Do Subsidies Provided to Public Transport in Madrid Favor Vertical Equity?

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ABSTRACT

Despite the widespread implementation of subsidy policies for urban transport in many cities, the equity evaluation of these policies still remains limited. There is scarce quantitative assessment of the distributional incidence of transport subsidy policies. This paper contributes to fill this research gap by developing a practical approach to evaluate the impact of fare subsidization on vertical equity. In the paper we implement a two-step methodology. First, we develop two main indicators to measure the social impacts of the "travel pass", which is a highly subsidized fare in order to examine the policy for its effectiveness in reaching the poor. Second, by using the latest disaggregated data from Madrid's Transportation Survey, we fitted a multiple regression model which found out that the use of the travel pass depends fundamentally on income level and accessibility to public transport. Since the quality of accessibility in the city is quite homogeneous, the subsidy policy associated with the travel pass is shown to be progressive because it is well targeted towards economically disadvantaged groups. Consequently, there seems to be evidence that subsidies provided to public transport in Madrid tend to favor vertical equity.

1. INTRODUCTION

"Equity refers to the distribution of impacts—benefits and costs—among members of the society and whether this distribution is considered appropriate" (Litman, 2013, p.2). 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 the society (Burton, 2000). However, despite the increasing interest in equity issues within the concept of sustainability, scholars admit that social impacts and the study of their distributional effects have traditionally received less attention than economic and environmental aspects. One of the difficulties of including social impacts within the evaluation of public policies is that there remains a considerable uncertainty surrounding what a social impact is, how to measure it, and how to evaluate distributional effects and equity issues (Geurs, Boon, &

Van Wee, 2009). 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" (Beyazit, 2011, p.118).

Therefore, nowadays there are scarce standardized methods to evaluate social and distributional effects of public policies. The 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 & Lucas, 2011). Consequently, there is literature addressing the concept of equity from different perspectives such as traffic fatalities (Anbarci, Escaleras, and Register, 2009; Anderson, 2010); noise pollution (Brainard, Jones, Bateman, & Lovett, 2004; Neitzel, Gershon, Zeltser, Canton, & Akram, 2009); air quality (Schweitzer & Zhou, 2010; Zuurbier et al., 2010), and the bond between accessibility and social exclusion (Geurs, Van Wee, & Rietveld, 2006; Kenion, Rafferty, & Lyons, 2003).

Much less is known about the equity consequences of transport policies. The literature available on the evaluation of transport policies is mostly focused on economic and environmental impacts rather than on social and distributional ones. One possible reason for this is detailed by Litman (2013), who states that there is no single way to evaluate transportation equity because equity evaluation depends on the type of equity, how people are categorized, which impacts are considered, and how they are measured. Bureau & Glachant (2011) claimed that "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 (p.746)".

As Nuworsoo, Golub, & Deakin (2009) observed, only few authors looked at equity aspects of transit fare policies per se. Equity considerations associated with fare policies and the distribution incidence of subsidies have hardly been analyzed in detail as it has always been assumed that subsidies always have progressive distribution effects (Vassallo, Pérez De Villar, Muñoz-Raskin, & Serebrisky, 2009). In this respect, despite equity often being the essential component of many debates about how to allocate public resources, social and distributional dimensions of public transport subsidies have drawn significantly less attention in the literature (Serebrisky et al., 2009).

This paper presents a thorough assessment of social and distributional effects of the public transport fare and subsidy policy in the City of Madrid. This research is based on a two-step methodology. First, we define and evaluate two quantitative indicators formulated on the basis of Madrid's Transport Survey 2004. And second, by taking advantage of this information, we 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, our aim is to get to know whether this public transport subsidy policy provides benefits to

those people with the greatest needs such as low-income groups.

The document is structured in the following way. Section 2 summarizes the literature review based on the social impacts of transport, especially equity impacts. Section 3 outlines the methodology, and addresses the concept of social justice related to the most highly subsidized fare in Madrid: the "travel pass." Section 4 discusses the results of the evaluation of the fare policy in Madrid. Finally, the 5th Section of the paper establishes a set of conclusions and recommendations for additional research areas in the field of transport equity.

