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Measuring the structural determinants of urban travel demand

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Abstract

To be best prepared for tomorrow's cities we need to forecast urban travel demand. To this end, this study calibrates an urban travel demand model which uses the principal structural variables that have been identified in the literature. It uses a robust econometric method which has been little applied in the sphere of transportation. The results show that two variables stand out from the others: the user cost of transport – by private car and public transport – and urban density. It is surprising, but explicable with the available data, that the demand functions estimated for a given country are independent from the group of countries to which it belongs.

Key words: urban travel, demand estimation, urban density, travel cost

1. Introduction[1]

There is strong social demand for data that allows us to foresee the future and prepare for it as well as possible. This expectation is becoming stronger and stronger as environmental concerns become more alarming. Transportation does not escape from this rule. Having an idea, for example, of the order of magnitude of urban travel would help us understand what tomorrow's cities may be like. One of the difficulties is to find the most appropriate forecasting model. This is the subject covered in this paper.

The estimation of long-term travel demand requires specific modeling which identifies the structural factors of travel. One of the first such factors to be identified was the quantity of goods or services available, be in private cars (Mogridge, 1967 and 1989; Evans, 1970; Jansson, 1989; Button and *al.*, 1993; Gakenheimer, 1999; Ortuzar and Willumsen, 2006; Holmgren, 2007) or in public transportation (Wardman, 2004; Bresson and *al.*, 2003, 2004; Garcia-Ferrer and *al.*, 2006).

The literature shows that other structural determinants are also considered, for example the user cost of a trip (McFadden, 1974; Paulley and *al.*, 2006), the income of the household that travels, (Schafer and Victor, 2000; Dargay and Hanly, 2002; Medlock and Soligo, 2002) or the spatial distribution of transportation (Kain and Fauth, 1977; Oum and *al.*, 1992; Giuliano and Dargay, 2006; Davidson and *al*., 2007).

Moreover, in addition to these structural factors, travel differences between different groups of countries also seem to play a role (Schafer and Victor, 2000; van de Coevering and Schwanen, 2006).

This paper describes a demand model based on these structural factors. We have verified that they are statistically significant and checked whether they have a similar impact on urban travel in different groups of countries. We have used a robust econometric method (2SLS, SUR, 3SLS[2], Chow's stability test, see Greene, 1993; Maddala, 2008) which has, to the best of our knowledge, only occasionally been used in the sphere of transport (apart from by Cervero and al., 2002; Zhou and al., 2008). We have then checked whether our findings agree with those in the literature.

Our results show that two variables stand out from the others: the user cost of trips (by private car and public transport) and urban density. It is these explanatory variables which stand up the best to the various econometric tests we have applied. The value of the elasticity coefficients, moreover, concurs with those in the literature. Furthermore, the estimated demand functions for a given country seem to be independent of the group of countries to which it belongs. This may seem surprising but it can be explained by our inability to take account of urban GDP in a satisfactory manner.

Following a literature survey on the structural factors that explain urban travel demand (Section 2), we will present the model that we have selected for estimating travel demand (Section 3) followed by our findings (Section 4).

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[1] While the views expressed in this paper represent only the view of its author, the latter would like to thank Yves Croissant and Dominique Bouf, respectively a senior lecturer at Université Lumière Lyon 2 and a researcher at the CNRS, for their helpful advice. We would also like to thank S. Le Corvec for rereading of the text with such care. Last, I would like to thank the two reviewers of Transport Policy for their constructive comments.

[2] The Double Least Square method (2SLS), the Seemingly Unrelated Regression (SUR), the Three Least Square method (3SLS).

2. A survey of the literature on the estimation of urban travel demand

2.1 The price effect

McFadden (1974) has revealed that price affects travel demand. In the case of the private car, demand increases when the user cost of the car falls. It also increases when income and the cost and waiting time for public transport increase. Likewise, demand for public transport travel rises when the user cost of the car increases and falls when the cost and waiting time for public transport increase.

