LOCATION EFFECTS ON TRIP GENERATION: EVIDENCE FROM MADRID METROPOLITAN AREA

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ABSTRACT

The relationship between land use and travel patterns has been studied in a number of cases, using several methods - aggregate and disaggregate approaches - and different focuses – trip frequency, automobile use, vehicle miles travelled and so on. Definitely, travel is generated by the need to undertake activities and obtain services, and there is a general consensus that urban components affect travel behaviour. However researches are still needed to better understand which components of the travel behaviour are affected most and by which of the urban components.

This paper studies the effect on trip frequency, public transport and private vehicle dependency of socio-economic, transport and land use characteristics. In particular the land use is defined in terms of type of neighbourhoods and types of dwellers. Methodological attributes are also included to test the effect of the type of survey, namely trip-based versus activity-based survey. Using a data-base from a survey conducted in 2006 and 2007 in Madrid, ordered probit models are estimated to analyse the effect of neighbourhood type and socio-economic characteristics on trip frequency, public transport and private vehicle use.

Our results show that the characteristics of the neighbourhoods are important to explain the trip frequency but the effect is quite different depending on the mode used for the trips. Our results confirm that living in low density increases the propensity to use the private vehicles, while it does not seem to have an impact on the propensity to make internal trips, i.e. with origin and destination in the same area. We also found that there is a positive correlation between the number of trips and the number of stops but only if the trips are made with the private vehicles while are not significant for the public transport.

Keywords: ordered probit models, land-use, trip frequency, auto-oriented lifestyle

INTRODUCTION

Travel is generated by the necessity to participate in activities located in places different from where we live or where we currently stay. And, as well known, there is a strong relationship between the land use characteristics of the areas where we move and the way we move, i.e. the characteristics of our trips. The link between travel demand and land-use has received quite little attention, but the literature has shown a growing interest in the last years. As discussed in Brownstone (2008) individuals and/or families choose where to live and work based, among other things, on their preferences for different types and durations of travel. Hence the most important methodological issue for all studies in this field is the self selection issue. The most common way to deal with this problem is by using instrumental variables that explicitly account for the residential effect in the choice of travel.

Instrumental variables are used in the literature to study vehicles miles travelled (VMT) (Boarnet and Sarmiento, 1998; Vance and Hedel, 2007; Zhou and Kockelman, 2007; Brownstone and Golob, 2008). and/or automobile ownership (Pushkarev and Zupan, 1977; Mogridge. 1985; Bhat and Guo. 2007; Eluru et al. 2009; Howell and Páez, 2009). Instrumental variables are also used to model the number of trips generated (trip frequency) but usually the reference is only to specific mode (Crane and Crepeau. 1998; Boarnet and Sarmiento, 1998; Cervero and Grorham, 1995) and/or purposes (Ewing *et al*., 1994; Agyemang-Duah *et al.*, 1995; Handy and Clifton, 2001; Limanond and Niemeier, 2003) or to specific category of people (Schmocker *et al*, 2005; Páez *et al*., 2007; Roorda *et al*, 2009). As far as we are aware Bhat (1999b) is the only one to use land use variables to model the number of stops in the tours, while recently few papers included instrumental variable to model activity participation (Bhat and Lockwood. 2004; Bhat and Srinivasan, 2005; Farber and Paez. 2009).

As highlighted by Kitamura *et al.* (Kitamura *et al*. 1997) there is a problem in distinguishing if the “observed association between travel and land use is real, or is it an artefact of the association between land use and the multitude of demographic, socio-economic, and transportation supply characteristics which also are associated with travel”. The relative importance of urban form characteristics versus socio-economic characteristics on travel distance as well as trip frequency was firstly tested by Hanson (1982), who found that socio-demographic descriptors explain more variation in trip generation than do spatial descriptors. In line with it, later Kitamura *et al.* (1997) concluded that the total number of trips is largely determined by demographic and socio-economic factors but it is not strongly associated with land use characteristics. While the generation of transit and non-motorized trips, and consequently modal split, is strongly associated with land use characteristics, defined in terms of study area (dummies), pedestrian bicycle facilities (dummies), micro-scale accessibility indicators (street characteristics, public transit service, location and types of establishments, parks, etc.) and macro-scale area descriptors (access to transit, density, etc). More recently Dieleman *et al.* (2002) found that there is a strong influence of personal characteristics and residential environment on modal choice and distance travelled. Personal characteristics remain important in travel behaviour when residential environment is taken into account.

In general, it can be concluded that almost all the studies, as expected, found that individual and family socio-economic characteristics strongly influence trip generation. On the other hand, the relation with the land use characteristics does not have a clear tendency and it strictly depends on how the land use is defined. Often the land use effect is measured in terms of accessibility (Agyemang-Duah *et al*. 1995; Limanond and Niemeier, 2003; Handy *et al*. 2005), distance from CBD or working place (Cervero. 1996), shape of the local street (Crane andCrepeau. 1998), residential density or a combination of these measures (Ewing *et al*. 1994; Cervero and Kockelman. 1997; Boarnet and Crane. 2001).

Few works studied the effect of the land use in terms of characteristics of the neighbourhoods. Some authors defined the neighbourhoods in terms of level of income (Paez *et al*. 2007), others (White Mountain Survey Company, 1991; Friedman *et al*. 1994) studied the effect of traditional versus suburban neighbourhoods, defined in terms of gridded patterns, local shops and services, and residential densities. Handy and Clifton (2001) analyzed the relation between neighbourhood's types and opportunity for local shopping and distinguished neighbourhoods in "traditional", developed in the early part of the century; "early modern", mostly developed between 1950 and 1970; and "late modern", developed after 1970. A similar classification was used also by Handy *et al*. (2005), but they distinguished neighbourhoods between traditional, those built mostly in the pre-World II, and suburban, those built more recently. Bhat and Srinivasan (2005) analyzed four location variables: land-use mix density, fractions of detached and non-detached dwelling units, area type variables (CBD, urban, suburban and rural), and residential county-specific variables. Of these, only residential area type and residential county-specific turned out to be statistically significant. However, the first were defined as dummy variables and the temporal framework was weekend. Cervero and Gorham (1995) analyzed the effect on the work trips by transit of the urban form defined as street type, intersections type and year of foundation of the neighbourhood. Farber *et. al* (2009) distinguished between urban-apartment and suburban dweller, while Crane and Crepeau (1998) used a detailed definition for the shape of the street but only one dummy variables for the housing type.