2. LITERATURE REVIEW

As Delbosc & Currie (2011) mentioned "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). While two dimensions of equity may contribute to the analysis, in this paper we focus on the vertical equity implications of transportation subsidy policies, applied to the case study of Madrid because there is scarce quantitative analysis of their distributional incidence on different income groups. Particularly, no equity analysis has ever been carried out on income and social class at a lower level than the metropolitan or the municipal level in the Madrid Metropolitan Area.

There are however other studies that have been developed in order to determine how users respond to changes in prices and service characteristics in the Madrid Metropolitan Area (Garcia-Ferrer, Bujosa, de Juan, & Poncela, 2006), and evaluate the impact on revenue stemming from the introduction of the "travel pass" (Matas, 2004). By estimating demand equations and elasticities and quantifying explanatory variables for the significant increase of 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" (Matas, 2004, p.212). The redistribution effects of urban transport subsidies at the municipal level in Spain were analyzed by Asensio, Matas, & Raymond (2003), who calibrated a model that took into account expenditure in urban public transport. From calculations of Gini indexes in different municipalities, these researchers concluded that, overall, urban public transport subsidies in Spain were progressive and had a positive redistributive effect.

Furthermore, a broad analysis of urban transport funding for the public transport policy in Madrid was developed by analyzing the evolution of public transport subsidies between 1995-2005 and the relationship of these subsidies with equity aspects (Vassallo et al., 2009). Based on a simple correlation analysis between the use of travel pass and the income per capita by geographical zone, the authors found that in Madrid city, the lower the level of income the higher the use of the travel pass. However, as Vassallo et al. (2009) pointed out, in the outer zones of the Metropolitan Area the correlation between the level of income and travel pass use was almost non-existent.

Research studies analyzing the impact of transport fare and subsidy policies in other cities are also scarce, and they put much of its attention on how to measure equity in particular cases using different procedures and approaches. For instance, Nuworsoo et al. (2009) analyzed the Alameda-Contra Costa Transit District's five alternative fare proposals, paying particular attention to their impacts on certain riders (gender, income group and race). The research based on a broadly applicable methodology to equity analysis, acknowledges that the riders' characteristics (such as income, age, and trip purpose) made them more sensitive to price changes than others. Moreover, the research conducted by Bureau & Glachant (2011) using disaggregated data from the Global Transport Survey, evaluates the distributional effects of alternative scenarios of urban public transport policies in the Paris Region (fare reduction and increase in the speed of public transport). These authors found that these changes were progressive and determined more benefits experienced by low-income populations from fare reductions than from increases in public transport speed.

According to Serebrisky et al. (2009), despite a large number of subsidy policies adopted for urban public transport, "there are virtually no quantitative assessment of their distributional incidence, making it impossible to determine if these policies are pro-poor" (p.715). In summary, despite the studies described above, there is still limited practical evidence about the social and distributive consequences of transport subsidies in the literature. Consequently, the results of this paper make an important contribution to the field.

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

In this section we describe the main characteristics of the public transport system in the City of Madrid, explain the databases used for the analysis, and define the methodology we designed to obtain the results.

3.1 Public Transport in Madrid: An Overview

More than 6 million inhabitants live in the Madrid Metropolitan Area, which is made up of 179 municipalities. About 50% of the population lives in the City of Madrid, in an area of

607 square kilometers. According to the National Institute of Statistics, the average population density of the city is 5,390 inhabitants per square km. The distribution of residential areas and employment centers gives rise to an urban structure that predominantly follows a monocentric model with radial trips from satellite settlements to the city center. This structure "makes Madrid well suited to public transportation use" (Matas, 2004, p.196). Actually, as the Transport Survey 2004 reveals, "there are 6,670,000 motorized trips every working day—48% served by public transport and 52% by car" (Monzon & Guerrero, 2004, p.427).

The city is split into 21 districts which are further subdivided into 128 neighborhoods. The income level of the poorest districts is around fifty per cent of the income level of the wealthiest districts so wealth distribution is fairly even compared to other cities. Unlike the trend followed by some cities of the world, the districts and neighborhoods located in the city center of Madrid are wealthier than the average of the city. These centrally located districts have better levels of accessibility to public transport than peripheral districts.

