate sustainability into existing appraisal processes. To analyse these tools and methods that can be used for the sustainability assessment of transport infrastructure projects, we reviewed reporting guidelines, frameworks, and more than 100 relevant academic studies.

2.3.1. *Project appraisal methods*

2.3.1.1. *Cost–benefit analysis.* CBA is the most widely used method to support decision-makers in appraising transport projects. It is a known and widely used technique that enables the comparison among alternatives under the objective of maximizing social welfare. This approach is generally employed as an ex ante method and it is based on the possibility of monetizing the user benefits (e.g. travel time savings) as well as the cost of investment and other “negative” effects (e.g. energy consumption, resources use, and CO₂ emissions). There are numerous textbooks and academic papers dealing with the theory and practice of this methodology — see, for example, (Gühnemann et al. (2012), Hyard (2012), Tudela, Akiki, and Cisternas (2006).

From a general perspective, the role of the CBA has been often discussed in the academic literature. Some authors support the adequacy of applying the CBA to evaluate public projects, and study its influence (e.g. Grant-Muller, Mackie, Nellthorp, & Pearman, 2001; Pearce & Nash, 1981), while others discuss some disagreements about its usefulness as a decision-making support tool and review the problems surrounding the use of this tool in the appraisal of large-scale infrastructure projects (e.g. Jones, Moura, & Domingos, 2014; Vickerman, 2007).

It is not the aim of this section to carry out an exhaustive critique of the well-known CBA method, but rather to evaluate its performance in the context of accounting for sustainability. Thus some key pros and cons together with a discussion about how sustainability can be included in the assessment of transportation infrastructure projects are presented in the following paragraphs.

First, when evaluating sustainability, CBA offers valuable support since it is a rigorous, transparent, and formal appraisal tool. In general, a substantial number of authors have argued that CBA can perform a comprehensive and useful methodology in the decision-making processes — see Beria, Maltese, and Mariotti (2011), Tudela et al. (2006). It is particularly suitable to support decision-making of infrastructure since it provides a “tangible and rational” judgement of benefits and costs from different alternatives of the project.

Conversely, there has been considerable research aimed at identifying substantive problems when appraising the sustainability of transport projects with a CBA.

By examining the prospect of CBA application in promoting or demoting sustainable development we found “abundant arguments disfavouring the application of CBA, represented by limitations such as: (i) trying to evaluate what are often not ‘evaluable,’ that is, non-economic values, and (ii) limited considerations regarding distributional equity (including inter-temporal equity)” (Omura, 2004, p. 44).

Given these drawbacks, we can claim that CBA suffers from the objectivity/subjectivity dilemma. In other words, the technique can be classified as “pseudo-objective” since it still has difficulties in quantifying non-market goods — see Mackie and Preston (1998), Niemeyer and Spash (2001). Examples in the transport context include the treatment of impacts such as travel-time savings — see, for example, Van Wee (2007) — CO₂ emissions — see, for example, Mandell (2013) — and road accidents — see, for example, Bristow and Nellthorp (2000). Furthermore, for the items that cannot be bought and sold in the market, the inter-temporal aggregation is still contentious, in that some authors suggest environmental discount rates — see Almansa and Calatrava (2007) — others estimate monetary impacts and apply traditional discount rates, while others opt for simple aggregation, even though the impacts may extend over a long period of time.

It is therefore interesting to mention that discounting has traditionally been a controversial issue since results are generally quite sensitive to the discount rate. Previous limitations have long been a subject of intense debate among economists. This fact suggests the need of a proper incorporation of this uncertainty throughout the analysis. In this respect, Almansa and Calatrava (2007) conducted a broad analysis of the discounting problem by adapting the CBA analytical theory in the context of sustainability assessment.

The tool is not able to include the triple bottom line in a precise and narrow manner since the monetization process is questionable for these intangible items. When the approach tries to price “priceless things”, there is a greater degree of uncertainty in measurement, forecasting, and evaluation. Furthermore, a typical CBA does not consider the full life cycle of a project, for example, end of life aspects are rarely included — see further detail about weaknesses of the CBA in Jones et al. (2014).

2.3.1.2. Multi-criteria decision analysis. The multi-criteria technique is a suitable decision-making methodology for “addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, multiple interests, and perspectives, and the accounting for complex and evolving biophysical and socio-economic systems” (Kowalski, Stagl, Madlener, & Omann, 2009, p. 1065). It can be described as a set of techniques rather than a single approach — see Munda, Nijkamp, and Rietveld (1998). The use of MCDA for different purposes has been increasing over the years. There are several studies where this approach has been applied in the field of transport (Cheng & Li, 2005; Friesz, Tourreilles, Han, & Fernandez, 1980; Frohwein, Lambert, Haimes, & Schiff, 1999; Giuliano, 1985; Iniestra & Gutiérrez, 2009; Khorramshahgol & Steiner, 1988). An extensive review of the MCDA method can be found in Huang, Keisler, and Linkov (2011), Kabir, Sadiq, and Tesfamariam (2013), Wang, Jing, Zhang, and Zhao (2009).

A number of authors have suggested that MCDA is the most appropriate tool to adopt for decisions based on an integrated sustainability appraisal (Janic, 2003; Tudela et al., 2006; Walker, 2010). For addressing sustainability the MCDA

usually includes the identification of sustainability criteria, the evaluation for each alternative¹, the assignment of weighting coefficients to the criteria, and finally the sustainability evaluation by using a method for ranking the alternatives.

MCDA offers a number of advantages for policy and planning analysis, compared to conventional economic welfare techniques (Munda, 1995). This tool is relevant when promoting public participation and enabling stakeholder involvement. With the MCDA method, several criteria can be taken into account simultaneously — including those difficult to monetize or quantify (Thomopoulos, Grant-Muller, & Tight, 2009).

A short example may serve to illustrate the advantage of accounting for multiple dimensions. As explained above, when appraising the sustainability of roadway projects, it is necessary to identify and evaluate sustainability criteria for each alternative. Table 1 presents a set of major items to be considered for the sustainability appraisal of highway projects over their life cycle. Appropriate criteria to measure sustainability should take into account economic efficiency, environmental protection, and also social aspects such as equity. It is essential to note, however, that despite some of these criteria can be monetized, but most of them are difficult to do it. Given the need to holistically capture economic, environmental, and social impacts, the multi-criteria scheme could be very effective since it accomplishes the goal of being multi-disciplinary. In addition, the MCDA scheme should be used to account for a more comprehensive range of impacts, taking advantage of recent advances in the environmental and social assessment fields of research.

However, despite the fact that MCDA can explicitly deal with different components of sustainability, the extensive study of multi-criteria techniques for trans-

Table 1. Sustainability criteria for highway projects throughout their life cycle

Sustainability component	Sustainability criteria	Description
Economic	Infrastructure costs (construction/maintenance/operating)	Monetized (with market prices)
	Travel time cost/saving	Monetized (Ongoing debate)
	Vehicle operating cost	Monetized (with market prices)
	Accident cost/saving	Monetized (Ongoing debate)
	Macroeconomic impacts	Difficult to quantify, difficult to monetize
Environmental	Energy consumption, resource use and CO ₂ emissions	Quantified but difficult to monetize
	Habitat fragmentation and negative effects on species	Quantified but difficult to monetize
	Air pollution	Quantified but difficult to monetize
	Noise pollution	Quantified but difficult to monetize
	Landscape degradation and negative visual impacts	Quantified but difficult to monetize
Social	Community disruption	Quantified but difficult to monetize
	Impacts on businesses and community services	Quantified but difficult to monetize
	Employment and labour standards	Quantified but difficult to monetize
	Distributive effects of the project	Difficult to quantify, difficult to monetize
	Occupational and community health and safety	Quantified but difficult to monetize

port projects has highlighted issues that require further analysis including: the inherent subjective qualitative assessment, the complexity of identifying impacts to be included and its measurement method, and the obtaining of weights to criteria (Browne & Ryan, 2011). In fact, the use of weights is the main unresolved matter of this methodology. It has to do with the transparency of judgements and their influence on the final results of a multi-criteria problem. This weakness has been the subject of severe criticisms by a number of authors — see, for example, Browne and Ryan (2011), Hobbs and Horn (1997).

To sum up, the multi-criteria approach provides a proper structure when dealing with sustainability of transport projects, but the assessment process tends to become highly subjective. In practice, the process for obtaining the relative importance of criteria might appear questionable. The “black box” concept should be considered as an important issue since it might cause a loss of credibility. In fact, “due to a lack of procedures for aggregating the evaluations of the individual criteria and unregulated weights that were left to the whim of the decision-takers” (Sayers, Jessop, & Hills, 2003); some governments — such as France — have moved away from the MCDA and returned to the “monetising approach”.

As a result, the multi-criteria analysis involves a certain level of subjectivity (Barfod, Salling, & Leleur, 2011; Beria et al., 2011). Qualitative assessment and the imputation of value-laden weightings to assumptions may lead to subjective biasing — see Munda (2004) and White and Lee (2009). According to Sayers, Jessop, and Hills (2003), the real challenge lies in finding a balance between these consistency and flexibility.

2.3.2. *Techniques for assessing environmental/social impacts*

2.3.2.1. *Life-cycle assessment.* LCA is a technique for assessing the environmental impacts of a product, activity, or process. The use of this analysis for decision-making involves an environmental performance assessment of the whole life cycle from “cradle to grave”, including material extraction, manufacturing, transport, and distribution, product use, service and maintenance, and end-of-life such as reuse, recycling, energy recovery, and final waste handling (Strippel & Erlandsson, 2004).

This approach has been widely used in the decision-making process, applied to a variety of fields including: energy and transport — for example, Matsuhashi, Hikita, and Ishitani (1996), Raluy, Serra, and Uche (2005) and Tahara, Kojima and Inaba (1997); water — for example, Dennison, Azapagic, Clift, and Colbourne (1998); and chemical sectors — for example, Ophus and Digernes (1996); among others. Despite the approach has been used for quantifying the environmental efficiency of some transport infrastructure projects, most of the studies have been focused on road infrastructure projects — see, for example, Strippel (2001).

The LCA usually provides valuable input for sustainability assessment since it constitutes a versatile tool that quantifies the environmental efficiency based on a “life-cycle approach”. As some authors admitted — see Baker and Lepech (2009), Keoleian and Spitzley (2006) — in practice, the LCA has become a common tool for the evaluation of the environmental performance since it provides metrics that can be used in the sustainability assessment of transport projects.

On the other hand, according to Reap, Roman, Duncan, and Bras (2008), although the analysis technique offers a coherent and comprehensive approach to environmental assessment of product systems, it still “suffers from problems

that degrade accuracy and increase uncertainty of assessment results". For example, these authors identified 15 major problem areas that reduce the accuracy of the tool, including difficulties with selecting impact categories, indicators and models, spatial variation, subjective values using weightings and problems in monetization methods, among others. In this respect, a broad review and explanation of uncertainties in life-cycle assessment was performed by Baker and Lepech (2009).

When accounting for sustainability, as some researchers have shown, the LCA has some drawbacks and still needs some improvements to increase its accuracy — see Loiseau, Junqua, Roux, and Bellon-Maurel (2012). For example, in this approach, all sustainability criteria are not fully incorporated since its primary purpose is limited to the assessment of the environmental consequences of a given activity. There is a need for integrating LCA into other appraisal tools, but LCA by itself is an incomplete tool to assess all the three dimensions of sustainability. Consequently, LCA can be regarded as a particular step to define a complete sustainability impact assessment tool.

From the literature, it is found that there are several limitations with "environmental tools" since they have a "general objective of encouraging greater environmental responsibility within the construction industry, but not toward sustainability as a whole" (Treloar, Love, & Crawford, 2004, p. 43). Furthermore, when applying LCA to transport projects, it is usually confined to materials and engine alternatives for construction machinery. It does not consider how energy consumption varies with different design parameters. As a result, the significant changes in the environmental effects captured through the LCA, scarcely include the design phase of the facility.