As it can be seen from this literature review, many different factors influence the relationship between travel demand and land use. These factors depend of course on which dimension (or characteristic) of the travel demand is considered and on how land use is defined. As pointed out by Brownstone (2008), there is no clear consensus about which feasible measures of attributes of the built environment and land use are important. And, there is little background information to compare the influence of land use and socio-economic characteristics on different travel demand dimensions.

In this paper we aim to try and answer the important question of which dimensions of urban environment may influence each travel dimension. Using a data set gathered in three different neighbourhood of Madrid we model the effect of socio-economic, land use characteristics on trip frequency, public transport (PT) and private vehicle (PV) dependency, as well as their relation with the number of stops and the propensity to perform internal trips, i.e. inside or close to the living area. Socio-economic characteristics include both individual and family characteristics, while the land use is defined in terms of type of neighbourhoods and types of dwellers. In particular this later variable is measured directly for each family, rather than on census data, to avoid the problem highlighted by Crane and Crepeau (1998) and Frank *et al.* (2008) that the census geography data aren't "necessary relate to the household in question that reside in that track". As in Paez et al. (2007) the effect of the level of income is accounted through the difference between affluent and low-income neighbourhoods. Methodological attributes are also included to test the effect of the type of survey (trips based versus activity based diary) and whether the survey was self-administered or face-to-face.

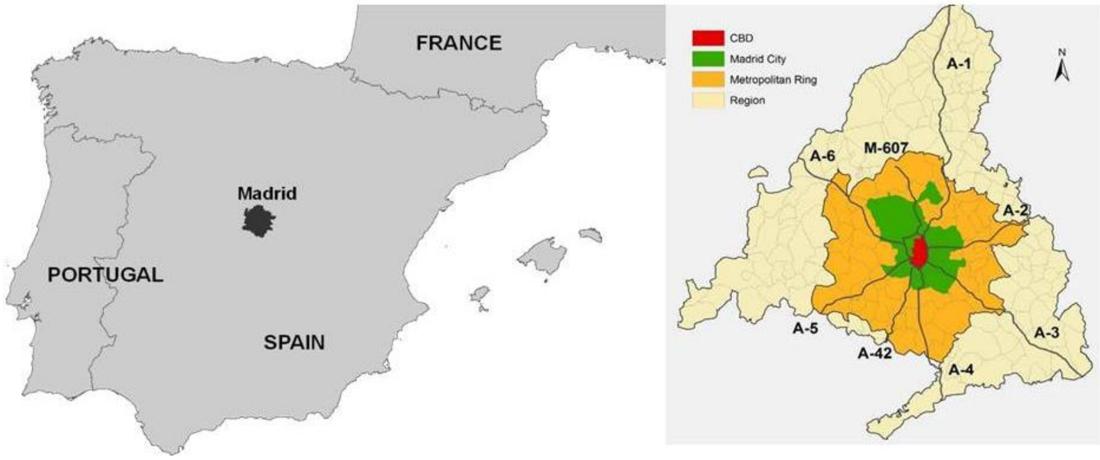
Finally, given the nature of the phenomenon, an ordered probit model is specified, in line with the recent advances in modelling estimation, This model has been already used to study the relation between travel demand and land use but they have mainly focused on automobile ownership and/or use (Mogridge. 1985; S. Handy *et al*. 2005) or to some particular trip category, such as shopping trips (Agyemang-Duah *et al*. 1995), activities performed only during the weekend (Bhat and Srinivasan, (2005)), or in the evening (Bhat. 1999a), mobility of elderly people (Paez *et al*. 2007), elderly and disables (Schmöcker *et al*. 2005); vulnerable categories ((Morency *et al*. 2009)).

The rest of the paper is organised as follows. Firstly we illustrate the characteristics of the area of Madrid and those of the sample used for our analysis. Then we discuss the model used and the choice of the variables. The main results are then discussed and finally our main conclusions summarised.

THE CASE STUDY: THE 'SPRAWLING' PROCESS OF MADRID

During the past 50 years Madrid changed from one-nuclear city to a poly-nuclear metropolis (Monzón and de la Hoz, 2009), as a consequence of an intense developing process accompanied by the dispersion in the land use: a phenomenon called *urban sprawl*. Madrid is divided into four regions: CBD (Central Business District), Madrid City, Metropolitan Ring and Regional (see Figure 1). These four regions are partitioned into eight areas around the radial highways that go from the city centre to the periphery. The Metropolitan Ring is growing, increasing their limits and gaining population from the Madrid municipality. In the last 20 years, people who lived in the Madrid municipality decreased from 65% in 1995 to 52% in 2006, confirming the lost of demographic weight of Madrid CBD in favour of the periphery. Madrid City and Metropolitan Ring are now characterized by low density areas, the dwelling type is single family or buildings with no more than three floors, these characteristics produce a scattered and fragmented urban lay-out.

Figure 1 Madrid Regional division



On the other hand, the separation between work places and residences contributes to land fragmentation and to increase the mobility (Valdés *et al.*, 2008). Data from INE - National Institute of Statistics- show that in 2004 52.2% of employment was located in Madrid while in 1998 this percent was 65%. The dispersion of the activity places makes people travel longer distances. At the same time, because of the lower public transport patronage outside the CBD, the motorization rate increased in suburban areas as well as car dependency. Data from INE confirm that around 40% of the individuals living in urban area do not have a car; while this percentage lowers to 19% in urban and suburban places.