The public transport system in the Madrid Metropolitan Area is made up of four modes. Two of them are the typical urban modes (underground rail system, and urban buses), and the other two are mostly metropolitan modes (commuter rail and interurban buses). Each mode is operated by a different public company with the exception of interurban buses, whose routes are franchised to different private companies. The integration of all the transport modes is achieved through a public authority called "Consorcio Regional de Transportes de Madrid" (CRTM) that is in-charge of coordinating modes and fares.

Besides the typical single and multi-ride (ten-trip ticket), a "travel pass" is available in Madrid to promote public transport usage. The "travel pass" is a monthly flat fare suitable only for frequent users, and it means an important implicit subsidy for them. Vassallo et al. (2009) report that on average travel pass users pay per trip 35.5% less than users of typical single and multi-ride tickets. This pass can be used during one month throughout all the public transport modes inside a certain ring. The holder of a "travel pass" can make unlimited trips inside the ring zone associated to the travel pass. There are also two special kinds of travel passes that address potentially vulnerable groups. A travel pass for young people (up to 23 years old) and a travel pass for the elderly (from 65 years old). In 2011, the young paid 35% and the elderly 77% less for a monthly travel pass compared to the regular travel pass fare.

After the implementation of an integrated fare approach in Madrid, essentially based on a monthly and annual travel pass introduced in 1987 there have been no studies aimed at quantifying the redistributive effects generated by the subsidization at a disaggregated level such as neighborhood or household level. It is important to mention that the implementation of the travel pass in Madrid can be considered a success in terms of promoting public transport usage because its implementation increased the number of trips

made by frequent users and raised the probability of attracting new ones.

On the other hand, as some studies show, the travel pass has had negative consequences in terms of financial sustainability because the coverage ratio (revenues from users/operation costs) of the public transport system in Madrid has been steadily decreasing over the years so the amount of public subsidies had to be increased progressively (see Fig. **1**). The above description allows us to claim that Madrid is therefore 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.
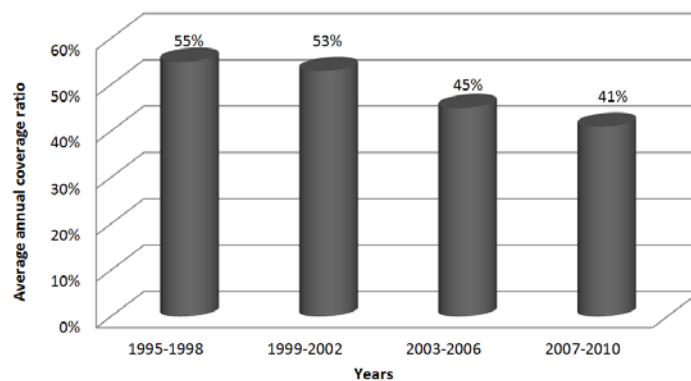

Fig. 1 – **Evolution of the Coverage Ratio in Madrid**

3.2 Data Collection

Every eight years the Madrid transport authority CRTM conducts a mobility survey in the Madrid Metropolitan Area. The last survey available at the time of writing this research was conducted in 2004. This survey provides travel data and travel trends over time. Since there are no more updated data, we conducted our research by using disaggregated data from the Transport Survey 2004. This survey enabled us to design a set of indicators to measure the distributional impacts at the neighborhood level. The situation nowadays is quite similar to the one in 2004 because the economic recession brought income and transport demand back to levels akin to those of 2004. Therefore, the results from 2004 are expected to be very similar to the present situation in terms of both income levels and public transport patronage.

In addition, we used the Madrid Statistical Yearbook to obtain information about the characteristics of the population per neighborhoods. This information enabled us to study the relationship between travel pass usage per neighborhood and variables characterizing the population of each neighborhood. Additionally, the CRTM provided us with data on public transport fares, subsidies, and accessibility per neighborhood.