2.3.2.2. Social assessment approaches. The evaluation of social impacts has been implemented by using several approaches. However, these approaches have often been less well-developed than economic and environmental assessment approaches. As an example, today there is no standardized method to evaluate social and distributional effects of transport projects.

Particularly, the inclusion of social aspects into LCA — called the SLCA — is still under progress. According to Jørgensen, Le Bocq, Nazarkina, and Hauschild (2008), SLCA methodologies are in an early stage of development where consensus building still has a long way to go. These authors stated that "some agreement regarding which impacts are most relevant to include in the SLCA in order to cover the field sufficiently seems paramount if the SLCA is to gain any weight as a decision support tool" (p. 96). Even though social impacts are considered within the scope of an impact assessment — see European Commission (2009) — greater attention is still given to economic and environmental aspects.

A study developed by the Evaluation Partnership and the Centre For European Policy Studies (TEP & CEPS, 2010) found some limitations that have to be addressed in order to set up an effective social assessment. They are the following:

- (1) The term "social impacts" is potentially too broad and has not been well defined yet;
- (2) The lack of appropriate tools to assess social impacts quantitatively is one of the most frequently cited challenges to effectively carry out social impact assessment. Most social assessments remain purely qualitative, and often very superficial.

2.3.3. *Rating systems and certification tools.* Rating systems and certification tools are a collection of best practices, which may be useful for practitioners in incorporating sustainability principles into projects. Best practices are typically associated with a common metric, usually called points or credits.

This metric quantifies each best practice in a common unit. In this way the diverse measurement units of sustainability best practices (e.g., pollutant loading in stormwater runoff, pavement design life, tons of recycled materials, energy consumed/saved, pedestrian access, ecosystem connectivity and even the value of art) can all be directly compared. (Veeravigrom, Muench, & Kosonen, 2015, p. 4)

Some rating systems weigh every best practice equally, while others establish different levels of importance for each best practice.

The sustainability evaluation tools “are typically produced by reputable governmental or non-governmental institutions, sometimes in collaboration with academia. They are intended to assess, compare, and award a planned or existing facility, depending on its performance against relevant sustainability criteria” (International Federation of Consulting Engineers, 2012, p. 17). According to Muench, Armstrong, and Allen (2012), rating systems are appealing for the following basic reasons:

- (i) they provide a common metric for the entire range of sustainable solutions, (ii) they measure sustainability and thus make it manageable, (iii) they allow for straightforward communication of sustainability goals, efforts and achievement, and (iv) they provide a reasonable context within which designers, contractors and material suppliers can be innovative in their solutions. (Muench et al., 2012, p.4)

There are specific rating schemes for evaluating sustainability of buildings, road construction projects and civil engineering works. As mentioned by some authors — see Clevenger, Ozbek and Simpson (2013), Simpson, Clevenger, Ozbek, Kohlman and Atadero (2014), the civil engineering rating systems are based on the building rating schemes which are well established. Very few scientific studies providing a review of sustainability rating systems are found in the literature — see Clevenger et al. (2013), Reid et al. (2012), Samberg, Bassok and Holman (2012). Some recent papers provide detailed explanation of the application of different sustainability tools to real case studies and its potential use — see, for example, Lester and Olmsted (2015), Sturgill, Dyke, McCormack, and Kreis (2015).

The rating and certification tools analysed as part of this research are listed in Table 2. They are tools in the field of transport and civil infrastructure as well as some other specialized tools for road projects. While rating systems share a number of common characteristics, they also have unique features since they emphasize different sustainability aspects. Table 2 includes eight prominent emerging sustainable rating systems and highlights the differences among them.

Similar to what happens with building sustainable tools (Reed, Bilos, & Wilkinson, 2009), existing or emerging certification tools for transport projects concentrate on the USA and the UK. However, some of these well-known systems are starting to be applied in other countries as well — see, for example, the InterAmerican Development Bank (2015). In this respect, the World Bank

Table 2. Different rating and certification tools

Sector	Tool	Country of origin	Main characteristics
All infrastructure	CEEQUAL	UK	<ul style="list-style-type: none">• The Civil Engineering Environmental Quality and Assessment Scheme (CEEQUAL) was developed by: The Institution of Civil Engineers (ICE)• Categories included: 9. project strategy, project management, people and communities, land use and landscape, communities, historic environment, ecology and biodiversity, water environment, physical resources, transport• Key features: can be used in new locations outside the UK. A key feature of CEEQUAL International is the guidance provided for a new weighting exercise specific to the new local area of the project. There is also a scheme for assessing term contracts
	Envision	USA	<ul style="list-style-type: none">• The infrastructure rating and recognition system EnvisionTM was developed by: the Zofnass Program for sustainable infrastructure based at the Harvard Graduate School of Design and the Institute for Sustainable Infrastructure (ISI)• Categories included: 5. quality of life, leadership, resource allocation, natural world, climate and risk• Key features: It has a unique category of climate and risk that accounts for natural hazards, and climate change mitigation and adaptation. Envision includes some planning elements in their rating —part of planning is choosing the right project^a
	LEED	USA	<ul style="list-style-type: none">• The Leadership in Energy and Environmental Design Rating System for Neighborhood Development (LEED[®]) was developed by: The US Green Building Council• Categories included: 7. sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, regional priority• Key features: is the most accepted and widespread sustainable rating system. It has strong emphasis on building design. It provides one definition, widely accepted by the building industry, for what currently constitutes a "green building"^b

(Continued)

Table 2. Continued

Sector	Tool	Country of origin	Main characteristics
Transport	GreenLITES	USA	<ul style="list-style-type: none"> • The Green Leadership in Transportation Environmental Sustainability rating program (GreenLITES) was developed by: The New York State Department of Transport • Categories included: 5. sustainable sites, water quality, material resources, atmosphere, innovation • Key features: strong emphasis on community impacts. Context specific (climate, guidance)^c
	Greenroads	USA	<ul style="list-style-type: none"> • The voluntary rating system GreenroadsTM was developed by: The University of Washington and CH2M HILL • Categories included: 7. project requirements, environment and water, access and equity, construction activities, materials and resources, pavement technologies, custom credits • Key features: tends to focus on material and design concerns, with a separate category for pavement. The system is oriented towards environmental aspects of projects, although access and equity are addressed^a
	I-LAST	USA	<ul style="list-style-type: none"> • The Illinois Livable and Sustainable Transportation (I-LAST) was developed by: The Illinois Department of Transportation, the American Consulting Engineers Council and the Illinois Road and Transportation Builders Association • Categories included: 8. planning design, environmental water quality, transportation, lighting, materials, innovation • Key features: strong emphasis on environmental criteria. Not a certification scheme, advisory in nature
	INVEST	USA	<ul style="list-style-type: none"> • The Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) was developed by: The US Department of Transport FHWA • Categories included: 3. systems planning, project development, and operations and maintenance • Key features: It is used as the federal highway's tool to encourage sustainable highway projects. It also has an extensive list of criteria and a framework for stakeholder communication^c
	BE ² ST-In-Highways TM	USA	<ul style="list-style-type: none"> • The Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways (BE²ST-In-HighwaysTM) was developed by: the recycled materials resource center based at the College of Engineering at the University of Wisconsin • Categories included: 9. social requirements including regulation and local ordinances, greenhouse gas emission, energy use, waste reduction (<i>in/ex situ</i>), water consumption, social carbon • Key features: its main focus is to quantify the sustainability impact of using recycled materials in pavements. Restricted to environmental, economic, and social issues related to quantifiable construction materials and processes^d

Note: ^aDondero, Rodgers, and Hurley (2013), ^bClark, Paulli, Tetreault, and Thomas (2009), ^cHirsch (2012), ^dLee, Edil, Benson, and Tinjum (2011).

developed a guide to assist developing countries in integrating environmentally sustainable elements into road transportation projects. This approach was built on five national and international sustainability rating systems — see Montgomery, Schirmer, and Hirsch (2014). Another interesting example that can be mentioned is the case of Argentina, where a CEEQUAL scheme, founded by the UK Institution of Civil Engineers, has recently been applied.

Rating systems provide guidance and constitute a good basis for integrating sustainability over the whole life cycle of infrastructure projects, from planning through operation and maintenance. Actually, rating systems have helped engineering designers to set credible sustainability items related to infrastructure design. Sustainable transportation rating systems are generally understood as useful tools whereby projects are ranked and scored against their sustainability performance by putting economic, environmental, and social aspects together. They are easy to understand, simple to implement, and highly flexible and adaptable. Considering the proliferation of rating systems throughout the civil engineering field in some markets, they have been successful tools with large-scale application and acceptance into the hands of practitioners.

Given the fact that most available sustainability rating systems for infrastructure are regionally based, they incorporate the context-sensitive nature of sustainability by promoting stakeholders participation and involvement. For example, when applying the CEEQUAL system — British assessment and award scheme — outside the UK, an international assessment with the local project team to adjust the weighting process for different sustainability criteria is conducted. The process ensures the importance of each criterion to be specific to the locality of the project, taking into consideration local regulations and practice of each country.

Overall, the most remarkable strength of rating systems is the holistic approach and the quantitative process defined to address sustainability. Furthermore, their philosophy is based on a good understanding of the sustainability concept. Some of them establish a clear trade-off among environmental, economic, and social aspects, while others such as EnvisionTM and the Infrastructure Voluntary Evaluation Sustainability Tool developed by the Federal Highway Administration (FHWA) — INVEST — just put together best practices. The latter is incorporated by including some general considerations related to equity and distributional impacts.

However, strictly speaking, certification programmes also have a number of weaknesses when dealing with the concept of sustainability. First, they lack transparency and objectiveness in the definition of criteria and selection of weightings, which are not based on standardized methods of performance measurement (Lee et al., 2011). In addition “to what extent sustainability is achieved remains uncertain since consensus does not exist as to the definition of sustainability for highway and infrastructure projects” (Clevenger, Ozbek, & Simpson, 2013, p. 7).

Second, despite the fact that they are based on similar methodological approaches with comparable categories (environment, water, energy, material, and technological and strategic innovation), the weight of the same categories across different rating systems — expressed as weights, points, or credits — shows considerable levels of variation (Hirsch, 2012). Then, rating systems are not comparable enough due to their unique characteristics and focus. Each tool works as an independent performance metric, with a particular philosophy and different sustainability objectives. Even though certain flexibility seems necessary to accommodate the specific characteristics of different projects, rating systems should aspire to reach a greater consensus.

Third, they are mostly focused on environmental issues related to construction processes and materials rather than operational phases. And fourth, despite these approaches can be implemented at the planning stage and then continue through design and construction stages, current practices, — at least in European Union countries — do not use them to assist in the decision-making process. Presently, CBA and MCDA are the most common forms of appraisal in EU member states to “make decisions” — see Bristow and Nellthorp (2000). Therefore, rating systems are not applied to conduct a comparison among different alternative designs to choose the most sustainable option.

2.3.4. *Frameworks, models, and guidelines.* In addition to rating systems, several models, decision support tools and frameworks have been developed to provide guidance on the appraisal of infrastructure projects — see International Federation of Consulting Engineers (2012). Since the number of tools, calculators, and guidelines available to assist practitioners is constantly growing, there is an extensive literature in parallel or in support of main appraisal tools and systems. In order to limit the present review to a manageable scope, we pay special attention to two of the most prominent transport appraisal guidelines available for decision-makers, practitioners, and public authorities in Europe: the UK Department of Transport analysis guidance — WebTAG, and (ii) the Scottish transport appraisal guidance — STAG.

Both frameworks — required for projects that need government approval — represent best practice transport appraisal guidance, providing expert advice for transport projects with regards to sustainability, and clearly establishing significant criteria for assessing options. Along with guidance on appraisal methods, they also include software tools on transport modelling — including modelling data and forecasting, variable demand models, and transport assignment models.

In summary, they are highly effective tools for identifying and quantifying sustainability impacts of transport projects and standardize the approach using detailed appraisal procedures. However, these approaches are targeted at the evaluation process rather than at the decision-making appraisal. As a consequence, the studied methodologies do not provide mechanisms for comparing all multiple trade-offs among impacts. They represent a full account of impacts, including monetized, quantified, and qualified ones, in form of “summary tables”, but they do not come up with a final aggregated value for sustainability. Because of this drawback, the selection process of the most suitable alternative may be based on subjective judgements.