The Household Travel Survey of Madrid (EDM) conducted in 1996 and 2004 (CRTM, 1998; CRTM, 2006) shows that:

1. The trips with origin and destination inside the Madrid CBD have decreased from 57% in 1996 to 48% in 2004.
2. The trips between Madrid CBD - Metropolitan ring and Metropolitan Ring-Periphery have slightly increased, but less than the radial trips. Therefore, it undergoes a backward movement. The trips between Madrid City and the Metropolitan Ring were 2,9 millions in 2004 while in 1996 were 37% more. The trips between Metropolitan Ring and Madrid Region were 216,885 in 2004 while in 1996 were 128% higher. On the other hand, trips with origin and destination outside Madrid have increased considerably from 17% in 1996 to 23% in 2004.

It seems that people are undertaking their activities near to the municipality and avoiding longer trips to CBD. People living in suburban and outer-edge areas usually work in other municipality nearby and they also usually travel for shopping to outskirts shopping malls. In fact, the actual scheme is to live in periphery, work and participate in activities in the periphery, in other municipality.

Travel surveys in Madrid Metropolitan Area

The data used in this study come from a survey conducted with the aim to analyse the influence of the type of questionnaire (activity-based against travel-based) on the mobility patterns (Monzón and Madrigal, 2007). The sample included 345 households, interviewed with the following methodology:

1. People were first contacted by phone and asked to participate in the study.
2. After the first contact, they received a letter explaining the survey and the questionnaire.
3. Respondents completed the questionnaire at home.
4. Finally, once the questionnaire was completed, it was collected from the households.

All the individuals older than 4 years where interviewed for a total of 943 individuals. In particular 174 households (and 463 Individuals) in the activity based questionnaire and 171 households (and 480 Individuals) in the travel based questionnaire. Information on the dwelling types were also gathered specifically for each family. Two different type of explanations for the survey were also used with different level of details.

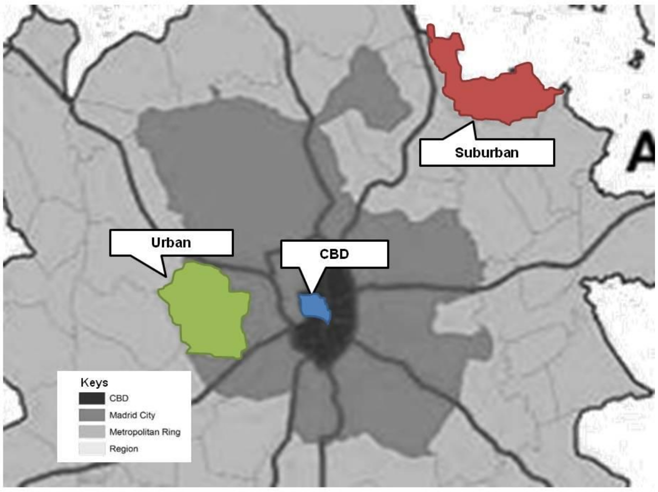
The survey was conducted in 2006 and then repeated (although not with the same individuals) one year after, in 2007. One of the reasons for repeating the survey was the need to enlarge the sample and to increase a new type of neighbourhood. In 2006 in fact the survey included two Madrid neighbourhoods: CBD and urban; in 2007 the suburban area was added. Although originally gathered for a different purpose, to test the effect of the type of survey, the survey appeared very suitable for the purpose of this paper, as the sample is evenly distributed among zones with different urban structure, different land use characteristics and activity opportunities, and different level of accessibility by public transport and private vehicles.

The three zones chosen for the survey have the following characteristics (Figure 1):

- CBD: this area (called *Chamberí*) corresponds to one of the 22 neighbourhoods of the Central Business District of Madrid. It is a traditional neighbourhood where several historical buildings are located and where people live mainly in apartments. It is characterised by good transit (bus and metro) and rail services and by a gross income[1] level that ranks the 4th of the 22 neighbourhoods of Madrid City. In 2004 the income of *Chamberí* was also 40% higher than the mean of the Region of Madrid.

- Urban: this area (called *Pozuelo de Alarcón*) is located 15 km west to the Madrid CBD but it is inside Madrid City. This is a car-oriented neighbourhood, where the supply of public transport services is limited. Urban dwellers tend to live in single family houses or detached houses. Pozuelo's average income level ranks the highest amongst the municipalities of the Region of Madrid. It was 66% higher than the mean of the Region of Madrid in 2004.
- Suburban: this area (called *Algete*) is located 30 km north-east to the Madrid CBD, in the Metropolitan Ring. This district has lower available gross income and fewer transit services than the other two selected neighbourhoods. Algete´s average income level ranks the 15th amongst the 179 municipalities of the Region of Madrid. It was 17% higher than the mean of the Region of Madrid in 2004.

Figure 2 – Location Map of the three study areas: CBD, urban and suburban



Before moving forward into the analysis of the neighbourhoods' characteristics, it is important to define the dwelling types used in the present work:

1. Single house is an independent structure intended for one household, separated by an open space or walls from all other structures.
2. Terraced house is a style of medium-density housing, where a row of identical or mirror-image houses share side walls.
3. Detached is a free-standing, a separate house. Typically only members of a single family live in this type of house.
4. Apartment, or flat, is a self-contained housing unit that occupies only part of a building. A room or suite of rooms designed as a residence and generally located in a building occupied by more than one household.

[1] Gross income is defined as the total income from a person or company, before tax, superannuation or payroll deductions

5. Condominium is a collection of individual home units along with the land upon which they sit. It is the form of housing tenure where an apartment house is individually owned, while hallways, heating system, elevators and exterior areas are common facilities in the piece.