3.3 Methodology for the Assessment of Vertical Equity Impacts

Following our research objectives, we developed a methodology for evaluating the impact

of fare subsidies on vertical equity in Madrid. To this end, we defined two steps: the development of indicators to measure the role of public transportation on social equity, and the study of the travel pass usage through potential explanatory variables.

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

The development of social equity indicators to measure the distributional impacts of public transport fare and subsidy policies in Madrid requires the selection of the type of equity to evaluate and the way to categorize people. In this respect we focused our research on vertical equity and we categorized people by income class (lower income areas). We decided to prioritize the economic needs of potentially vulnerable groups over other needs in order to evaluate whether the subsidy policy in the city is progressive with respect to income per capita.

To evaluate vertical equity, we chose indicators simple to calculate, easy to explain, reliable, specific, representative, and easy to validate. To conduct this research two quantitative indicators were developed by monitoring the effectiveness of travel pass policy favoring disadvantaged groups. Below we show the selected indicators and the way that they should behave to promote vertical equity with respect to income and social class.

1. Percentage of travel pass usage per neighborhood (TPU). This indicator is an indirect measurement of transport affordability. Vertical equity would mean that a significantly higher percentage of population in the poorest neighborhoods should benefit from the travel pass compared to the wealthiest neighborhoods.
2. Average user cost per trip of travel pass users across Madrid neighborhoods (ACT). This indicator evaluates the average cost per trip of travel pass users across neighborhoods. To favor vertical equity lower income people should be expected to pay less per trip than non-vulnerable groups.

3.3.2 Variables that Might Explain the Use of the Travel Pass

We designed and fitted a linear regression model to explain the use of the travel pass and to evaluate the distribution of transport subsidy benefits among different income groups in Madrid. We calibrated a model to estimate the relationship between a dependent variable— the number of people who have the travel pass per neighborhood —and some explanatory variables, which are supposed to influence the travel pass usage.

To conduct this statistical analysis we built up a data base panel with 128 observations, corresponding to the 128 neighborhoods of Madrid Metropolitan Area. We set up a model for predicting the use of the travel pass per neighborhood trying the following independent variables characterizing each one of the 128 neighborhoods: income per capita, neighborhood area, total population and potential population (defined in numeral 4.1) for the regular, the young and the elderly travel pass, % of population of high, medium-high,

medium, medium-low and low socio-economic status, motorization, number of people with different levels of education: illiterate, without studies, first grade/secondary education, high school, basic/superior professional training, diploma courses, bachelor´s degree and doctorate studies, employed, unemployed, active population, inactive population (women and men), housing price per square meter and, public transport accessibility.

The public transport accessibility was determined through a proxy indicator calculated by summing up the following weighted variables: underground rail (weighted x5), urban bus (x1), and commuter rail stations (x10) together with the lines inside each neighborhood (x1) and divided by the total area. We can reasonably assume that access to a rail station gives more accessibility to the network than a bus stop.

Since multicollinearity is a traditional problem in regression analysis and in order to avoid erroneous inferences from possible relationships between predictor variables, we examined collinearity 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 a high correlation between two variables was found, we excluded one variable from consideration.

Consecutively, multiple regression analysis was employed to predict the use of the travel pass. By constructing the full model with all predictor variables obtained after the detection of multicollinearity, we obtained the full model R^2. We also tested the significance of the coefficients of the model, to discard variables with no influence on the dependent variable. The significance test was aimed at determining the validity of the null hypothesis (H_o) "the coefficient of the independent variable is equal to zero", meaning that the corresponding independent variable does not have an influence on the dependent variable. H_o is accepted depending on the p-values. We adopted a 5% significance, thus accepting H_o if the p-value was 0.05 or higher. On the other hand, if it were lower than 5%, we would not have enough evidence to think the coefficient is equal to zero, and so we would reject H_o.

After starting with a full model and eliminating variables according to this test, we obtained a final model, where all the coefficients were significantly different from zero. We ran different models until we found the optimum in terms of the multiple correlation coefficient R, the residual standard error and a test of significance for R. On the basis of the results, we carried out a final examination of the actual signs of the linear coefficients and compared them with their predictable signs.