Considering the elasticity of demand with respect fuel prices can improve out understanding of the price effect, showing that rising fuel prices reduce car travel (Goodwin, 1992). However, the value of the coefficients varies according to the model, the nature of the data (cross-sectional, time series, panel, short or long term) and the country (Hanly and *al.* 2002; Holmgren, 2007).

Bresson and *al.* (2004) have also shown, in the case of public transport, that the elasticity of demand with respect to fuel prices is positive. However, this elasticity is lower than the fare variation elasticity of demand. This has led these scholars to judge that a fare reduction may play a substantial role in increasing public transport use. For Paulley and *al.* (2006), the fare elasticity of transport demand depends on the mode of transport and the period, the fare elasticity for buses being –0.4 in the short term and –1 in the long term. Their values for the metro, were –0.3 in the short term and –0.6 in the long term.

2.2 The income effect

Travel demand is also affected by an income effect. Mogridge (1967) used the distribution of incomes and expenditures to estimate the number of cars there would be thirty years later. However, the values he obtained for the income elasticity and the price elasticity of car demand were criticized by Evans (1970) on the grounds that they did not take account of inflation.

Dargay and Hanly (2002), and Bresson and *al.* (2004) have shown there to be a negative relationship between the number of bus trips and income level. Conversely, they have shown there to be a positive relationship between income and car use. Economic growth leads, in particular, to higher car ownership rates (Ortuzar and *al.*, 2006).

One of the difficulties of attempting to investigate income is that the effect of income is even more correlated with sociodemographic variables than the effect of the other variables (Garcia-Ferrer and *al.*, 2006). These variables include household size (Lyons and *al.*, 2002) and the economic situation (Gakenheimer, 1999)[3].

The income variable also appears to reveal differences between countries. Dargay and Gately (1999) have shown, in connection with total vehicle stock and the economic development of different countries, that the rise in car ownership rates linked to rising *per capita* income, is greater the faster the country's economy is growing (as, for example, in South Korea and Taiwan). Button and *al.* (1993), paying particular attention to the lowest-income countries, have shown that car ownership rates become increasingly sensitive to income as these rates and income increase. However, while the stock of vehicles is dependent on *per capita* income levels,

[3] With regard to this issue see also Cameron et al. (2003) and Holmgren (2007).

the level of market saturation varies according to the country with reference, in particular, to the user cost of the vehicle (Medlock and Soligo, 2002).

In order to consider the effect of income on travel practices, Schafer and *al.* (2000) bring in the concept of Travel Time Budget (TTB) developed by Zahavi (1973) and Roth and Zahavi (1981). Zahavi shows that “on average, humans spend a fixed amount of their daily time budget travelling”, the travel time budget (TTB). Moreover, the per traveler travel time budget is typically higher for the lowest incomes (Roth and Zahavi, 1981). Over a wide range of income levels, Schafer and *al.* have made the assumption that the travel time budget was stable. However, they make it clear[4] that although the travel time budget remains constant on average, more detailed analysis may reveal a large number of variations. In the case of data for 1960-1990 for 11 regions, Schafer and *al.* have also shown that in those groups of countries with the highest incomes, such as North America and Europe, income and travel increase in the same proportions. However, more detailed analysis reveals significant differences between these groups: for example, with a *per capita* income of $10,000, *per capita* travel in European countries attains only 60% of the level in North American countries. This difference reflects differences in infrastructure, urban density, population, and the user cost of transport modes. Similar cross-country differences in travel behavior have also been highlighted by van de Coevering and Schwanen (2006).

2.3 The quantity effect

Mogridge (1967; 1989) has shown that demand is also affected by quantity. This is assessed on the basis of available quantities of goods and services, measured in terms of the number of car trips, car ownership rates (Jansson, 1989) and the number of passenger-seat kilometers (Bresson and *al*., 2004).

More generally, an increase in the amount of a good that is available (cars or public transport) has a positive impact on demand. For the period between 1975 and 1995, Bresson and *al.* (2004) have shown that the reduction in public transport use was principally due to rising car ownership, although this effect has diminished over time with the slowing of the rate of increase in car stocks.