Table I reports the land-use and the transport characteristics of the residential areas. Table II illustrates the sample socio-economic characteristics while Table III reports the average trip rates (i.e. the average number of daily trips made in the sample) for those who have travelled the day of the interview.
As mentioned before, the three neighbourhoods have quite different characteristics. Their main differences stand in the dwelling type, in the income level, in the family structure, in the accessibility by public transport and, as a consequence, also in the motorization rate. The dwelling type in CBD is clearly characterized by apartments, while urban and suburban are composed mainly by single family in urban and urbanization area. The number of car per household is clearly lower in the CBD than in the urban and suburban areas, where around 95% of the households have more than one car. At the same time both urban and suburban areas have a less efficient transport system, therefore mobility in CBD is mainly transit-oriented while in the urban and suburban areas people tend to have auto-oriented lifestyles.

Table I – Characteristics of the areas

Site characteristics	**CBD**	**Urban**	**Suburban**
Distance from CBD	0	15 Km	30 Km
Area (km²)	4.69	43.20	37.88
Population	145,934	81,365	19,345
Density (Inhabitant/km²)	31,115	1,883	510
Available Gross Income (2007)	22, 068 €	28,203 €	19,664€
Urban Land	81 %	55.28 %	15.34 %
Land use Factors			
- Retails/km²	68.66	0.63	1.90
- Restaurants/Km²	112.15	2.31	0.55
- Leisure places/km²	25.16	0.42	0.48
Car/ inhabitants (2008)	0.465	0.560	0.564
Commuter Rail stations	1	2	-
Metro stations (#)	18 (12 lines)	17 (light rail)	-
Intermodal stations	2	-	-
Bus lines	22	19	9
Interurban	-	19	8
Connecting with CBD		17	7
Connecting with other Municipalities		2	1
Urban	22	-	1
Night service	4	3	-
Bus Stops	153	288	68

Additionally, people living in the CBD are on average older than those living in the urban and suburban areas, which could explain the lower average trip-rate. Table III shows that 40% of the trips in CBD, 39% in the urban and 44% in suburban area, are “internal”, i.e. carried out inside the municipality or district. Internal trips can be explained (and at the same time are an indicator) of mixed land uses and the proximity to destinations, which makes prefer places near the zone and activities in nearby places (shopping, and work activities). As expected the CBD is characterized by mixed land-use and by a much higher numbers of opportunities for leisure activities. Hence, in principle, we should expect more internal trips in CBD than in the other two areas. However, the exploratory analysis shows a slightly different figure, as internal trips are higher in the suburban. This can be explained by the distance of the suburban area from other district with competitive opportunity. A comparative analysis between the opportunities inside each district and those in other districted compared with their distance would maybe help in explaining such effect. We do not have currently this information but we plan to do this analysis as part of our future research.

More interesting is to analyze modal split by trip purpose. The exploratory analysis shows that 54% (while only 8% in the CBD) of the internal trips in urban and suburban areas are made by car, which means that driving is a matter of proximity, i.e. local places reduces total driving. The result does not the work of (Handy and Clifton. 2001) who found that local shopping does not reduce total driving significantly.
Table III reports the t-test analysis on the statistical difference among categories. Along demographic dimensions, the worker group contains the highest person-trip rate, while unemployed group present the lowest rate. Similarly, the mean of leisure category more than 50 percent is higher than the group of less than 50%, indicating that leisure respondents tend to make more trips. All of those variables are included in the model, in the next part, and discussed in the final part of this work.

Table II Socioeconomic Characteristics

Characteristics	CBD	Urban	Suburban	Total
Sample Size				
Households (in the population)	117 (59,680)	125 (5,880)	103 (24,072)	**345** **(89,632)**
Respondents	288 (145,943)	372 (19,345)	283 (81,365)	**943** **(246,644)**
Gender				
Male (% in the population)	48% (43%)	49% (50%)	54% (48%)	
Female (%in the population)	52% (57%)	51% (50%)	46% (52%)	
Age				
4-13 years	5%	5%	8%	**6%**

Characteristics	CBD	Urban	Suburban	Total
14-21 years	12%	11%	18%	**13%**
22-29 years	11%	15%	8%	**12%**
30-49 years	25%	23%	37%	**27%**
50-64 years	30%	37%	19%	**30%**
Greater than 65 years	17%	9%	10%	**12%**
Dwelling type				
Single family	2%	32%	29%	**22%**
Terraced House	0%	48%	33%	**29%**
Detached	0%	4%	7%	**4%**
Apartment	93%	14%	23%	**41%**
Condominium	5%	2%	4%	**4%**
Marital Status				
Single	43%	38%	31%	**38%**
Married	51%	57%	64%	**58%**
Widow	4%	3%	1%	**3%**
Divorced	2%	1%	3%	**2%**
Household Size				
1	8%	1%	2%	**3%**
2	24%	15%	18%	**19%**
3	27%	26%	25%	**26%**
4	26%	42%	45%	**38%**
5+	14%	16%	10%	**13%**
Cars per household				
0	20%	5%	3%	**9%**
1	48%	20%	39%	**34%**
2	28%	46%	41%	**39%**
3+	4%	29%	17%	**18%**
Employment Status				
Worker	51%	51%	55%	**52%**
Work/study	2%	2%	1%	**2%**
Student	20%	21%	19%	**20%**
Retired/ Unemployed	20%	16%	18%	**18%**
Other Occupation	7%	10%	7%	**8%**

Table III Trips Characteristics

Characteristics	CBD	Urban	Suburban	Total
Trips (*)	567	768	624	1,959
Trip type				
External	60%	61%	56%	59%
Internal	40%	39%	44%	41%
Modal Split for Total Trips				
Public Transport	43%	23%	17%	27%
Private Transport	24%	61%	65%	52%
Non-Motorized	33%	15%	19%	22%

Characteristics	CBD	Urban	Suburban	Total
Modal Split for External trips				
Public Transport	56%	34%	26%	38%
Private Transport	34%	65%	73%	59%
Non-Motorized	9%	0%	1%	3%
Modal Split for Internal trips				
Public Transport	22%	7%	5%	10%
Private Transport	8%	54%	54%	41%
Non-Motorized	69%	39%	41%	48%
Average Person-trip				
Mean	2.60	2.65	2.72	
Median	2.00	2.00	2.00	
Variance	1.37	1.18	1.71	

(*) It refers only to those who travelled. 206 individuals who have not travelled have been excluded from this analysis.