Finally, other two inherent weaknesses of these tools have to be mentioned. First, the social and distributional impacts continue to be based mostly on a simple qualitative approach that does not consider the aggregation of impacts over the whole life cycle of the project; and second, as recognized by the UK Department for Transport, they could benefit from restructuring since the guidance has grown large and requires rationalizing.

2.4. Comparative Analysis of Sustainability Methods and Techniques and Limitations of Existing Research

On the basis of the literature reviewed above, we were able to identify five *sine qua non* requirements for a tool to become appropriate for appraising sustainability: (i) full approach, (ii) life-cycle approach, (iii) rigorous trade-offs, (iv) transparent

approach, and (v) adaptability to the context. We propose to compare the various techniques and methods described in the previous sections with regard to those essential requirements, to identify the five most significant research needs that should be tackled to improve the sustainability appraisal of transport infrastructure projects.

2.4.1. Requirement number 1 (full approach). Sustainability appraisal methods should analyse the widest range of impacts of a transport project including the so-called three pillars of sustainability — environmental, economic, and social criteria — including equity over generations. We borrow this idea from the “three-legged stool” of sustainability proposed by Elkington (1998), which is now consensually applied in the academic literature and the practice of public policy-making for the sustainability definition — see, for example, Dondero et al. (2013), European Commission (2006, 2009), Hueting and Reijnders (2004), White and Lee (2009). A proper tool for the sustainability assessment should include all those aspects that define fundamental principles of sustainable development.

However, despite the fact that most researchers and practitioners agrees on the need to incorporate economic, social, and environmental items to be taken into account in addressing sustainability, there is no consensus yet on what items should be measured. Regardless of the existence of a large number of checklists and guidelines to take into account all the impacts caused by transport infrastructure projects, a widely accepted and standard sustainability list of criteria against the options to be compared is lacking. On the basis of this analysis, it is possible to set the first limitation of the existing research: *to clearly define a widely accepted list of sustainability items for transport infrastructure projects.*

There is a need to prepare a thorough list of items to characterize sustainability. In order to make this list, it might be helpful to take advantage of the existing knowledge already provided by frameworks, guidelines, and rating systems. Creating a widely accepted list of key items requires the active involvement of governments, academics, and practitioners. The list should be especially careful to avoid overlapping among economic, social, and environmental items.

2.4.2. Requirement number 2 (life cycle approach). Authors widely acknowledge that sustainability assessments should include the whole life cycle of the project, and not just one of the stages. As explained in Section 2.2, this point was addressed by the Brundtland Commission and other academic authors (Gilmour et al., 2011; Munasinghe et al., 2001; Sijtsma, 2006; Stamford & Azapagic, 2011). Thus, we can hardly speak of a desirable tool for appraising the sustainability of transport projects if it does not measure the impacts caused by the facility throughout its life cycle. Sustainability tools should be able not only to capture all the impacts, but also to define upstream and downstream impacts over the whole life cycle, from conception through construction, operation, maintenance, end of life processing, and final disposal.

However, this requirement is not always easy to apply to real projects. For example, in the case of roads, despite the FHWA admitting that “the sustainability characteristics of a highway or roadway project should be assessed and considered for implementation throughout its life cycle, from conception through construction, operations, and maintenance” (Federal Highway Administration, 2012); the evaluation of the sustainability of roads has focused on the construction

process. Up to now, the application of the sustainability concept to the roadway life cycle is mostly based on energy and material employed in the project.

One possible reason justifying the difficulty of conducting a life-cycle analysis has to do with the second research need: *to conduct a proper inter-temporal aggregation*. One of the most important challenges for improving life-cycle evaluation is to define a standardized and accepted approach for inter-temporal aggregation of environmental, social, and economic impacts. The main reason why it is difficult to aggregate “tangible and intangible” aspects over the life span of the project is that there is no clear consensus for assessing the effect of time and future uncertainties for environmental and social aspects. Setting the right discount rate for each sustainability item is a matter that also deserves future research.

This requirement has been widely considered in the literature. Many authors have mentioned the need for additional research in the field of discounting, especially for non-market goods. For an overview of this approaches to discounting based on a different rationale for tangible and intangible effects, see, for example, Almansa and Calatrava (2007), Guo, Hepburn, Tol, and Anthoff (2006), Hepburn and Koundouri (2007), Kula and Evans (2011), Pearce, Groom, Hepburn, and Koundouri (2003), Sumaila and Walters (2005). In summary, this aggregation process is still under discussion for example, some authors suggest environmental discount rates, others apply monetary values and use traditional discount rates, while others claim for a simple aggregation even though impacts spread over a long period of time.

2.4.3. *Requirement number 3 (rigorous trade-offs)*. When evaluating sustainability of transport projects, it is necessary to set the weights of different sustainability criteria in order to measure better their relative impact. Setting up clear trade-offs implies understanding the extent to which the worsening of a certain sustainability item might be offset by the improving of another one. For example, in a hypothetical application of the REMBRANDT technique — see Olson, Fliedner, and Currie (1995) — to derive criteria weights for a new transport project, decision-makers have shown a strong preference for infrastructure cost savings over the positive effects on employment. This means that they assume the first criteria to be more positive for society. Consequently they strongly prefer to save money in investment, maintenance, and operating costs rather than having positive indirect effects such as changes in economic climate and labour markets due to the construction of the new project.

However, until now “decision-aiding techniques do not overcome the problem associated with incomparable quantities” (Browne & Ryan, 2011). Despite the tension between ecological, social, and economic perspectives on sustainability, very few studies can be found in the literature addressing the issue of valuing all these attributes in the same analysis. Examples in the literature include particular studies for determining the trade-off between two specific effects such as environmental care and long-term growth — see Gradus and Smulders (1993); capital accumulation and environmental quality — see Becker (1982). Other research works include the trade-off between two specific dimensions of sustainability such as economic growth and environmental quality — see Den Butter and Verbruggen (1994) — or environmental protection versus economic development — see Feiock and Stream (2001).

Given the fact that, as far as the authors are aware, there are no previous studies that include the analysis of the relative importance of all the sustainability criteria

in transport projects and, recognizing the importance of weighting the impacts for a rigorous and objective sustainability assessment, we propose this requirement as the third essential feature of an appropriate tool to quantify sustainable practices. Sustainability appraisal methods and techniques should use analytical and rigorous methodologies for comparing all trade-offs among economic, environmental, and social aspects.

In connection with this requirement, a third research need is now evident: *to define a transparent approach for determining the relative impact of each sustainability item*. For an appropriate sustainability assessment, it is necessary to determine priorities for sustainability items (called criteria weights) based on a standard, transparent, and consistent methodology. As of today there are no standardized methods for evaluating the trade-offs among economic, environmental, and social aspects in transport projects. Consequently, decision-makers fail in setting the weightings in a transparent and precise way.

This issue, found in MCDA, rating systems and models, clearly requires further analysis. In fact, it is so complex that in the most used appraisal guidelines in Europe (WebTAG and STAG) there is no weighting information provided and decision-makers must apply their own judgement when weighing the impacts to accomplish the final assessment of the transport project — see Geurs, Boon, and Van Wee (2009).

2.4.4. Requirement number 4 (adaptability to the context). In the sustainability arena, there is a need for a more objective way to evaluate projects by considering the sensitivity of the criteria in its geographical and social context. However, with few exceptions, this issue is not specifically addressed in the literature. Authors suggesting the context-sensitive nature of sustainability are those related to rating systems worldwide. As Veeravigrom et al. (2015) pointed out, many authors agree on the need to develop or adapt a rating system specifically for the context within which it will be used — see, for example, Liang (2012), Säynä-joki, Kyrö, Heinonen, and Junnila (2012), Sev (2011). Thus, these authors have acknowledged that different location and time scales may lead to different priorities.

On the basis of this assessment we have also considered that specific priorities associated with sustainable analysis may differ in different places and social conditions. Hence, for a holistic sustainability assessment of transport projects, appraisal tools should be able to address the context-sensitive nature of sustainability by identifying the particular relevance of each impact within the specific characteristics of the social and geographical context where the project is located.

Within this scenario, a major research need emerges: *adapting sustainability to the context where the project is based*. Sustainability appraisal tools do not have many provisions to address the specific characteristics and concerns of the society where the project is located. Most of the appraisal tools available take into consideration the same level of importance no matter the social or geographical context of the project, without considering that different regions may have very different problems and needs. For example, for a transport project to be developed in Spain the present level of unemployment is higher than the European average and its trend is relentlessly worsening. Consequently, the importance of the social sustainability item “creation of jobs” should be much higher in Spain than in other countries where unemployment is not an issue.

To overcome this limitation, it will be necessary to evaluate sustainability items which are particularly sensitive in the geographical area and under the social circumstances where the project is located, and to identify the relevance of each sustainability item within the proposed site and surrounding area.

2.4.5. *Requirement number 5 (transparent approach).* Sustainability appraisal tools and methods should be transparent, rational, and formal instruments in order to minimize ambiguity — understood as the lack of clarity with regard to the methodological principles — and ensure consistency and accuracy — interpreted as the closeness of measured results to acknowledged accurate results. Hence, more rigorous the tool the better the control of systematic bias will be, and the higher its acceptability for academics and practitioners.

The research following this requirement is: to *combine existing tools and methods for the sustainability appraisal of transport infrastructure projects*. When dealing with sustainability of transport projects, there is hardly ever a single solution resulting from the appraisal process. Prioritizing different alternatives is a common problem because decision-making processes claim for a commonly accepted, comprehensive, and reliable appraisal method for sustainability assessment. Although a number of tools already in place have made valuable progress towards a more complete approach aimed at assessing the socio-economic and environmental feasibility of these projects, they lack a more integrated, consistent, and systematic approach to be applied.

2.4.6. *How do existing tools comply with these requirements?* As none of the tools and methods already analysed are suitable for a holistic assessment of the sustainability of a transport projects, further research is recommended to explore existing tools in order to use them more effectively for sustainability appraisal.

Table 3 gives a qualitative comparison of the different methods analysed on the basis of the literature review described above. We included tools which are restricted to a single criterion (economic/environmental or social) that is, CBA, LCA, and SLCA, as well as those with a multiple approach, that is, MCDA, rating systems, models, and frameworks. Each column describes to what extent the five requirements previously explained are met by each method. In order to facilitate the interpretation of the analysis, we set an assessment “score” that follows these principles: “√” for a requirement which is covered by the sustainability appraisal tool (SAT), “≈√” for a requirement which is partially taken into account by the SAT, and “X” for a requirement which is not covered at all by the SAT. The scoring comes from a consensus of the authors of this paper made after a careful review of the scientific and practice literature — some references supporting our analysis are shown in brackets — as well as from our knowledge of the different methodologies. In any case, it does not constitute an absolute assignment, but serves as a reference from what is considered acceptable for the appropriate appraising sustainability.