The quality of public transport, in terms of frequency, speed, network density and network access time has also been investigated (Vande Walle and *al.*, 2006; Wardman, 2004; Paulley and *al.*, 2006). The results nevertheless show that improvements in the quality of public transport ultimately result in a very limited increase in demand (Bresson and *al.*, 2004).

2.4 The spatial effect

Lastly, urban travel demand is affected by spatial factors. Kain and Fauth (1977) have considered urban development as measured by the population density in each zone and the socioeconomic characteristics of the households and the location of their jobs and residences in order to explain their modal choice. Dargay and Hanly (2004) have highlighted the need to consider the relationship between transport and the use of space. For Small and Verhoef (2007), travel decisions are influenced by the density of buildings and the type of activity.

[4] Page 174.

Button and *al.* (1993) have demonstrated that there is a positive relationship between car ownership rates and the level of urbanization. But this relationship applies only up to a point. Beyond this point, the infrastructure becomes so saturated that the higher the urban density the more car use, car ownership rates, the number of trips and energy consumption are reduced (Camagni and *al.*, 2002).

Paulley and *al.* (2006) have shown that demand for bus transport depends on the residential zone. Individuals who live in rural zones with low population densities tend to be more dependent on car relying less on public transport, than those living in urban zones. The fare variation elasticity of bus travel in the English counties was calculated as –0.51 in the short term compared with –0.21 in metropolitan zones.

As Crane (2000) has reported, it remains difficult to identify how the use of urban space impacts on travel practices. Furthermore, Handy (1996) has shown that the urban activities mix has a negative effect on car use, while emphasizing the complexity of this finding. This complexity is also apparent when we consider the form of the city, even if a polycentric structure seems to result in lower energy consumption by traffic. This scholar shows, for example, that the larger the city the longer individuals' journeys, but the size of the city does not seem to have a direct effect on modal choice.

The user cost of a given transport mode, income and the available quantities of goods and services have therefore become classical structural variables for estimating urban travel demand. Current practice is also to consider spatial variables when making estimates, but it seems easier to use urban density as a variable than urban form or the distribution of urban functions. However, variables that describe the quality of public transport services seem to have less of an effect on demand. Last, some questions about possible differences in travel practices between groups of countries remain unanswered.

3. The urban travel demand estimation model

3.1. The data

Even if the data were collected rather long ago (1995) and have been the subject of some criticism (voiced again by van de Coevering and Schwanen, 2006), the data in the IUTP database allow us to make international comparisons as regards demography, urban structure, the economy and the transport system for 100 of the world's cities[5] (Bonnafous, 2003; Joly and *al.* 2006). What we are setting out to do is to model the structural determinants of demand with a robust method and not to estimate future travel demand.

In addition, as changes in behavior take time and we are considering the long term, we are quite able to use data that are not very recent.

[5] Lille, Lyon, Marseille, Nantes, Paris Glasgow, Manchester, Oslo, Bologna, London, Hambourg, Geneva , Athens, Newcastle, Rome, Ruhr, Turin, Brussels, Stockholm, Milan, Helsinki, Barcelona, Zurich, Stuttgart, Copenhagen, Berlin, Frankfurt, Dusseldorf, Graz, Berne, Vienna, Munich, Madrid, Amsterdam, Moscow, Warsaw, Budapest, Prague, Cracow, Istanbul,Lisbon, Houston, San Diego, Phoenix, Atlanta, Denver, Los Angeles , Chicago, Calgary, San Francisco, Washington, Vancouver, Ottawa, New York, Montreal, Toronto, Perth, Wellingtom, Brisbane, Sydney, Melbourne, Sapporo, Singapore, Osaka, Tokyo, Hong Kong, Curitiba, Salvador, Mexico City, Sao Paulo, Rio de Janeiro, Bogota, Santiago, Buenos Aires, Brasilia, Caracas, Cape Town, Johannesburg, Cairo, Casablanca, Abijan, Harare, Tunis, Dakar, Riyadh, Tel Aviv, Tehran, Kuala Lumpur, Taipei, Ho Chi Minh City, Seoul, Bangkok, Jakarta, Delhi, Beijing, Guangzhou, Manila, Chennai, Mumbai, Shanghai.