Table IV T-test for Trip Frequency

Variables	N	Mean	Std. Dev.	t-statistic	*p*-value
Age groups					
4-13 years	55	1.09	0.701	0.997	0.320
14-21 years	120	1.05	0.532	0.883	0.378
22-29 years	103	0.98	0.641		
30-49 years	245	1.20	0.780	2.675	0.008
50-64 years	265	1.11	0.846	1.529	0.128
Greater than 65 years	105	0.80	0.965	-1.593	0.113
Occupation					
Worker	491	1.16	0.712	4.232	0.000
Work and student	15	0.93	0.704	0.436	0.663
Student	189	1.04	0.591	2.575	0.011
Retired/ Unemployed	166	0.83	0.934	*Reference*	
Other occupation	79	1.08	1.035	1.895	0.059
Travel Attributes					
Leisure category	928	1.06	0.775	-2.371	0.018
	15	1.53	0.640		
Public Transport user	747	1.03	0.838	-3.282	0.001
	196	1.18	0.446	*Reference*	
Internal Trips	700	0.94	0.773	-8.845	0.000
	243	1.43	0.660		

Variables	**N**	**Mean**	**Std. Dev.**	**t-statistic**	***p*-value**
Driver License	270	0.92	0.720	*-3.57*	0.000
	673	1.12	0.790		
Neighbourhood Attributes					
Location factors					
CBD	288	1.00	0.761	-1.846	0.065
Urban	372	1.07	0.770	-0.816	0.415
Suburban	283	1.12	0.794	Reference	
Dwelling Type					
Single family	206	1.01	0.814	Reference	
Terraced House	271	1.12	0.766	-1.490	0.137
Detached House	35	1.09	0.562	-0.531	0.596
Apartment	386	1.05	0.782	-0.540	0.590
Condominium	35	1.17	0.785	-1.092	0.276

ORDERED PROBIT REGRESSION MODEL FOR TRIP GENERATION

The Ordinal Regression procedure enables building models, generate predictions, and evaluate the importance of various predictor variables in cases where the dependent variable is ordinal in nature. The *ordered probit* model is a generalization of the tyical probit model to the case of ordinal dependent variables (McKelvey and Zavoina, (Zavoina. 1975). Individuals facing ordinal decision processes can be thought to associate utility y^* with alternative number of trips. Then, ordered probability models are based on a latent regression:

$$y_i^* = \beta' x_i + \varepsilon_i$$

where y_i^* is the utility of individual i , which is an unobserved dependent variable decomposed into the usual systematic and random components; x_i is a vector of explanatory variables, β is a vector of coefficients or model parameters, and ε_i is a Normal distributed error term with mean zero and covariance matrix $\sigma^2 I$. Following Greene's notation (Green, 2008), it is assumed that the discrete and ordered observations y_i = 0,1,2,…J are generated according to the following mechanism:

$y_i = 0$ if $y_i^* < \mu_0$,
yi = 1 if $\mu_0 < y_i^* \leq \mu_1$,
yi = 2 if $\mu_1 < y_i^* \leq \mu_2$, and so on

Where, μ's are a set of threshold parameters that are estimated together with the vector of parameters β. The thresholds depend on the problem at a hand. In our case, we will set up three different models to study the trip frequency, public transport and (motorised) private vehicles use. Trip frequency had a four-point numerical scale, so the model assumed the following specification:

$y_i = 0$ if $y_i^* < \mu_0$, then Trip= 0
$y_i = 1$ if $\mu_0 < y_i^* \leq \mu_1$, then Trip=1 and 2
$y_i = 2$ if $\mu_1 < y_i^* \leq \mu_2$, then Trip= 3 and 4
$y_i = 3$ if $y_i^* > \mu_2$, then Trip is higher than 5

In other words, the individual *i* does not travel if the utility y_i^* is lower than given threshold μ_0. Similarly, if the utility y_i^* is between μ_0 and μ_1, the individual makes 1 or 2 trips. If the utility y_i^* is between μ_1 *and* μ_2, then the individual makes 3 or 4 trips and finally; the individual *i* makes 5 trips or more if the utility y_i^* is higher than μ_3. Note that the index *J* is one less than the number of categories in the responses which in this case is equal to 3.

Public transport and private vehicle use have instead a two-point numerical scale, defined as follows:

$y_i = 0$ if $y_i^* < \mu_0$, then *Trips* ≤50%
$y_i = 1$ if $y_i^* > \mu_0$, then *Trips* >50%

Where Trips= number of trips made by each individual with public transport or a motorised private vehicle.

The probability of observing y_i is given by:

$$\Pr(\mu_1 < y_i < \mu_0) = \Phi\left(\frac{\mu_0 - \sum_{k=0}^{K} \theta_k X_{kj}}{\sigma}\right) - \Phi\left(\frac{\mu_1 - \sum_{k=0}^{K} \theta_k X_{kj}}{\sigma}\right)$$

Where Φ is the cumulative standard normal density function and the log likelihood (L*) is a function of ($\beta_0, \ldots \beta_K$ and $\mu_2, \ldots \mu_{J-1}$).

Utility specification and model results

Using the dataset gathered for the area of Madrid several ordered probit models were estimated with different specification for the utility function. As reported in Table V, the explanatory variables used in our models include personal, travel related attributes and neighbourhood characteristics. Some of these variables need explanation. In particular the travel time is the total time spent travelling during the day of the interview. Table V reports the specification used in the models reported in this paper, but others measures (total travel time in minutes and average time across the daily trips) were also tried but the specification was inferior. It is also important to note that in our sample 45 % of the individuals had a total travel time around an hour, this is the reason why we specified one category exactly equal to one hour.