The main results coming out of Table 3 is that despite the numerous sustainability tools available, none of them seems to be useful for appraising sustainability in a thorough way. While there are positive characteristics associated with each tool, some practical issues remain unsolved. The tools analysed in this research did not succeed in fulfilling all the requirements cited above. Table 3 also highlights that methods may show complementary features: for example, some of them have problems with non-economic values, whereas others enable incorporating other

Table 3. Qualitative comparison of methods and tools for sustainability assessment of transport infrastructure projects

Tool	1. Full approach	2. Life-cycle approach	3. Rigorous trade-offs	4. Transparent approach	5. Adaptability to the context
Project appraisal methods	<p>≈√ Problems with non-economic values^a. Assessing equity has certain limitations^b</p>	<p>≈√ In practice, limited considerations regarding the full life cycle (e.g. end of life of materials are rarely included)</p>	<p>≈√ Well-known limitations when converting all values into monetary terms^c</p>	<p>√ In general rigorous, transparent, and formal^d, but assumptions hidden behind a single result^e</p>	<p>≈√ Values for economic objects are context sensitive. Context is also incorporated through the discount rate. There has been and still is considerable debate about it^f.</p>
MCDAs	<p>√ Allows to incorporate other aspects apart from the economic ones. Several criteria can be taken into account simultaneously^b</p>	<p>≈√ Strive to have a life-cycle focus but in practice this objective is not always reached</p>	<p>≈√ Involves a certain element of subjectiveness^{g,d}</p>	<p>≈√ Criteria weighting may be subjective: black-box concept</p>	<p>≈√ Usually incorporated through decision-makers' judgements. In practice, this process may be highly questionable</p>
Environmental/social assessment methods	<p>× Social and economic aspects are not taken into account in LCA study^{h,i}.</p>	<p>√ Used to quantify environmental impacts and resource consumption during the entire life cycle^l.</p>	<p>× It Does not consider economic and social aspects</p>	<p>√ Although it is a standardized tool, still needs improvements to increase its accuracy^k</p>	<p>× Included interactions between activity and the surrounding environment but not the context-sensitive nature of sustainability</p>
SLCAs	<p>× Economic and environmental impacts are not included within its scope</p>	<p>≈√ It may potentially include social impacts in all stages for its life cycle^l</p>	<p>× It Does not consider economic and environmental aspects.</p>	<p>≈√ Short history, a number of fundamental issues have not been agreed on and resolved^m</p>	<p>× Efforts will have to be made to adopt the context when defining indicatorsⁿ.</p>

Sustainability assessment methodologies	Rating systems	✓ The triple bottom line is included but in practice they are mostly focused on environmental issues and on the construction stage. In theory, they consider the full life cycle of projects ^o	≈✓ They lack transparency and objectiveness in the selection of criteria and weighting process ^p .	≈✓ Thought as an instrument for a specific context, and that limits its applicability to other contexts
	Frameworks ^q	<div> <div> ✓ High-level assessment of social, economic, and environmental aspects </div> <div> ≈✓ The project life cycle is not fully considered for items such as the social ones </div> </div>	<div> <div>✗ Not applicable, they do not aggregate results into a single value.</div> <div> ✓ Reliable and accurate tools, but the selection of the best alternative may be subjective. </div> </div>	<div> ≈✓ Thought as frameworks for a specific context, and that limits their applicability to other contexts </div>

Note: "✓": this requirement is completely covered by the SAT; "≈✓": this requirement is partially taken into account by the SAT; "✗": this requirement is not covered by the SAT.

^aOmura (2004); ^bThomopoulos, Grant-Muller, and Tight (2009); ^cBeria, Maltese, and Mariotti (2011); ^dBeria et al. (2011); ^eBrowne and Ryan (2011); ^fSijtsma (2006); ^gBarford et al. (2011); ^hLiimatainen (2012); ⁱStripple (2001); ^jLoiseau et al. (2012); ^kReap, Roman, Duncan, and Bras (2008); ^lHauschild, Dreyer, and Jørgensen (2008); ^mJørgensen et al. (2008); ⁿGrieshammer et al. (2006); ^oReid, Davis, and Bevan (2012); ^pLee et al. (2011). ^qFrameworks included in this table refer to those described above.

aspects apart from the economic ones. As a result, we conclude that an integration of current tools with complementary attributes could be beneficial for effectively handling sustainability in the *ex ante* appraisal of project alternatives.

3. Conclusions and New Ideas to Improve Sustainability Appraisal

The literature review conducted in the previous sections shows that, although the concept of sustainability has gained increasing importance, the comprehensive sustainability appraisal of transport infrastructure projects is still an unresolved matter. In this review, we found that none of the existing tools includes the necessary requirements to be appropriate for appraising sustainability of transport projects: for example, to integrate the widest possible range of impacts compliant to a life-cycle approach, to provide a rigorous method to analyse the balance among the “triple bottom line” aspects, and to include the context-sensitive nature of sustainability. Consequently, despite the fact that the current approaches offer some value for sustainability assessment, none of them can be used to carry out a holistic appraisal. However, we point out that among the existing tools, the MCDA approach seems to be the most suitable technique because of its flexibility to incorporate sustainability drivers.

Taking into account that finding an optimal tool to appraise sustainability of transport projects is a complicated issue, and being aware that a compromise is necessary between accurateness and workability, we can propose some ideas to improve sustainability appraisal. Taking advantage of the complementary relationship found among current tools — see [Table 3](#) — we propose a combination of the MCDA with other tools for a more complete sustainability assessment of transport projects.

As the first approach, we suggest integrating the multiple criteria approach methodology with the single criterion approach (composite tool) in order to keep the strengths of each appraisal method. Based on the assumption that MCDA and CBA can be used in tandem, it will be appropriate to seek a solution for expressing the CBA results into the same language as the MCDA results. Composite decision support models — based on combining methodologies for economic, environmental, and social assessment — are lacking in the state of the art. Despite the fact that recent studies have tried to combine these methodologies — see [Barfod et al. \(2011\)](#), [Gühnemann et al. \(2012\)](#), [Sijtsma \(2006\)](#) — in practice “effective implementation has proven elusive” ([Gühnemann et al., 2012](#)). The “combined tool” should be able to take into account several criteria simultaneously — including those difficult to quantify — with a life-cycle focus. In addition, this composite tool should be rigorous, transparent, and formal, and will incorporate the context-sensitive nature of sustainability in the analysis.

From the attempt to combine the strengths of the current appraisal methods to address sustainability, special attention should be given to two specific aspects: (i) the inter-temporal aggregation of environmental, social, and economic impacts to improve the life-cycle evaluation and (ii) the process of setting the weights of each sustainability criterion. A potential approach to tackle the first problem may include alternative discounting methods according to the characteristics of the specific sustainability criteria: for example, those that can be quantified and monetized with market prices; those that can be quantified and are not bought and sold in the market; and those that cannot be quantified. On the other hand, a potential approach for increasing the rigour and objectivity in the setting of the

weights of the MCDA may consist of incorporating the sensitivity of each criterion to the social and geographical context where the project is situated, and setting the trade-offs among different criteria from consensus-based comparative judgements and preferences.

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Notes

1. Sustainability criteria are defined as the basic fundamentals or principles used to judge the sustainability of transport projects and to compare the alternatives. They can be grouped into different sustainability components (economic/social/environmental).

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SETTING THE WEIGHTS OF SUSTAINABILITY CRITERIA FOR THE APPRAISAL OF TRANSPORT PROJECTS

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Abstract. Although the Multi-Criteria Decision Analysis (MCDA) has made progress towards appraising and measuring the performance of smart and sustainable transport projects, it still has important issues that need to be addressed such as the problem associated with incomparable quantities, the inherent subjective qualitative assessment, the complexity of identifying impacts to be included and its measurement method, and the corresponding weights. The issue of trading-off different sustainability criteria is the main unresolved matter. This problem may lead to lack of accuracy in the decision making process. This paper presents a new methodology to set the weights of the sustainability criteria used in the MCDA in order to reduce subjectivity and imprecision. We suggest eliciting criteria weights based on both expert preferences and the importance that the sustainability criteria have in the geographical and social context where the project is developed. This novel methodology is applied to a real case study to quantify sustainable practices associated with the design and construction of a new roadway in Spain. The outcome demonstrates that the approach to the weighting problem has significance and general application in a multi-criteria evaluation process.

Keywords: sustainable transport; multi-criteria analysis; decision making; criteria weighting; pairwise comparisons; REMBRANDT.

Introduction

Transport systems and infrastructure construction consume large amounts of energy and industrial products. Since the emergence of the concept of sustainability as an international priority in the 1980–1990s, there has been a growing interest in exploring strategies to promote smart and sustainable transport. Nowadays, there is a growing demand to make transport infrastructure more sustainable without compromising conventional goals (i.e., cost, quality, and schedule). Planners strive to mitigate the impacts – on the environment, the economy, and society – throughout the whole life cycle, from conception through construction, operation, maintenance, end of life processing, and final disposal.

Although there are many approaches aimed at assessing the socio-economic and environmental feasibility of transportation projects, currently there is no standardised or commonly agreed methodology offering a reliable measurement of sustainability when appraising and evaluating transport projects over their life-cycle. The available literature on smart and sustainable infrastructure (see Dasgupta, Tam 2005; Gilmour *et al.* 2011; Tsai, Chang 2012) points out that policymakers are in need of practical tools and techniques to assess sustain-

ability in all the life stages of infrastructure projects. In the EU, appraisal is generally seen as a means aimed at supporting the process of planning transport systems. The most common forms of appraisal in use in the EU member states are Cost Benefit Analysis (CBA) and Multi-Criteria Analysis (MCA) – see Bristow, Nellthorp (2000).

Although these traditionally accepted techniques offer valuable support for assessing transport projects, they hardly ever address all the components of sustainability (economic, social and environmental) in a thorough way. This research focuses on one of the most common forms of appraisal of sustainable transport systems and infrastructure: the Multi-Criteria Decision Analysis (MCDA). Despite MCDA can explicitly deal with different components of sustainability; there remain some fundamental gaps that may lead to lack of accuracy in the results of a decision making process. One of the main problems of this widely used technique for selecting the best alternative with respect to multiple criteria is precisely setting the weights to sustainability criteria in a transparent and precise way. MCDA can introduce subjectivity when evaluating the weights selected to rank different criteria.

As a new contribution to the state of knowledge, an adaptation of the traditional MCDA is developed aimed at addressing these issues and making the decision process more rational and accountable. We propose an adaptation of the weighting process that directly tackles the issues in assigning weights in a typical MCDA. To that end, we have designed a composite weighting model that allows the incorporation of consensus-based comparative judgments and preferences, along with the geographical and social context of the project.

The paper is structured as follows. Section 1 summarises the literature review on Multi-Criteria Decision Making (MCDM) for smart and sustainable transport, illustrating the knowledge base for criteria weightings. Then, the new method for obtaining preference weights is presented in section 2. Section 3 discusses the results of the application of this weighting approach to a real example of a new roadway; and last section provides a set of conclusions and final recommendations.

1. Multi-Criteria Decision Analysis for the Sustainability Appraisal of Transport Projects

Smart and sustainable transport projects are appraised in practice through a number of tools or methodological frameworks. These methods encompass the traditional analytical methodologies, as well as a number of current sustainability tools such as rating systems, frameworks, and appraisal guidelines. Among these methods, the MCA has become increasingly popular. However, as claim by Bueno *et al.* (2015), despite the fact that the current approaches offer some value for sustainability assessment, none of them can be used to carry out a holistic appraisal. Moreover, there is stillroom to improve the current tools for smart and sustainable transport infrastructure systems.

The MCDA is introduced in the following section by highlighting its strengths and weaknesses. Our aim is to examine how it works and identify whether it provides a suitable framework to integrate sustainability into existing appraisal processes.

Multi-criteria Decision Analysis

The multi-criteria technique is a suitable decision making methodology for 'addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, multiple interests and perspectives, and the accounting for complex and evolving biophysical and socio-economic systems' (Janic 2003). Its use for different purposes has been increasing over the years. There are several papers where this approach has been applied in the field of transport, for instance (Iniestra, Gutiérrez 2009; Cheng, Li 2005; Friesz *et al.* 1980; Frohwein *et al.* 1999; Giuliano 1985; Khorramshahgol, Steiner 1988). Recently, Macharis, Bernardini (2015) provided a wide overview of the increasing use of MCDA methods in the evaluation of transport projects.

Within the sustainability appraisal context, the MCDA usually includes the following main steps. First,

the alternative's formulation and selection provided by decision makers. The second stage corresponds to the identification of sustainability criteria and the evaluation for each alternative. Sustainability criteria are defined as the basic fundamentals or principles used to judge the sustainability of transport projects and to compare the alternatives. They can be grouped into different sustainability components (economic/social/environmental). Third, the assignment of weighting coefficients to the criteria and finally, the sustainability evaluation by using a method for ranking the alternatives.