Furthermore, to detect and prevent over fitting, we used the cross validation technique. Based on a 10-fold cross validation test, we estimated how accurately our predictive final model will perform in practice. Finally, according to econometric practice, we interpreted elasticities of independent variables with respect to the use of the travel pass.

4. ANALYSIS AND RESULTS

In this section we show the results of the indicators that we used to evaluate the impact of the travel pass use on vertical equity across different neighborhoods. For the TPU, we display the results over a map showing the indicator for one hundred and twenty eight neighborhoods making up Madrid City. The neighborhoods were split into three different income levels: low income (between €6,894 and €10,310 per capita) shaded in a light tone in the map, medium income (between €10,310 and €14,700) shaded with medium tone in the map, and high income (between €14,700 and €31,218) shaded with a dark tone.

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

4.1.1 Percentage of Travel Pass Usage per Neighborhood (TPU)

The first indicator measures the percentage of population in each neighborhood using the travel pass. Within each neighborhood we calculated the potential population (P_{pi}) of travel pass users by summing up the potential population for the regular, the young and the elderly travel pass. The criteria to get either a special travel pass or a regular pass depend on age based on the criteria established by the CRTM. For example, the potential population for the young travel pass is defined as people under 23 years of age living in the neighborhood while the potential population for the elderly travel pass of the neighborhood is defined as people aged 65 years and over living in the neighborhood.

The *TPU* indicator was calculated through the following ratio. The numerator of the equation was obtained through the Transport Survey 2004. The denominator is the sum of potential population for all types of travel pass per neighborhood.

$$TPU_i (\%)=Residents\ of\ neighborhood\ i\ that\ actually\ use\ the\ travel\ pass/\ P_p \qquad (1)$$

General *TPU* values per neighborhoods are shown in Figure 2. The values represent the travel pass usage per neighborhood. According to this indicator, there is some evidence that subsidies contribute to promote social equity in the city because the percentage of travel pass usage appears to be higher in the less favored neighborhoods of Madrid. Furthermore, based on the calculations of this indicator, we found that 88% of the neighborhoods with high percentage of travel pass usage are low income areas. Highest percentages of the travel pass use fall on the less favored neighborhoods such as Campamento (*TPU*=34%), Justicia (*TPU* =33%) and La Chopera (*TPU* =31%).

These results support the hypothesis that the policy regarding the travel pass is vertically equitable because the highest percentages of this indicator are distributed among economically disadvantaged people. Given that the travel pass is the most highly subsidized fare in Madrid, the public transport policy provides the greatest benefit to lower-income groups.
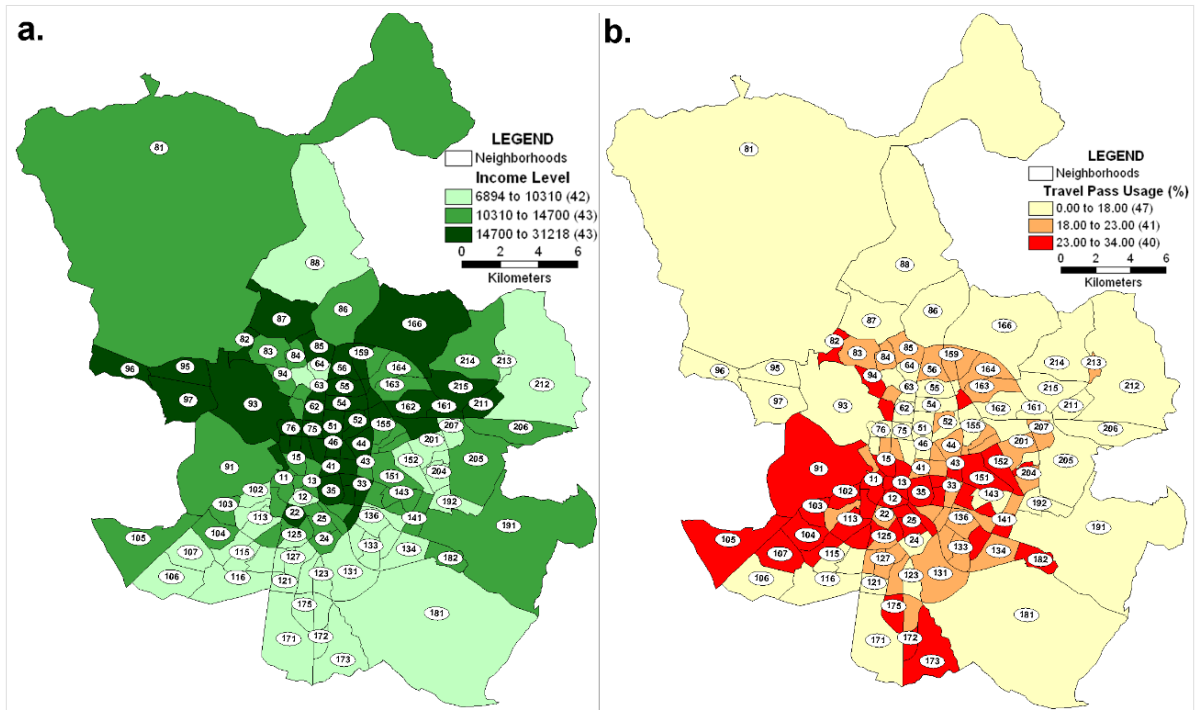
Fig. 2 – Income level (a) and Percentage of Travel Pass Usage per Neighborhoods (b) (Source: Authors´ figure)