The trip (or tour) attributes, such as the purpose or the mode, are measured considered the first trip of the day. The reason is that all the trips in our sample started from home and we are mainly interested in the characteristics of the residential areas of our respondents. Other measures will be explored in our future work. For the variable that measures if the trip had origin and destination in the same district where the respondent lives (Internal trips) we measured the fraction of internal trip during the survey day as we were interested in the whole trips performed during the day.

Table V Variable definition

Variable	Definition
Personal attributes	
Age cohort	
4-13 years	Yes=1; otherwise 0
14-21 years	Yes=1; otherwise 0
22-29 years	*Base category*
30-49 years	Yes=1; otherwise 0
50-64 years	Yes=1; otherwise 0
>65 years	Yes=1; otherwise 0
Gender	
Male	Yes=1; otherwise 0
Female	*Base category*
Occupation	
Worker	Yes=1; otherwise 0
Work and student	Yes=1; otherwise 0
Student	Yes=1; otherwise 0
Unemployed	*Base category*
Car ownership	Yes=1; otherwise 0
Driver License	Yes=1; otherwise 0
Household Structure	
Single With Child	*Base category*
Single No child	Yes=1; otherwise 0

Variable	Definition
Trips attributes	
Internal trips	≥ 50% internal trips =1 otherwise 0
Travel time	
Time Cat 1	(Travel Time = 1hr) =1; otherwise 0
Time Cat 2	(Travel Time > 1hr) =1; otherwise 0
Public transport (PT)	If the first trip is by PT=1; otherwise 0
Private vehicle (PV)	If the first trip is by PV=1; otherwise 0
Stops	# of stops inside each tour
Neighbourhood Attributes	
Location factors	
CBD	Yes=1; otherwise 0
Urban	Yes=1; otherwise 0
Suburban	*Base category*
Dwelling Type	
Single-family	*Base category*
Terraced house	Yes=1; otherwise 0
Detached	*Base category*
Apartment	Yes=1; otherwise 0
Condominium	Yes=1; otherwise 0
Survey Method	
Questionnaire	If Travel-Based = 0 If Activity-Based = 1;

Variable	Definition
Married No Child	Yes=1; otherwise 0
Married With Child	Yes=1; otherwise 0
Others No Child	Yes=1; otherwise 0
Household Size 4+	# of person > 4 years old

Variable	Definition
Survey presentation	If face to face = 0 If Self-administred = 1;
Primary Activity	
Shopping	Yes=1; otherwise 0
Accompanying person	Yes=1; otherwise 0

The results of the models estimated are reported in Table VI. In particular six ordered probit models are reported: the first two models (TRIP-FREQ1 and TRIP-FREQ2) refer to trip frequency, i.e. the total number of trips carried out in a day by each individuals. The first model (TRIP-FREQ1) was estimated including all the individuals, even those who did not move at all, hence the model explains the effect of not moving at all versus making a certain number of trips. In this model 3 thresholds that represent the demarcation points on the continuous latent propensity scale that identify the following observed discrete values of person- trips: zero trips, 1-2 trips, 3-4 trips and more than 4. The second model (TRIP-FREQ2) instead includes only those who made a trip and explains only the choice of how many trips carry out. This model has three thresholds as it does not include the first class (zero trips). Models PT-FREQ2 and PV-FREQ2 explain the trip frequency respectively by public transport and private vehicles. These models are estimated using only those individuals who performed a trip and the index 2 is added in analogy with the previous notation. Both models have three thresholds. The last two models instead (PT-USE and PV-use) have only one threshold as it explain whether the percentage of trips carried out by public transport and by private vehicles is greater or less than 50%.

It is important to mention that many others categories have been estimated, grouping the trips in different ways from 2 to up 10 categories. But models estimated with these other categories were inferior to those reported in Table VI. It is worth noting that the estimated threshold are (almost all) highly significant (p-values less than 0.05) and in ascending ordered showing that the intended order is correct. Reverse threshold estimates is sufficient evidence to conclude that the empirical ordering is consistent with the intended ordering (Andrich *et al.*, 1997).

Looking at the models results in Table VI[2], differently from many findings in the literature, we found that many socio-economic variables are not significant, while our neighbourhood attributes are generally highly significant. However, it is interesting to note that these later attributes seem to be relevant in discriminating between making or not a trip but not in the number of trips carried out. This result can be appreciated comparing models TRIP-FREQ1 and TRIP-FREQ2. On the other hand the

[2] SPSS 15.0 version was used to estimate the models, although many other software are available such as LIMPDEP, SAS, STATA.

neighbourhood attributes have an impact on the trips frequency by PT and by PV and, even more interesting; this effect is correctly the opposite in the two models. Compared to the suburban area, living in the CBD or in an apartment reduces the number of trips made with a private vehicle while it increases the frequency of the trips by public transport. The same effect occurs but much less pronounced in the urban district.

The purpose of the first trip of the day is also relevant in explaining trip frequency. In fact, if the first trips is made for shopping or to accompanying someone, it is likely that after other trips will be performed during the same day maybe to go to work or to pick up the same person who has been accompanied in the first trip. In line with the expectation, this effect is true for the trips made with the private vehicle, while it is the opposite for the trips made with the public transport. These results are consistent in all the models that explain private vehicle and public transport use.

Another interesting result is the effect of the number of stops. Of course a certain positive correlation is expected between the number of trips and the number of stops. And this result is confirmed in the first two models of total trip frequency. However, as expected, the effect seems to be strictly related to the mode used. In fact, the number of stops is significant only when the trips are made with the private vehicles while are not significant for the public transport.

Regarding the structure of the trips, it is interesting to note that the variable that measures the trips made inside each area has a different effect in the models. In fact, internal trip has a positive effect on the total number trip but has a negative effect on the frequency of the trips made by public transport (maybe due to the longer time usually spent) while is irrelevant for the trips made by private vehicles.