A number of authors have suggested that MCDA is the most appropriate tool to adopt decisions based on an integrated sustainability appraisal (Hyard 2012; Munda *et al.* 1998; Walker 2010). Munda (1995) says, that MCDA offers a number of advantages for policy analysis, compared with conventional economic welfare techniques. Several criteria can be taken into account simultaneously – including those difficult to monetize or quantify. Then, the technique allows capturing the full range of impacts of a project (Thomopoulos *et al.* 2009). MCDA also promotes public participation and enables stakeholder involvement.

However, despite the fact that MCDA can explicitly deal with different components of sustainability, the extensive study of multi-criteria techniques for transport projects has acknowledged issues that require further analysis including: the inherent subjective qualitative assessment, the complexity of identifying impacts to be included and its measurement method, and the obtaining of weights to criteria (Browne, Ryan 2011).

In fact, the use of weights is the main unresolved matter of this methodology. It has to do with the transparency of judgements and their influence on the final results of a multi-criteria problem. This weakness has been the subject of severe criticisms by a number of studies – see for example, Browne, Ryan (2011), Chen *et al.* (2013), Hobbs, Horn (1997), Wibowo, Deng (2011). The following section presents one of the most significant research needs that should be undertaken in order to improve the appraisal of transport projects when employing a multi-criteria approach: the use of weights and how these might be obtained in practice.

Criteria Weighting: a Gap in the Process

A number of methods for determining criteria weights in MCDA have been developed. There are thorough studies performed by different authors about weight assessment techniques – see for example by the following: Harte, Koele (1995) and Barron, Barrett (1996).

In general, there exist two weighting methods: the equal weights and the rank-order weights. The last is classified into three categories: subjective – such as pair-wise comparison, Delphi method or Analytical Hierarchy Process (AHP); objective – such as Least Mean Square (LMS), entropy method or the vertical and horizontal method; and combination weighting method – such as multiplication synthesis and additive synthesis. Wang *et al.* (2009) provided a comprehensive review of the weighting methods for MCDA.

Within this context, as Hobbs and Horn (1997) pointed out, 'the theory definitely favours trade-off judgements as a technique for choosing weights'. Macharis and Bernardini (2015) in their turn pointed out the importance of integrating decision makers in the process for obtaining weights to several criteria not yet very common in current transport projects. Some recent papers provide an overview of the theory and lessons learned from an alternative extension of the traditional MCDA where the stakeholders are explicitly taken into account during the project analysis, the Multi Actor Multi Criteria Analysis (MAMCA) (see for example, Macharis *et al.* 2012; Bergqvist *et al.* 2015; Turcksin *et al.* 2011; Sun *et al.* 2015).

In practice, the process for obtaining the relative importance of criteria might appear questionable. The 'black box' concept should be considered as an important issue since it causes a loss in credibility. In fact, 'due to a lack of procedures for aggregating the evaluations of the individual criteria and unregulated weights that were left to the whim of the decision-takers' (Sayers *et al.* 2003); some governments – such as France – have moved away from the MCDA and returned to the 'monetising approach'.

As a result, the MCA involves certain subjectiveness (Beria *et al.* 2011; Barfod *et al.* 2011). Qualitative assessment and the imputation of value-laden weightings to assumptions may lead to subjective and non-transparent biasing – see Munda (2004) and White, Lee (2009). Moreover, the fact that criteria weights are context-dependent (Ribeiro 1996) is not fully addressed in the MCDA and in practice this process may be highly questionable.

Trying to solve above-mentioned issues, some research has been conducted on the development of various approaches for criteria weighting in MCDA. Rezaei (2015), for example, proposes a new method called best-worst method that derives weights based on a pairwise comparison of the best and the worst criteria/alternatives with the other criteria/alternatives. Wang (2015) presents a fuzzy MCDM model based on a simple additive weighting method and the relative preference relation. Finally, Chen *et al.* (2014) propose an integrated weighting method that narrows the gaps between objective and subjective perspectives and offers more reasonable results.

However, despite these advances, there remains significant room for improving the setting of the weights in a practical and precise way. Novel approaches usually require complex mathematical tools, are not easy to manage or suffer from problems in modelling the subjectiveness of human decision processes. Policy makers are still in need of standardized and practical methods for evaluating the trade-offs among economic, environmental and social aspects in transport projects.

Overall, the main finding of this review is that despite the well-known strengths of the MCDA approach, it still can be improved for measuring the performance of smart and sustainable transport projects. The following section discusses a flexible approach to overcome the obstacles pointed above.

2. A Flexible Approach to Obtain Criteria Weights Incorporating the Context of the Project

The objective of this section is to present a novel process to setting the weights of sustainability criteria so as to tackle the issues previously mentioned. The novelty of the method is the separate consideration of expert preferences and the objective characteristics of the criteria in the geographical and social context of the project. The benefits of this separation are:

- the higher expected efficiency of the weighting process. In our methodology, experts were asked to state preferences among different criteria irrespective of the context and the magnitude of the impacts; then, criteria weights for sustainability items can be used for many projects because the methodology is flexible enough to adjust the weights;
- the higher expected rigorous mechanism for comparing all trade-offs among economic, environmental and social aspects. Since experts were asked to express graded comparative judgements between different criteria without having information about the project and the context; their valuation of trade-offs implies a clear representation of the extent to which the worsening of one criteria might be offset by the improving of another one;
- the higher expected objectivity of the weighting process. Our methodology considers that sustainability criteria contributes to sustainability to a greater or lesser extent depending on how sensitive they are in the context where the project is developed.

The composite model is aimed at obtaining improved weighting coefficients (designated as Improved Weights – IWs) to the sustainability criteria – see the Eq. Weights come from the context (severity level) and the consensus-based comparative judgments and preferences (Convergent Weights – CWs). These terms will be explained in greater detail below.

$$IW_i = CW_i \cdot SL_i$$

where: IW_i – Improved Weight for criterion i ; CW_i – Convergent Weight for criterion i ; SL_i – Severity Level of criterion i .

Identifying the Severity Level

As stated before, the main purpose of this step is to establish sensitivity aspects related to the geographical and social context where the project is located. In our methodology, Severity Levels (SL) for each item are obtained by adding scores achieved from the evaluation of the Present Situation (PS) and the trend in the project context. The higher the SL, the more sensitive the criteria in the context. As shown in the Eq., SL are integrated into the appraisal process by considering them part of the weighting method.

The integration of the context should be independent of the criteria magnitudes and even of the project

itself, and involves identifying the relative importance of each criterion to the sustainability appraisal in a certain context. The PS of each criterion must be evaluated using a defined scale. The analyst then compares the value for the context with an acknowledged reasonable value for this specific criterion (defined as the average value for other similar contexts). It allows policy makers to put the environmental, economic and social performance of the region where the project will be implemented into context, by ‘benchmarking’ them to other countries with similar geographic, social or regional characteristics.

The criterion is likely to have a greater impact on global sustainability if the PS is considered to be much worse than the acknowledged reasonable value of similar social and economic context. Therefore, a score is allocated to the PS for each criterion in context according to Fig. 1. In this case, the question of what is much/slightly/moderately better or worse could be answered by the current state of knowledge or legislation in the particular discipline of the criteria.

A short example may serve to illustrate the process of evaluating of the PS presented in previous paragraphs. Imagine two transport projects with the same characteristics but implemented in different countries: Germany and Spain. To solve the problem of understanding the importance of the social sustainability item ‘employment effects’ (i.e. the PS for this criterion) for both projects, we need to compare the unemployment rate in Germany and Spain with the average value for different European countries. According to the World Bank database, the percentage of the labour force that is without work – and is actively looking for work – is 5.3% for Germany and 26% for Spain, whereas the average of the unemployment rate in European countries is 10.9%. In the case of the project to be developed in Germany, we can reasonably assume that the PS for this criterion is much better than the context average, and 0 points should be assigned. In contrast, in the case of Spain, the PS is much worse and, according to Fig. 1, 5 points should be given to this criterion.

To calculate the level of severity our methodology proposes to evaluate also the trend, in addition to the PS, for each criterion in the geographical context where the project is located. The main outcome of the present task is the classification of each item trend as ‘improving’, ‘stable’ or ‘worsening’ and the allocation of the corresponding score (0 points, 1 point and 2 points, respectively).

Continuing with the example described above, the percentage of the unemployment rate in Spain was increasing at the time of appraising the project while in Germany was decreasing for many decades. Then, for the first case, the criterion trend should be classified as ‘worsening’ and a total of 2 points should be allocated. In contrast, for the case of Germany, 0 points should be assigned. In summary, the ‘employment effects’ item is more sensitive and it has higher level of importance for a project to be implemented in Spain and then, according to the Eq., it should have a higher weight than the same item for the German project.

In order to conduct a thorough evaluation of the project, the previously described process for the ‘employment effects’ item should be repeated for each one of the set of major sustainability items to be considered for the project over its life-cycle.

Obtaining Convergent Weights

As recognised by Gühnemann *et al.* (2012), the weight allocated to each criterion and sub-criterion in the framework should also reflect the decision-makers’ preferences. Since it aims to narrow the gap between theoretical sustainable requirements, current design practices and decision-making processes, it is considered crucial to incorporate the decision-makers’ preferences irrespective of the context. In order to incorporate decision-makers preferences, we propose to use a combination of the Ratio Estimation in Magnitudes or decibels to Rate Alternatives which are Non-Dominated system (REMBRANDT system); and the Delphi method.

A pairwise comparison method is required to determine the weights for each criterion in order to establish a trade-off between different criteria. We use the REMBRANDT technique to derive weights, since it is a further development of the well-known original *Analytic Hierarchy Process* (AHP). As consensus is rarely reached in practice, the Delphi technique – see Linstone, Turoff (1975) – should be used to achieve a convergence of opinion from experts. The process can be completed throughout the following stages:

- (1) *Questionnaire design.* Pairwise comparisons are organised based on a previously identified criteria list. Experts are then asked to compare the importance of different sustainability criteria based on a –8 to +8 scale known as the REMBRANDT scale – see Olson *et al.* (1995).

Fig. 1. Evaluation of the Present Situation (PS) for each attribute

- (2) *Conducting a survey.* A number of experts are selected to complete the questionnaire. The survey needs to reflect the views of as many interested parties as practicable. A minimum of 30 respondents is required for this weighting exercise to be robust.
- (3) *REMBRANDT calculations.* Each expert surveyed has to complete a matrix of preferences. Each element of the matrix represents the preferences stated by the expert. Criteria weights are then obtained using the REMBRANDT technique – see Olson *et al.* (1995).
- (4) *Statistical test.* A statistical test is conducted to evaluate the convergence of opinion for a weighting process to be deemed robust and valid. For this methodology, we developed a simulation based on a cross validation technique to estimate the level of consensus among the panel of experts. For this purpose, we used the R software (<http://www.r-project.org>).

The test consisted in dividing the data of the experts surveyed (weights obtained from experts) into two equal-sized parts. The test then compared the answers of both groups in order to find significant differences. This procedure was repeated 1000, 10000 and 100000 times with randomly selected groups. The result was a p-value distribution for each criterion. The p-value was used to analyse the data set and test the null hypothesis (Ho): both groups' answers are significantly different. We adopted a 5% significance, thus accepting Ho if the p-value was 0.05 or lower. If it were higher than 5%, we would not have enough evidence to assume there are significant different answers, and would therefore reject Ho.

If the level of consensus is sufficient (p-values higher than 0.05), a Delphi method will not be necessary. In this case, the average of the weights obtained from the survey is used as the Convergent Weights (CWs). Otherwise, if the statistical test is unable to prove the required level of consensus, the Delphi technique is applied to achieve a convergence of opinion on weight estimations until CWs are obtained. Multiple interactions are used to achieve consensus for the panel of experts. The procedure for this second round is summarised in the following steps:

- *Step 1.* A summary of the general result is returned to the experts surveyed, allowing them to revise their judgements or specify their reasons for remaining outside the consensus.
- *Step 2.* The procedure specified in (3) and (4) is repeated; that is, the REMBRANDT calculations for criteria weights and the statistical test.
- *Step 3.* The iterative process can be stopped once consensus is achieved.