4.1.2 Average User Cost per Travel Pass Trip across Madrid Neighborhoods (ACT)

The average user cost per travel pass trip intends to know whether people using the travel pass in low-income neighborhoods are more subsidized than people using the travel pass in high-income neighborhoods. We applied this methodology separately for each type of travel pass user (regular, youth and elderly) in order to know the subsidy effect on every group. Based on the number of residents per neighborhood that actually use the travel pass and the fares of each type of travel pass, we calculated the amount of money spent by them on transportation per month (AMI_i). From the Transportation survey, we obtained the number of monthly trips made with each type of travel pass per neighborhood. On the basis of this information, we calculated the average user cost per trip (ACT_i) per neighborhood and type of travel pass as follows:

$$ACT_i\,RPT\,(€)= AMI_iRTP \,/\, TMT_iRTP \qquad (2)$$
$$ACT_i\,YPT\,(€)=AMI_iYTP \,/\, TMT_iYTP \qquad (3)$$
$$ACT_i\,EPT\,(€)=AMI_iETP \,/\, TMT_iETP \qquad (4)$$

Where,

$ACT_i\,RTP=$ Average user cost per trip for residents of neighborhood i using a regular travel pass.

$ACT_i\,YTP=$ Average user cost per trip for residents of neighborhood i using a youth travel pass.

$ACT_i\,EPT=$ Average user cost per trip for residents of neighborhood i using an elderly travel pass.

$AMI_iRTP=$	Amount of money spent by residents of neighborhood i on transportation per month using regular travel passes.
$AMI_iYTP=$	Amount of money spent by residents of neighborhood i on transportation per month using young travel passes.
$AMI_iETP=$	Amount of money spent by residents of neighborhood i on transportation per month using elderly travel passes.
$TMT_iRTP=$	Total monthly trips of regular travel pass users living in neighborhood i.
$TMT_iYTP=$	Total monthly trips of youth travel pass users living in neighborhood i.
$TMT_iETP=$	Total monthly trips of elderly travel pass users living in neighborhood i.

To be vertically equitable, the *ACT* ratio should be lower in the less favored neighborhoods. This would mean that travel pass users from poorer neighborhoods are highly subsidized per trip than those from richer neighborhoods. However, results for the *ACT* ratio suggests a fairly equal treatment of all people (regardless of their income level), which is, strictly speaking, not vertically equitable with respect to income. Subsidies to travel pass users do not distinguish between low and high income neighborhoods. High income users of the travel pass pay on average €0.47 per trip with the regular travel pass, €0.33 per trip with the youth travel pass and €0.13 per trip with the elderly travel pass. Lower income users pay similar amounts of money for a trip made with the regular and young travel pass, whereas they pay €0.14 per trip with the elderly travel pass.