Among the socio-economic variables it is interesting to note that, as expected, the presence of young people (specifically 4-13 years old) increases the frequency of the trips by private vehicle while decreases the frequency of the trips by public transport.

Finally, it is important to mention that the type of the questionnaire used is significant only to explain the trip frequency by private vehicles, and it has a positive effect. This seems to confirm the activity-based surveys are indeed important when there are many trips with several (often short) stops as when private vehicles are used. But more analyses are needed to confirm this result.

CONCLUSIONS

In this paper we studied the effect of socio-economic, land use characteristics on trip frequency, public transport (PT) and private vehicle (PV) dependency, as well as their relation with the number of stops and the propensity to perform internal trips, i.e. inside or close to the living area. A data set gathered in three different neighbourhoods of

Madrid was used to estimate several ordinal probit models that include several individual and family characteristics, as well as three variables to describe the type of neighbourhoods and five variables for the types of dwellers. The relation between the number of stops and the trip frequency was also studied as well as the effect of two methodological attributes: the type of survey and the type of information.

We found that trip rates are strongly associated with neighbourhood attributes, such as dwelling type, distance to CBD, public transport service and so on. It is important to note that socioeconomic characteristics became not significant while neighbourhood attributes are generally highly significant. Moreover, the effect of suburban neighbourhood is clear in both public transport and private vehicle use, people residing in suburban area make more car- trips and this effect persist explaining the percentage of trips during the day (PV-USE and PT-USE). Internal Trips and number of stops shown an interesting effect in almost all model, showing that the relationship of number of car-trips is associated with the number of stops, while public transport use does not . The methodology implemented here leads us to consistent results. The results reveal the importance of measuring geography characteristics on sampled households, instead of census data. We analyzed three travel characteristics with the same set of variables, it was important to compare and contrast results. The comparison of results showed which dimensions of neighbourhood type influences which dimensions of travel behaviour. Similarly, the individual approach, implemented here, represents better travel behaviour, in which decisions are associated to habits or requirements, such as number of trips.

In general words, given the importance of land use policy distribution in the implementation of transport measures, the land use and transport policy should be directed on optimal land-use measures, which encourage mixed land-use. Similarly, the Green Paper (CEC—Commission of the European Communities, 2007), customized solutions could serve better suburban areas, such as transport on demand or transport services that interlink usually radial and city-centre oriented connections.

It is important to clarify some constraints of our work. It would have been very easy for land use to be correlated with an unmeasured variable that itself is significant. Afterwards, future research should explore variables relate urban forms in order to obtain a better fit of the model, i.e. density, neighbourhood type, trip-distances, land-uses and others. Since is based on 3 of 76 neighbourhoods of Madrid the sample size could constrain to some extent the breadth of our findings. However, the objectives of this paper have been to investigate the impact of location on travel behaviour, instead of trying to extend the results to Madrid Region. The sample size by neighbourhood is representative of neighbourhood population, covering the travel patterns. additionally, as further research is also interesting to analyze a social context of urban mobility. Sustainable mobility includes the equity in social participation, which leads to the question: are the amenities in the neighbourhood good enough so that people do not need to travel outside their zone? Or is the transport a constraint that restricts mobility?..

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Table VI Ordered Probit Model Results
***Significant values are showed in bold**