3. An Example Applied to a Transport Project

To demonstrate the feasibility and usefulness of the proposed methodology, this section describes its application to a decision-making case study concerning the design and construction of a new interurban roadway in Spain.

First, appropriate criteria to measure the performance of the different alternatives were identified – taking into account economic efficiency, environmental protection, and social aspects. The list of criteria for this real case study is shown in the Table, second column.

Beyond previously identified sustainability criteria, we had to identify the attribute in context to evaluate the performance for each criterion. For example, in order to have information about the importance for the 'investment costs' criterion, we may evaluate the 'budgetary availability for infrastructure spending' attribute in context. The Table (third column) also presents the list of criteria to be evaluated in context.

To help better illustrate how to incorporate the context into the process, the Table presents a complete evaluation of the PS and the trend for each criterion in the particular geographical area where the project is going to be located (Spain). This information was obtained mainly from the World Bank database, the Eurostat data source yearbook and other official sources. We allocated a score to the PS for each criterion in its context (*shown in italics*, below the 'average in context' value). The trends for each particular criterion were classified, and a score was allocated to each attribute trend (*shown in italics*). Finally, the severity level was obtained by adding together the scores for the PS and the scores from the trend.

Taking the example of 'employment effects' explained above, we obtained a severity level of 7 points to this item – see the Table. This result comes up of adding the points assigned to the PS of this criterion in the context of Spain (5 points) plus the points given for revealing a worsening trend (2 points).

Another example can be given for the 'distributive effects of the project' criterion. We took advantage of the information provided by Eurostat for the most widely used measure of income inequality, the Gini coefficient. The value of this coefficient in Spain was around 0.34, while the average of the EU countries was 0.29. Since the PS is considered to be moderately worse than the average value in context, a score of 4 points will be ultimately assigned to this item according to Fig. 1 (see the Table). In addition, since the trend for the Gini coefficient is stable, 1 point will be assigned to this criterion. As a result, a severity level of 5 points was obtained for the 'distributive effects of the project' criterion.

This means that, at the time of conducting this analysis, the 'distributive effects of the project' item is likely to have less importance in the context of Spain than the 'employment effects'. As a consequence, assuming the same CW for both criteria and according to the Eq., the 'employment effects' item should have a higher final weight (IW).

To obtain the preference weights, we organised pairwise comparisons based on the list of previously identified criteria in order to consider the opinions of stakeholders for a sound decision process. We asked 250 experts to complete a questionnaire to determine priorities among the different criteria related to roadways throughout their life cycle. The survey included experts from transportation research centres, public sector

Table. Present Situation (PS) and trends for attributes in context

Sustainability component	Criterion	Criterion to evaluate in context	Units	Present situation	Average in context	Trend***	Severity level (0–7 POINTS)	Improved weights (IW)
Economic	Investment costs	Budgetary availability for infrastructure spending	%	2	5 (4)	↘ (2)	6	5
	Maintenance costs							5
	Road operating costs							5
	Vehicle operating costs							4
	Accident costs	Road accident rates	Deaths per 100,000 inhabitants	5.4	4 (4)	↘ (2)	6	17
Environmental	Travel time	Average congestion level	%	16	23 (1)	– (1)	2	2
	Energy consumption*	Energy consumption	GJ per year	135.59	163.86 (2)	↗ (0)	2	2
	Fuel consumption	Energy consumption	Kilograms of oil equivalent per person per year	3228	3985 (2)	– (1)	3	3
	CO ₂ emissions**	CO ₂ emissions	Metric tons per capita	5.85	7.32 (1)	↗ (0)	1	1
	Habitat fragmentation and negative effects on species	Environmental fragility of the habitat	(1–5)	5	3 (5)	– (1)	6	6
	Landscape degradation/ negative visual impacts							7
	Noise pollution	Noise levels	Population exposed to traffic noise above 65 dB	27.7%	30% (2)	↘ (2)	4	4
Social	Community disruption	Aggregated indicator of community cohesion	%	35%	70% (5)	– (1)	6	10
	Impacts on businesses and community services	Fragility of business environment	(1–5)	4	2 (4)	↘ (2)	6	11
	Employment effects	Unemployment rate	%	–26.3%	–11.2% (5)	↘ (2)	7	11
	Distributive effects of the project	Gini coefficient	Dimensionless quantity	0.34	0.29 (4)	– (1)	5	8

Notes: *Including total energy consumed in the construction-maintenance (i.e. extraction of materials and resources), and operating phase (i.e. fossil fuel energy consumption); **Including the carbon embodied in construction materials, fossil fuels and construction machinery vehicles (construction and maintenance) and the carbon embodied in vehicles and fossil fuels and direct emissions due to combustion of fossil fuels (operation); ***According to the methodology, classified as: improving (↗), stable (–) or worsening (↘).

managers, specialists from international organisations (the World Bank and the European Investment Bank, among others), as well as professors, researchers, designers and practitioners. In the questionnaire, respondents were asked to state their preferences for each pairwise comparison and mark their choices, presented as the REMBRANDT scale. The questionnaire explicitly asked to answer about the criteria irrespective of the context of the project and the magnitude of the impacts. The specific project to be evaluated was not mentioned in the questionnaire.

Based on their personal view of the relative importance of the economic, environmental and social criteria defined for this case study, we obtained criteria weights by using the REMBRANDT technique – see Fig. 2. The decision-makers showed a strong preference

for accident cost savings over other criteria. Differences were not very significant for environmental and social criteria. A weak preference was found for all social criteria over environmental and even economic criteria in terms of sustainability. This implies that the worsening of a sustainability item could be offset by improving a social aspect. Nevertheless, the magnitude of the impact is important in the final sustainability evaluation.

Finally, the level of consensus among the panel of experts was estimated by using the statistical test based on a cross validation technique developed by our methodology. We divided the data into two parts and compared the answers of the experts surveyed in both groups. We repeated the procedure 1000, 10000 and 100000 times, and finally obtained a p-value distribution for each sustainability criterion – see Fig. 3.

Fig. 2. Summary of results from the weighting survey

Fig. 3. P-value distributions

These results showed reported p-values higher than 0.05, allowing us to conclude that the level of consensus is good enough so the implementation of a Delphi method was not necessary at the end.

As indicated in the statistical process, we assumed criteria weights derived from the weighting survey as the final CWs. These were subsequently adjusted with the severity level. Finally, an IW was found for each sustainability criterion by applying the Eq. Results are shown in the last column of the Table.

Conclusions and Discussion of Findings

In this paper, we proposed a new and transparent method for effectively assisting decision makers in determining the criteria weightings for transport project appraisal.

This approach obtains the weights by considering separately the sensitivity of the criteria in the geographical context where the project is situated, and the trade-offs among different criteria from consensus-based comparative judgments and preferences. To show the applicability of the methodology proposed in this paper, we applied it to a real road project in Spain. The practical implementation of this approach demonstrated that it is suitable for setting the weights of different sustainability criteria in roadway projects. This example shows that the proposed weighting method has a number of advantages including:

- its simplicity and comprehensibility; this facilitates the understanding and usage of this method for practical applications;
- its flexibility and ability of replication; it can be adapted to different real-world applications. It also has the advantage of allowing, for many road projects, the use of the same consensus-based comparative judgments and preferences results obtained from the survey conducted in this research;

- its ability to increase the efficiency, rigor and objectivity of the process aimed at setting the weights; it adequately handles the subjectivity of the process of trading-off different sustainability criteria.

Future research should continue testing the applicability and usefulness of the proposed methodology by applying it to other real-world case studies and comparing the results with other approaches for setting weightings. We also suggest improving the method's validation by applying it to projects that were already appraised to compare the results of our methodology ex-post. This way, some relevant questions such as what would have happened if we had proceeded according to other different weight method (for example, with the final selection of the best alternative) can be answered.

Finally, the novel weighting method is expected to have significance and great potential to be implemented in the multi-criteria evaluation process aimed at assessing sustainability. However, much research should be conducted in order to solve other well-known issues of the MCDA such as the inter-temporal aggregation of environmental, social and economic impacts to improve the life-cycle evaluation.

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4. RECOMMENDATIONS, CONCLUSIONS AND FURTHER RESEARCH

This section summarizes the compliance with the objectives defined earlier (Section 4.1), main conclusions (Section 4.2), practice-oriented recommendations (Section 4.3), and further research that may be drawn from the contents of this Thesis (Section 4.4).

4.1 Fulfilment of research objectives and summary of contributions

As previously explained in Chapter 1, the main objective of this Thesis was to provide knowledge for assessing social and distributional impacts of transportation policies and their potential equity consequences from the sustainability viewpoint. The research pursued four specific objectives:

- (i) Obtain lessons about the incidence of different transportation policies (e.g. transport subsidies, transport benefits, and road pricing) on social inclusion, particularly on income distribution;
- (ii) Understand the three-dimensional concept of sustainability—including the most relevant tools for its assessment—and the role of social impacts within the sustainability framework;
- (iii) Explore the integration of social and distributional impacts into the existing appraisal process; and,
- (iv) Draw policy recommendations based on the analysis and findings from (i) to (iii) above, in order to provide useful and practical suggestions for local transport planners when evaluating policies, specifically in meeting social objectives.

Concerning the first objective, the research took advantage of the results from different surveys conducted to those users experiencing the advantages or disadvantages of different transportation policies. By applying econometric

methodologies and statistical techniques such as regression and discrete choice models, the impact of three different policy alternatives on low-income people has been explored, particularly: (i) public transport fare subsidies, (ii) the provision of transportation subsidies and benefits to employees, and (iii) road pricing strategies. The following papers were developed with a common structure: introduction, state of knowledge, methodology, description of the case study, modelling results, discussion and conclusions:

- a) The first paper (Paper I, Chapter 2) developed a practical approach to evaluate the impact of fare subsidization on vertical equity, taking the City of Madrid (Spain) as case study given its high subsidization rate. The research is based on a two-step methodology. First, two quantitative indicators formulated from Madrid's Transport Survey were defined and evaluated. Second, a multiple regression model was calibrated to study the variables explaining the use of the travel pass. By exploring the equity implications of the travel pass approach, the research determined whether this policy particularly benefits the people in most need, namely low-income groups.
- b) In the same line, the second paper (Paper II, Chapter 2) examined the relationship between commuter benefits and mode choice for commuting trips in the States of New York and New Jersey (US). Based on individual data from the Regional Household Travel Survey, a multinomial logit model was adopted to identify the extent to which transport benefits can incentivize modal change in daily travel behavior. From the equity viewpoint, it also explores whether the differences between wealthy and nonwealthy residents explain commuter modal variability when controlling for other potential explanatory factors.
- c) Finally, a third paper (Paper III, Chapter 2) was developed to explore users' perceptions towards interurban toll roads in connection to equity issues. Based on individual data from a nationwide survey conducted to road users in the Spanish toll network, different discrete choice models were adopted to estimate the probability of supporting different road pricing schemes: an express toll lane, a time-based scheme and a flat-fee charging system. The paper also analyses the relative importance of different explanatory variables related to (i) personal socioeconomic characteristics, (ii) trip-related attributes,

and (iii) personal attitudes with regard to toll facilities. Finally, it evaluates whether the support of users towards alternative pricing options is directly related to their income, as might be expected based on the political debates over equity.

Regarding the second objective, a complete review of the concept of sustainability —covering the three dimensions: economic, ecological and social— was conducted in an academic paper (Paper IV, Chapter 3). It explored a number of tools and methodological frameworks available to perform the sustainability appraisal and the evaluation of transport projects and policies. In this paper, a wide overview of the state of the art of the sustainability domain is provided. The limitations and the challenging points on the sustainability appraisal are exposed and the five major challenges needed to be addressed are examined. Finally, the paper included a set of conclusions, final reflections and recommendations for future research areas in this field.