However, the difference on the average user costs per trip between regular, youth and elderly travel passes is evident. The user cost per trip is €0.47 with a regular travel pass, €0.33 with a youth travel pass, and €0.13 with an elderly travel pass. This fact shows equitable distribution of benefits and costs among minority groups such as young people and the elderly.

According to the *ACT* indicator, we cannot claim that subsidies support vertical equity because subsidies applied to travel pass users are equally distributed across neighborhoods. Nevertheless, since residents of low income neighborhoods have a higher travel pass usage than the ones in richer neighborhoods (shown by the *TPU* indicator), the poorest neighborhoods still receive greater subsidy than the richest.

In this respect, a more comprehensive equity evaluation is needed in order to understand what causes could explain the level of travel pass usage in a given neighborhood. In the next section we show how significant explanatory variables are found through the fitting of a model.

4.2 What Variables May Explain Travel Pass Usage?

In this section, we intend to identify what variables might explain the use of the travel pass across neighborhoods. To this end, we used a multiple regression model. For this model, we needed to remove all the co-linear variables within the set of selected variables. After

that, we evaluated whether the parameters of the regression were significant or not. If they were, we interpreted the results in terms of vertical equity.

Before starting with the computation of the model, we evaluated whether multicollinearity was present in the data. Given the fact that the linear model was correlated between the logarithms of all variables, the correlation matrix was obtained for the logarithms of all independent variables. After inspecting the correlation matrix, we decided to remove the following variables:

- potential population for the regular, the young and the elderly travel pass,
- % of population of high, medium-high, medium, medium-low and low socio-economic status,
- motorization,
- number of people with different levels of education,
- employed, unemployed, active population, inactive population (women and men),
- housing price per square meter.

All these variables were highly correlated with the rest of the variables, so they did not provide any further information to the linear model. After removing the co-linear variables, we calibrated a multiple regression model, setting the variable "number of travel passes acquired by people from a certain neighborhood" as dependent variable. To fit the model, we needed to transform the set of variables, since their relationship was unlikely to be linear. For this purpose, we used the Box-Cox transformation for linear models (Box & Cox, 1964), who suggested using a logarithmic transformation. For this reason, the correlation matrix explained in the previous paragraph was also done with logarithmic transformations.

Once we obtained the transformed variables, we calibrated a linear model using multiple regression. In this model, not all the variables had coefficients significantly different to zero. We repeated the linear model removing all the variables that were not significant so we ended up calibrating a model on the basis of three endogenous variables: the income per capita in the neighborhoods, their population, and their accessibility. The correlation coefficient for this model was strong (multiple R-squared: 0.7841, adjusted R-squared: 0.7788, and p-value: < 2.2e-16). The results show that, the use of the travel pass in Madrid is very well explained by just these three independent variables: the income per capita in the neighborhoods, the total population, and the level of public transport accessibility (see Table 1).

The final model shows a good overall level of fit and all the regression parameters were significant at the 99% level so there is strong statistical evidence supporting these relationships. Table 1 also shows the comparison between the sign expected and the sign obtained for regressions that we ran. All the signs obtained were in line with the results expected. For instance, as we hypothesized, we found a negative sign for the variable "income level", meaning that higher levels of neighborhood income are related to a lower

use of travel pass. The same applies to "accessibility", with a positive coefficient in this case.

Independent variable per neighborhood	Coefficient /elasticity	Std. error	Sign expected	Sign obtained	p-value
Income level	-0.75	0.14	-	-	$p \sim 0$***
Population	1.11	0.07	+	+	$p \sim 0$***
Accessibility	1.06	0.18	+	+	$p \sim 0$***

*** 99% confidence level.

Table 1 – Model Results (Source: Authors´ calculations)

Finally, the predictive equation can be expressed as follows:

$$\log(Travel\ pass\ usage_i) = 3.19 - 0.75 \log income_i + 1.11 \log population_i + 1.06 \log accesibility_i \tag{5}$$

Where,

$Travel\ pass\ usage_i$	= Number of travel pass users in neighborhood i.
$Income_i$	= Income per capita in neighborhood i.
$Population_i$	= Total population in neighborhood i.
$Accessibility_i$	= Public transport accessibility in neighborhood i.