	TRIP-FREQ1			**TRIP-FREQ2**			**PV- FREQ2**			**TP-FREQ2**			**PT-USE**			**PV-USE**		
	Parameter	Wald	Sig.	Parameter	Wald	Sig.	Parameter	Wald	Sig.	Parameter	Wald	Sig.	Parameter	Wald	Sig.	Parameter	Wald	Sig.
Threshold =0 .00	-0.233	0.645	0.422	1.827	19.494	**0.000**	0.548	2.690	0.101	0.871	5.265	0.022	0.411	0.865	0.352	0.889	4.405	0.036
Threshold = 1.00	2.012	46.169	**0.000**	3.643	68.283	**0.000**	2.079	37.395	**0.000**	2.644	44.876	**0.000**						
Threshold = 2.00	3.537	123.642	**0.000**				3.139	78.034	**0.000**	4.209	60.994	**0.000**						
Age 4-13	0.647	6.368	0.012	0.274	0.533	0.465	0.817	7.851	0.005	-1.269	10.648	**0.001**	-1.095	6.576	**0.010**	0.613	3.312	0.069
Age 14-21	0.283	2.549	0.110	-0.029	0.011	0.917	-0.283	1.866	0.172	-0.100	0.219	0.640	0.154	0.467	0.495	-0.251	1.110	0.292
Age 30-49	0.147	1.133	0.287	0.202	1.079	0.299	-0.091	0.380	0.538	0.054	0.099	0.753	-0.021	0.014	0.907	-0.264	2.302	0.129
Age 50-64	0.363	6.943	0.008	0.530	7.657	0.006	0.328	4.973	0.026	-0.235	1.841	0.175	-0.328	3.157	0.076	0.164	0.884	0.347
> 65	0.291	1.985	0.159	0.984	11.152	**0.001**	-0.136	0.285	0.594	0.342	1.550	0.213	0.105	0.124	0.725	-0.224	0.592	0.442
Worker	0.675	20.366	**0.000**	0.527	5.846	0.016	0.363	4.056	0.044	-0.104	0.241	0.623	-0.335	2.163	0.141	0.261	1.572	0.210
Work and Student	1.001	7.685	0.006	0.607	1.204	0.272	0.407	0.889	0.346	0.183	0.168	0.682	-0.185	0.148	0.700	0.410	0.722	0.395
Student	0.542	6.183	0.013	0.511	2.379	0.123	0.091	0.126	0.723	0.300	1.098	0.295	-0.025	0.007	0.935	-0.334	1.288	0.256
Single no child	0.018	0.007	0.932	-0.068	0.056	0.813	-0.058	0.056	0.813	0.036	0.020	0.888	0.149	0.290	0.590	-0.220	0.597	0.440
Married no child	0.072	0.422	0.516	-0.105	0.467	0.495	-0.065	0.289	0.591	0.231	2.580	0.108	0.293	3.546	0.060	-0.210	2.142	0.143
Others no child	0.151	0.617	0.432	0.175	0.476	0.490	0.024	0.013	0.909	0.287	1.574	0.210	0.312	1.528	0.216	-0.125	0.242	0.623
Household Size 4+	-0.068	2.657	0.103	-0.027	0.212	0.645	-0.001	0.000	0.991	-0.026	0.219	0.639	0.015	0.065	0.798	0.026	0.203	0.652
Internal Trips	0.529	27.134	**0.000**	0.282	5.149	0.023	0.018	0.031	0.861	-0.413	11.728	**0.001**	-0.481	13.154	**0.000**	-0.092	0.600	0.439
Driver	0.360	10.229	**0.001**	0.008	0.002	0.960	0.796	29.946	**0.000**	-0.445	10.384	**0.001**	-0.229	2.311	0.128	0.863	27.829	**0.000**
Urban	-0.566	14.949	**0.000**	-0.365	3.368	0.066	-0.755	20.018	**0.000**	0.609	11.678	**0.001**	-0.109	0.352	0.553	0.508	7.894	**0.005**
Suburban	-0.326	9.751	**0.002**	-0.096	0.458	0.499	-0.142	1.602	0.206	0.490	12.227	**0.000**	-0.520	7.222	**0.007**	0.719	14.217	**0.000**
Terraced House	0.137	1.568	0.210	0.038	0.066	0.798	0.094	0.666	0.414	-0.233	2.437	0.119	-0.106	0.443	0.505	0.102	0.533	0.465
Apartment	0.285	4.551	0.033	0.332	3.338	0.068	-0.330	5.062	0.024	0.428	6.338	0.012	0.400	4.702	**0.030**	-0.432	6.422	**0.011**
Condominium	-0.018	0.006	0.938	0.153	0.258	0.611	-0.788	8.641	**0.003**	0.631	5.930	0.015	0.625	4.779	**0.029**	-0.724	6.119	**0.013**
AccompainingTour	1.154	39.503	**0.000**	0.677	11.420	**0.001**	0.316	3.282	0.070	-0.516	5.056	0.025	-0.715	6.577	**0.010**	-0.102	0.232	0.630
ShoppingTour	0.698	11.048	**0.001**	0.617	6.479	0.011	-0.282	1.502	0.220	-0.435	2.423	0.120	-0.413	1.944	0.163	-0.738	7.396	**0.007**
Survey Presentation	-0.390	12.378	**0.000**	-0.392	5.648	0.017	0.121	0.898	0.343	0.041	0.081	0.776	0.126	0.657	0.418	0.260	3.082	0.079
Questionnaire	0.034	0.169	0.681	0.022	0.035	0.852	0.167	3.182	0.074	-0.013	0.015	0.902	-0.035	0.092	0.762	0.074	0.456	0.499
Time Cat 1	0.180	2.996	0.083	0.486	13.407	**0.000**	0.070	0.463	0.496	0.460	14.668	**0.000**	0.295	5.318	**0.021**	-0.068	0.316	0.574
Time Cat 2	-1.029	83.323	**0.000**	1.405	66.698	**0.000**	-0.011	0.006	0.937	1.286	65.083	**0.000**	0.734	17.896	**0.000**	-0.574	11.538	**0.001**
Total_Stops	1.827	194.071	**0.000**	1.443	110.582	**0.000**	0.525	36.933	**0.000**	0.086	0.850	0.357	-0.259	4.524	**0.033**	0.117	1.268	0.260
Public	0.677	45.500	**0.000**	-0.390	7.974	**0.005**												
	TRIP-FREQ1	**N**	**%**	**TRIP-FREQ2**	**N**	**%**	**PV-FREQ2**	**N**	**%**	**TP-FREQ2**	**N**	**%**	**PT-USE**	**N**	**%**	**PV-USE**	**N**	**%**
Categories	0.00	206	21.8%	1.00	520		0.00	330	44.8%	0.00	488	66.2%	0	541	73.4%	0	379	51.4%
	1.00	520	55.1%	2.00	168	70.6%	1.00	305	41.4%	1.00	222	30.1%	1	196	26.6%	1	358	48.6%
	2.00	168	17.8%	3.00	49	22.8%	2.00	83	11.3%	2.00	26	3.5%						
	3.00	49	5.2%			6.6%	3.00	19	2.6%	3.00	1	0.1%						
Total		943		Total	737			737			737			737			737	
Model	**-2 Log Likelihood**			**-2 Log Likelihood**			**-2 Log Likelihood**			**-2 Log Likelihood**								
Intercept Only	2,095.003			1,113.281			1,521.591			1,087.128			819.972			979.616	819.972	
Final	1,388.090			720.260			1,250.276			857.941			675.390			749.191	675.390	
Chi-Square	706.913			393.021			271.315			229.188			144.581			230.425	144.581	

	TRIP-FREQ1	TRIP-FREQ2	PV- FREQ2	TP-FREQ2	PT-USE	PV-USE	
df	27	27	26	26	26	26	26
Sig.	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Goodness-of-Fit							
Chi-Square							
Pearson	19,394	1,171	2,492	1,477	622	712	622
Sig.	0.000	1.000	0.000	1.000	0.316	0.02	0.316
Deviance	1,368	709	1,206	826	615	711.630	615
Sig.	1.000	1.000	1.000	1.000	0.394	0.02	0.394
Pseudo R-Square							
Cox and Snell	0.527	0.413	0.308	0.267	0.178	0.268	0.178
Nagelkerke	0.590	0.528	0.349	0.342	0.260	0.358	0.260
McFadden	0.334	0.349	0.173	0.204	0.169	0.226	0.169