As for the third objective, a feasible methodology was developed to obtain improved weighting coefficients to the sustainability criteria, including social aspects and equity considerations (Paper V, Chapter 3). As a contribution to the state of knowledge, an adaptation of the traditional MCDA —in assigning weights— is developed aimed at making the decision process more rational and accountable. Finally, as a result of the final objective, and in the light of the research work developed in the current Thesis, some recommendations at the practice-oriented level are provided in this chapter —see Section 4.3 below. Policy and practice-oriented recommendations discussed in this Thesis intend to shed some light on how to measure the incidence of transport policies and propose ways to improve their targeting properties with regards to social inclusion.

4.2 Conclusions and research findings

This section provides the most relevant findings of this research, which gives answer to the research questions (RQ) drawing from the literature previously discussed. The general conclusions and findings are divided into five areas, corresponding to the research questions described in Chapter 1, Section 1.4. In

addition, the sub-section 4.2.6 presents cross-case conclusions on the equity implications of transport policies, which correspond to the second part of research questions 1, 2 and 3.

4.2.1 General conclusions related to the Research Question 1

RQ1: How to measure the social and distributional impacts of fares and subsidy policies in urban transport? Is it possible to implement transport subsidies with a progressive distribution of benefits?

- Further efforts can be done to improve the distributive impacts of transport subsidies. As the case of Madrid showed, transport policies aimed at making transport more affordable to the low-income people are possible. Implementing transport subsidies with a progressive distribution of benefits constitutes a feasible option.
- The way public transport subsidies meet social needs of the disadvantaged people should be carefully addressed in the planning and design stage. Given that equity is often the key component in debates on subsidies, it is advisable to early guarantee a pro-low-income effect of this type of transport policies. The opportunities to achieve social equity objectives vary and eventually diminish as a policy moves through the various stages of its lifespan.
- There is a need to reconsider how to measure the social and distributive dimensions of public transport subsidies in practice. Despite there are some common techniques to quantify vertical equity with respect to income (such as the Gini index, the Theil coefficient or the Coefficient of Variation), these approaches usually require detailed information which is not always available—as is the case for individual income data in Madrid.
- An alternative methodology is proposed to evaluate the distributive incidence of urban transport subsidies when current data is not detailed enough. It basically consists on (i) the calculation of indicators easy to understand and relatively ‘low-data intense’, and (ii) the development of simple modelling approaches at the macro level to explore the relationship between the income level and the effects of subsidies.

4.2.2 General conclusions related to the Research Question 2

RQ2: To what extent the TDM programs based on providing transportation subsidies and benefits to employees can incentivize changes in daily travel behavior? Are user's decisions on daily mode choice influenced by income levels?

- The first conclusion regards the strong and significant relationship observed between commuter benefits and transportation mode choice. This result is important insofar as policy efforts are directed towards reducing car dependency and promote sustainable modes in the US and elsewhere.
- In this respect, employer benefits should be acknowledged as a key component to be included and properly drawn when designing a sustainable transport policy package for daily mobility.
- Benefits for public transportation may be an effective means to make public transport and soft modes more attractive to commuters, thus increasing efficiency and sustainability.
- Employer-paid benefits for driving do not contribute to promote sustainability objectives since they are associated with a lower likelihood to choose public transportation and soft modes for commuting trips.
- On the other hand, bike-related benefits such as trip-end facilities for cycling at work play a key role in determining the likelihood of bike commuting.
- A critical component of the evaluation of a given transport benefit program should take place at the planning stage. A proper understanding of the objectives and goals of the program may help in the program evaluation. However, these evaluations are sometimes difficult to put into practice since the programs involve individual behavior patterns, which are complex and difficult to model in practice.
- Models built on the basis of household travel surveys may perform better (by reducing potential bias in the results) than surveys limited to those individuals receiving a transport benefit. Nevertheless, detailed information on household travel patterns is not always available, especially in some contexts where data collection efforts are not frequent.

4.2.3 General conclusions related to the Research Question 3

RQ3: What are the factors influencing public acceptability towards different road pricing schemes? Are perceptions of fairness towards road schemes determined by the level of income?

- Attitudinal factors may have a greater impact on charging acceptability compared to personal socioeconomic characteristics.
- Users' perceptions and conditionings towards tolling noticeably vary with the type of charging scheme proposed. In particular:
 - Acceptability towards express toll lanes is mostly influenced by the perceived effectiveness of the toll facility in contributing to save travel time.
 - Feeling forced to use the toll road plays a significant role in explaining levels of acceptability in the case of time-based pricing schemes.
 - The type of vehicle driven and the type of trip usually made are the most important factors explaining acceptability towards a flat-fee scheme.
- Real users of a toll network seem to have different preconceptions surrounding different pricing schemes. Particularly, respondents relate a time-based charge to a higher burden to be borne while they see a flat-fee charge as a way of saving money.
- As the users feel obliged to use the toll road, they are less prone to accept a time-based scheme, but more favorable to a flat-fee system. Then, this result means that respondents who feel being captive users—those who do not have an alternative option for their daily travel—accept or reject a scheme depending on its ability to achieve substantial cost savings.

4.2.4 General conclusions related to the Research Question 4

RQ4: Which are the sine qua non requirements for a tool to become appropriate for appraising sustainability according to the equity principles? Are available tools for assessing transport projects and policies appropriate according to the sustainability principles?

- Although the concept of sustainability has gained increasing importance in the last decades, the comprehensive sustainability appraisal of transport infrastructure projects and planning decisions is still an unresolved matter.
- On the basis of the literature reviewed, five *sine qua non* requirements for a tool to become appropriate have been identified for appraising sustainability according to the equity principles:
 - **Full approach:** appraisal methods should analyse the widest range of impacts comprising the so-called three pillars of sustainability—environmental, economic and social criteria—, and including equity over generations.
 - **Life-cycle approach:** Sustainability assessments should include the concept from ‘cradle to grave’ for both a transport project (planning, construction, implementation, maintenance, reuse, recycle, etc) and a transport policy (planning, implementation, evaluation, end-of-life).
 - **Rigorous trade-offs:** appraisal techniques should use analytical and rigorous methodologies for comparing all trade-offs among economic, environmental and social aspects.
 - **Adaptability to the context:** tools should consider the sensitivity of the criteria in the geographical and social context where the policy or the project is going to be implemented.
 - **Transparent approach:** Sustainability appraisal tools should be transparent, rational and formal instruments in order to minimize ambiguity and ensure consistency and accuracy.
- The existing tools did not succeed in fulfilling all the requirements cited above. Consequently, although the current approaches offer some value for sustainability assessment, none of them seems to be useful for appraising sustainability in a thorough way.
- However, among the existing tools, the MCDA approach seems to be the most suitable technique because of its flexibility to incorporate sustainability drivers in an integrated way.
- Methods may show complementary features. This suggests that an integration of current tools with complementary attributes could be beneficial for

effectively handling sustainability in the ex-ante appraisal of project alternatives (e.g use MCDA and CBA in tandem).

4.2.5 General conclusions related to the Research Question 5

RQ5: How to effectively evaluate the trade-offs among social, economic and environmental aspects in transport projects and policies as appropriate matters for social concern?

- Considerable research would be needed to quantify social impacts and to concurrently assess economic, environmental and social impacts of a transport intervention, especially on different groups of people.
- Despite MCDA can explicitly deal with different components of sustainability, there remain some fundamental gaps that may lead to lack of accuracy in the results of a decision-making process. Particularly:
 - Additional research should be conducted in order to solve well-known issues of this methodology such as the inter-temporal aggregation of environmental, social and economic impacts.
 - One of the main problems of this technique is precisely setting the weights to sustainability criteria in a transparent and precise way.
- To improve the potential role of social impacts in decision-making, alternative approaches should be considered to effectively evaluate the trade-offs among social, economic and environmental aspects in transport projects and policies.
- Potential approaches aimed at overcoming the issues in assigning weights in a typical MCDA should consider two key aspects for a rigorous and objective sustainability assessment:
 - The sensitivity of the criteria in the geographical context, and
 - The trade-offs among different criteria from consensus-based comparative judgments and preferences.
- The methodology described is an important step forward in the field since it offers decision-makers an alternative weighting scheme based on the sustainability theory. It is expected to have significance and great potential

to be implemented in the multi-criteria evaluation process aimed at assessing sustainability.

4.2.6 Equity implications of transport policies

The following Table 4.1 is a summary of the conclusions obtained from the analysis of equity effects of the different transport policies analyzed in this Thesis e.g. transport subsidies, transport benefits, and road pricing.

The main conclusion obtained from Table 4.1 is that the effect of different transport planning decisions on income greatly varies across case studies. Vertical equity principles are fulfilled by the transport subsidy policy in the city of Madrid, while the link between transport subsidies influencing daily mode choice decisions and income distribution in New York and New Jersey could not be evidenced. On the other hand, support for pricing schemes was found largely independent of the distribution of income, since the level of support for road pricing policies was not correlated with this variable. Therefore, a common trend should not be expected since each case study has its own particularities, such as the context for which the policies are proposed and the nature of the policy itself.

Table 4.1 Summary of equity effects of transport policies

Context	Transport Policy evaluated	Is it the transport policy vertically equitable?	Reasons supporting this statement
Madrid (Spain)	The public transport fare and subsidy policy (travel pass)	Yes. There is evidence to conclude this.	<ul style="list-style-type: none"> • Income level plays the most significant role in influencing public transport use. • The lower the income level, the greater the use of the travel pass. • This subsidy policy is progressive, since it establishes a fairness of treatment between individuals with different income levels.
New York and New Jersey (USA)	Transportation subsidies and benefits to employees	No. There is no evidence to conclude this.	<ul style="list-style-type: none"> • The income level was not found statistically significant to explain mode choice decisions. • Differences between wealthy and nonwealthy residents within NY and NJ do not appear to explain commuter modal variability. • This finding could be explained by the fact that vehicle ownership may be capturing somehow the income effect. • In fact, income may well be a catchall bucket for other economic variables that were omitted from the model.
Spain	Road pricing schemes (user's acceptability)	No. There is no evidence to conclude this.	<ul style="list-style-type: none"> • Support for alternative pricing options does not seem to be related to income. • Differences between wealthy and low-income drivers do not appear to explain variability in their acceptability towards road pricing schemes. • Income did not evidence to influence acceptability. Then, it seems that low-income drivers are not disproportionately burdened by tolls or they do not perceive it. • However, this case has two particularities that make it less likely to raise public concerns: (i) it evaluates perceptions towards hypothetical implementations, which may be highly subjective; (ii) toll road users in Spain do not lack attractive travel alternatives which offers a way of ameliorating adverse impacts.

4.3 Practice-oriented and policy recommendations: how current transport policies may be improved from the social perspective

The following is a summary of some policy recommendations at the practice-oriented level, in the light of the research work developed in the current Thesis. The main goal is to link the conclusions obtained from the previous papers in the transport planning and social perspective.

1. Transport planners are encouraged to consider the following points when implementing transport subsidy policies:
 - Current transport subsidies may be effective means to make the low-income people better off and thus a progressive distribution should not always been assumed. There is a need to rigorously evaluate whether these policies are achieving social equity objectives.
 - The adoption of public transport policies may lead to an increasing financial support. As a consequence, decision-makers should be able to ensure effective strategies by achieving a balance between equity and efficiency goals.
 - Take advantage of an interesting practical approach developed by Foster (2004) to measure the distributional impacts of policies, which has not been widespread applied in practice. By applying this methodology, policy-makers would be able to determine the proportion of low-income people that does not receive any benefit (error of exclusion) compared to the percentage of beneficiaries that should not be receiving the subsidy since they are not economically disadvantaged people (error of inclusion). This analysis can help policy-makers to identify distributional failures associated to a certain transport subsidy and to 'adjust' them in order to ensure progressiveness.
 - Policy-makers, as a first approach to the valuation of equity issues surrounding transport subsidies, should ask themselves the following questions:

- Are the target populations of the subsidy policy transport disadvantaged? How the access to transport is related to income?
 - Is there any evidence to conclude that the transport policy is equitable with respect to income?
 - Is the transport policy making transport more affordable to the less wealthy people?
 - Is the subsidy policy incurring in errors of inclusion or exclusion?
2. The following key recommendations should be followed when implementing a commuter transport benefit policy:
- Policy-makers and practitioners should take into account that transit benefits are key drivers of mode choice decisions. Thus, implementing effective travel demand management measures may boost transit ridership and reduce personal vehicle use.
 - A comprehensive package of policies seems to be more effective than implementing isolated policy actions. There is a need for implementing proactive policies that promote alternative and sustainable modes combined with policies that make car use less attractive. Through e.g. transit benefits programs, decision-makers can easily influence commuters travel behavior, whereas controlling other determinants such as car use (e.g. towards road charging, gasoline taxation, car purchase policies) may be more difficult to implement or may result in negative public attitudes.
 - Employers and policy-makers should ensure that benefits do not discriminate against any group of employees. To that end, transport benefit programs should be flexible enough as to adapt themselves in order to provide a fair treatment to low-income employees or to compensate them for potential inequities.
 - Providers of transport benefits and subsidies to employees should ask themselves the following questions as a first step towards the identification of equity concerns that can arise:
 - To what extent are the commute costs being covered by subsidies? Are there significant differences in the level of coverage between low-income employees and the wealthiest ones?