Since the predictive equation was estimated 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 our double log equation (5), -0.75, 1.11 and 1.06 are the elasticity coefficients for the income level, the population and the accessibility variables, respectively. This result means that ceteris paribus a 10% increase in income level will generate a 7.5% decrease in the travel pass usage per neighborhood, while a 10% increase in accessibility will generate a 10% increase in the travel pass usage per neighborhood.

Finally, we tested the internal validity of the model by means of a 10-fold cross validation method. In this validation process we divided the set of neighborhoods in 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. Then the model was applied to the test set (i.e. the 10% of the remaining neighborhoods). Then, we evaluated the Mean Squared Relative Error (MSRE) of the prediction of the test set. This procedure was repeated 5000 times, with randomly selected training and test sets. The median error for this simulation was 3.4%. The average error was 26.2% with a standard deviation of 56.6%. The error distribution is highly skewed, which explains the difference between the median and the average values. Most of

the simulations had a very low MSRE, but in some specific cases the MSRE was very high. Figure 3 shows a boxplot of the errors of this simulation with 5000 random sets. Most of the models had a MSRE lower than 5%. This test reinforces that our model can accurately predict the use of the travel pass.
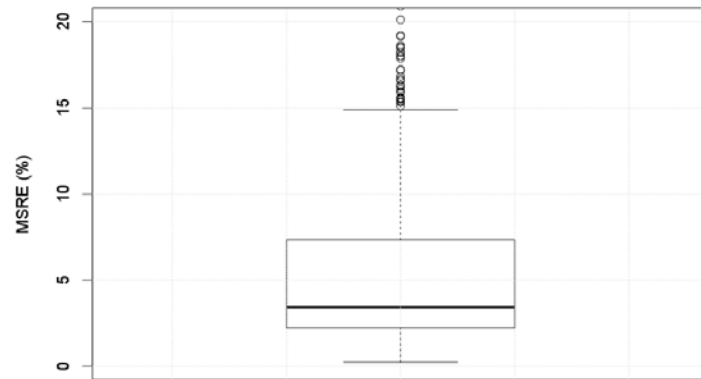

Fig. 3 – A Cross Validation Results

In summary, we found that in Madrid the use of the travel pass is fairly well explained by variables such as accessibility to public transport and the income level. From the results of our model, we observed that the use of the travel pass and its subsidy benefits increase when the average income per capita level of the neighborhood decreases. Consequently, since accessibility in the city is quite homogeneous (the proxy indicator does not change significantly among different neighborhoods), there is clear evidence that public transport subsidies tend to be progressive with respect to income. Consequently, it is possible to claim that the current subsidy policy to travel pass usage in Madrid benefits lower income areas.

5. CONCLUSIONS

From this research we have reached some interesting conclusions regarding 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 people in richer areas so they benefit much more from public subsidies. The results are categorical enough to confirm that public transport subsidies give special consideration to poor neighborhoods compared to wealthy ones. According to this indicator, it is possible to conclude that the subsidy policy of the travel pass is well targeted towards the least wealthy people. However, according to the *ACT* indicator, the cost per trip of travel pass users slightly varies across neighborhoods. This suggests that travel pass users in the lowest income neighborhoods pay the same amount per trip compared to high-income neighborhoods.

The multiple regression model explains very well the use of the travel pass in terms of three variables: population, accessibility and income level. The lower the income level of

the neighborhood, the greater the use of the travel pass. When comparing two neighborhoods in Madrid with the same standards of accessibility, we find that people in the poorer neighborhoods use the travel pass more than the wealthier neighborhoods. According to these results we can claim that the subsidy policy in Madrid is progressive since it establishes a fairness of treatment between individuals that differ in income. This means that vertical equity principles are fulfilled insofar as the transport policy is favoring economically disadvantaged groups.

Finally, the results of this research are limited by the aggregated nature of the data, which is collected at the level of neighborhood. The accuracy of the results of this research would be improved by using data from a completely disaggregated survey where more accurate characteristics and preferences of individuals may be captured.

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