- Do all employees have access to the same benefits packages? Do these strategies fairly benefit transit riders and car owners?
 - How much are the benefits subsidizing employees driving alone? Is there any evidence to conclude that low-income employees have to face barriers to receive these subsidies?
 - Is there any evidence of discrimination against the most economically and socially disadvantaged employees?
 - Is there any evidence that measures have to be taken to equalize benefits across different groups of employees?
3. The following policy recommendations might be addressed to decision-makers when considering the implementation of road pricing schemes:
- It is crucial to keep in mind that public acceptability greatly depends on the perception of the distribution of gains and losses, which can be managed. Public opposition to charging can be reduced by policy-makers, for example, if revenues are recycled, losers are compensated and the public understand the purpose and benefits coming from this policy.
 - An important aspect that decision-makers should consider regarding users' acceptability is the type of road pricing strategy to be implemented. Reactions to price changes are expected to be much stronger and more negative for those schemes associated with greater variability (time, distance or delay-based charging mechanisms) than for fixed charge systems. As a consequence, policy-makers should pursue options technically feasible, transparent and easy to understand.
 - The premise that the acceptability of each scheme is influenced by factors of a different nature is a necessary precondition for an acceptable pricing scheme. A proper understanding of these differences can help planners to enhance acceptability for each specific type of pricing mechanism.
 - The fact that attitudinal factors explain acceptability better than socioeconomic variables, constitutes another important factor that provides useful insight for transportation professionals. Understanding attitudes, as well as the reasons behind them, seems to be a crucial aspect for predicting social behavior and reactions towards new transport pricing schemes.

- Despite the effect on low-income users is unclear, equity impacts of road pricing should not be ignored. Before implementing these strategies, transport planners should ensure that they are not discriminating against disadvantaged groups in terms of income. This can be, however, a complicated matter in practice since there is no consensus on which measure to apply.
 - Decision-makers should ask themselves the following questions as a first step towards the identification of equity issues surrounding interurban road pricing schemes currently implemented:
 - How is the distribution of income among current and potential users of the toll road facility? Are low-income people car-captive travelers?
 - Is there any evidence that the road scheme applied is particularly harming low-income drivers or residents? Is the pricing policy progressive or regressive in equity terms with respect to income?
 - How is the distribution (and the perception of the distribution) of gains and losses of the proposed pricing system for the low-income users?
 - Which appropriate proposals can ameliorate the adverse impacts caused by the road charge: e.g revenue recycle, exemptions, discounts, etc? Are economic disadvantaged people being compensated?
4. Finally, when evaluating sustainability decision-makers are encouraged to consider these key points:
- Implementing sustainability principles become more effective at the planning stage than as part of an ex-post evaluation. Policy-makers should start the sustainability appraisal of transport policies at the planning stage because, at this point, they have a greater influence on the future performance of the planning decision.
 - Verifying the sustainability of an already existing project or policy can be useful to 'recycle' best practices and procedures in future interventions, due to the retrospective character it implies.
 - Decision-makers should pursue a proper evaluation of the social impacts of transport interventions. Furthermore, setting the weights to sustainability

criteria—including the social dimension— should be conducted in a transparent and precise way.

As a final point, it is worth discussing to what extent transport policies have the potential to tackle poverty and inequality. It is clear that the evaluation of vertical equity helps policy-makers and planners to better plan—or to reform— policies in order to improve their targeting properties so that the impact on low-income groups is considered. However, there is probably a structural limit to the ‘responsibility’ of the transport policy in making the lower-income people better off. Among the reasons that support such argument, the following facts could be mentioned:

- Transport policies pursue different objectives that may consider social equity to a greater or lesser extent (e.g increasing the use of public transport, congestion relief, environmental improvements and revenue generation to face public budget constraints);
- “The poor are not just ‘transport poor’ but rather poor in an encompassing way” (Serebrisky et al.,2009, p.735). Due to the multidimensional characteristic of poverty, the capability of transport policies to help lower-income households is constrained;
- Vulnerable populations may lack of complete access to transport services (transport disadvantaged). This means that some transport policies such as public transport subsidies are not always able to reach lower-income people, and consequently, a progressive distribution of the benefits is not always guaranteed;
- There are some variables and effects external to the transport sector, and therefore, it would be unrealistic to expect that the transport policy can serve by itself all the poverty alleviation objectives. For example, a transport project may have positive effects on employment but its influence on well-being is limited and determined by the social and geographical context where the project is located (e.g structural unemployment).

4.4 Future research

Several aspects for further research arise from the results of this Thesis. Given that there are different specific objectives, a great variety of issues can be mentioned. The following areas should be pursued to expand the current research:

- *With regard to the analysis of social and distributional effects of public transport fares and subsidy policies on vertical equity:*

Future studies on the analysis of public transport subsidies should evaluate whether they are effectively meeting social and distributive objectives. Equity concerns are imperative in effective policy implementation. A proper evaluation of the incidence of public transport fares and subsidy policies on vertical equity would probably help to reform policies to improve their targeting properties. However, as mentioned in this Thesis, a standard methodology for the appraisal of equity impacts of transport policies is lacking. Future research efforts could continue (i) exploring methods for measuring the social and distributive dimensions of public transport subsidies in practice, and (ii) testing the applicability and appropriateness of the proposed methodology by applying it to other transport subsidy policies.

On the other hand, travel surveys in Spain only capture travel patterns in all existing modes within the area but do not use to provide information of income at individual or household level. This makes difficult to explore the links between transport disadvantage and social exclusion. As a consequence, the results of this research are constrained by the aggregate nature of the data, which is collected at the neighborhood level. Accuracy would be improved in future researches by using data from a completely disaggregated survey which captures more precise individual characteristics and preferences. Additionally, future studies could analyse the potential impact of the economic crisis on the results. Unfortunately, recent data from transport surveys are not available yet in Madrid.

- *With regard to the analysis of the provision of transportation subsidies and benefits to employees:*

Several aspects for further research arise from the results and limitations of this study. Firstly, additional efforts are needed to extend the current multilevel analysis in order to estimate more accurately how much of the variability observed in the mode choice variable is attributable to individual variables, and how much may correspond to a group effect (geographic area of residence). Future contributions should attempt to refine this analysis by adopting more complex econometric specifications such as multilevel multinomial logistic regression models. Secondly, additional research should delve more deeply into how self-selection may help to a better understanding of travel behavior. At this respect, more complex models such as structural equation modelling could be developed in order to address the potential self-selection bias effect on the results. Thirdly, the quality and quantity of the benefits provided should be examined in greater detail, particularly the influence of changes in the magnitude of benefits on mode choice. Additionally, since our research considered only the main mode in a multimodal trip, future studies should also explore the relationship between commuter benefits and the combination of several modes for origin-destination relationships.

On the other hand, most travel behavior analyses have explored the influence of the income effect in mode choice as part of explanatory factors. However, social analyses of modal split, particularly with respect to lower-income groups and neighborhoods, are not well documented within the literature. Given their applicability in transport appraisal guidance or social justice analysis, exploring the links between social exclusion and transport mode choices is a pending task.

More rigorous analysis on the relationship between commuter benefits and transportation mode choice is needed. Presently, most studies —with few exceptions— are based on surveys conducted to transit benefits recipients instead of disaggregated data from travel surveys, which can reduce bias and introduce higher variability because respondents are not limited to those individuals receiving a transport benefit. More research should be conducted to accurately determine the impacts of commuter benefit packages on employee travel behavior.

Furthermore, understanding how commuter benefits work is not only a matter of concern for employers. As commuter benefit packages are supposed to influence mode choice decisions, policy-makers should also be interested in this kind of assessments.

Finally, a research field that is closely linked with this research topic is the evaluation of accessibility as a social indicator and as a variable influencing transit ridership. In that respect, future research is needed in order to improve the practical approaches applied in this Thesis for the cases of Madrid and New York-New Jersey. The consideration of population served rather than area covered by transit facilities—as it has been done for the case of Madrid— would be highly useful for estimating this variable more precisely. Furthermore, a more detailed evaluation may consider the use of a distance-decay function instead of fix distances thresholds to transit facilities—see Gutierrez et al. (2011) for further details.

- *With regard to the analysis of the perception of fairness towards the acceptability of road pricing schemes:*

From the results of this particular transport policy, some aspects can be pointed out for further research. Since our analysis only considered work trips, future studies should extend this analysis by exploring other trip purposes. In addition, potential differences in acceptability across groups of respondents, i.e. users and non-users of toll roads, should be analyzed in greater detail by adopting more suitable econometric specifications such as multilevel models.

On the topic of road pricing, the first issue for discussion is under what circumstances the impact on low-income car owners can be consider progressive. However, in real-world cases it is very difficult to precisely measure the equity implications of a proposed scheme given the complexities of the transportation networks involved. In this respect, acceptability arises as a good proxy for measuring equity since it may reflect an overall sentiment of fairness towards a policy initiative. Nevertheless, the question whether it is possible to apply a road pricing scheme both acceptable and effective has not been clearly answered yet. This leads to another major direction for further research, which is to continue investigating the acceptability of road pricing from an equity perspective.

Future studies analyzing road pricing decisions in terms of justice and acceptability may also focus on contexts scarcely addressed up to date, such as interurban roads or toll networks already in operation. In addition, as there has been little research into the effects of different pricing systems on acceptability, it constitutes a subject for further research.

- *With regard to the role of social impacts in decision-making:*

From the attempt to combine the strengths of the current appraisal methods to address sustainability, special attention should be given to three specific aspects:

- (i) The assessment of social and distributional impacts;
- (ii) The inter-temporal aggregation of environmental and social impacts to improve the life-cycle evaluation;
- (iii) The process of setting the weights of each sustainability criterion.

The first limitation leads to the first major direction for further research, which is to conduct research to improve methodological soundness of social assessment of transport planning decisions. On the other hand, the second issue for discussion is to define an accepted approach for inter-temporal aggregation of environmental, social and economic impacts, given that the current methods and tools do not fully ensure the proper aggregation of environmental and social aspects. A potential approach to tackle this problem may include alternative discounting methods according to the characteristics of the specific sustainability criteria: e.g. those that can be quantified and monetised with market prices; those that can be quantified and are not bought and sold in the market; and those that cannot be quantified.

Finally, the third major direction of research worth pursuing is to increase the rigor and objectivity in the setting of the weights of the social, economic and environmental aspects in order to measure their relative impact. To guarantee a correct sustainability assessment, priorities for sustainability items (criteria weights) must be established based on a standard, transparent and consistent methodology. Future studies regarding the issue of putting economic, environmental and social aspects together could overcome some of the shortcomings of this Thesis in relation to the proposed methodology —see Chapter

3. For example, such studies should continue testing the applicability and usefulness of the proposed methodology by applying it to other real-world case studies and comparing the results with other approaches for setting weightings. We also suggest improving the validation of this method by applying it to projects or policies that were already appraised to compare ex-post results of the developed methodology. This way, some relevant questions such as what would have happened if a different weighting method had been used (for example, with the final selection of the best alternative) can be answered.

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