Last, as we have identified estimation problems for walking and bicycle trips[6], we shall only consider private car and public transport.

3.2. The demand function

Based on the above literature review, we shall select the following general form for the travel demand function, which is denoted by *D*:

$$D = f(p_{CAR}, p_{PT}, q_{CAR}, q_{PT}, I, d_U)$$

Where p_{CAR} is the cost of the private car, p_{PT} is the cost of public transport, q_{CAR} is the available quantity of car travel, q_{PT} is the available quantity of public transport, I is the income, d_u is the urban structure.

This breaks down into car travel, denoted by D_{CAR}, which is measured by the number of daily car trips *per* person and public transport travel, denoted by D_{PT}, which is measured by the number of daily public transport trips *per* person:

Car travel $D_{CAR} = f(p_{CAR}, p_{PT}, q_{CAR}, I, d_u)$

Public Transport travel $D_{PT} = f(p_{CAR}, p_{PT}, q_{PT}, I, d_u)$

The explanatory variables break down as follows:

- the cost of the car (p_{CAR}) which is the average user cost of a car trip; the cost of public transport (p_{PT}) which is the average user of a public transport trip[7],
- the available quantities (q_{CAR}, q_{PT}) which are respectively the length of the roads[8] for 1,000 inhabitants divided by the area of the city and the number of in-service *per capita* public transport vehicle kilometers divided by the surface area of the city,
- the income (I) which is estimated on the basis of the *per capita* urban GDP,
- the urban structure (d_u) which is derived from the urban density.

As the database does not contain an income variable, we have used the urban GDP[9] to give an idea of the standard of living in the city in question. Furthermore, the absence of data that have been purchasing power parity adjusted means there is a major bias in the comparison between the cities. The differences in pricing levels and variations in exchange rates have not been eliminated. This bias may explain why some of the collected data are so surprising. For example, in 1995, the GDP for Paris was almost twice that of London ($41,000 compared with $22,300)[10].

[6] No Madrid resident uses a bicycle at all, and walking accounted for 38% of trips in Paris in 1995 ! However, in 1994, the French Ministry of Transport estimated that walking accounted for 23% of trips in Greater Paris (D.A.E.I.-S.E.S., 2004).

[7] The IUTP database does not contain origin-destination data as are used in conventional traffic assignment or geographic distribution models (Ortuzar and Willumsen, 2006). We therefore do not know the exact length of a trip in terms of distance. The car cost that is considered is the "average user cost of a car trip", which is given for a reference trip that corresponds to an average annual mean travel distance that includes weekends (Vivier, 2001, p.7).

[8] This unit was used by Cameron and al. (2003, p.272), Mogridge (1989, p.69). Jenelius (2009) also relates it to the surface area of the city.

[9] Data were converted to 1990 US $ but not in purchasing power parity. See the explanation given by Kenworthy and Laube (p.699, 1999) and our criticism in the rest of this paper.

[10] When the pound dropped out of the European Monetary System, it was greatly undervalued compared to the German Mark to which the French currency was bound. British prices fell by 73% in relation to French prices in 1995 (CEPII, 2002).

Finally, we have made the hypothesis that estimated demand is satisfied by the available supply.

3.3 The estimation method

By treating the regression function coefficients as elasticity coefficients, we estimated a *log-log* relationship between travel demand (by car and public transport) and the explanatory variables of price, quantity, income and urban structure. This logarithmic transformation also has the benefit of reducing the risk of heteroskedasticity (Greene, 1993; Bourbonnais, 2004; Maddala, 2008[11]) although it does not completely eliminate it. As stated by Maddala (2008, p. 199), to estimate a regression model: "One of the assumptions we have made is that errors u_i in the regression equation have a common variance σ^2. This is known as the homoskedasticity assumption. If the error does not have a constant variance, we say they are heteroskedastic" (Maddala, 2008, p.199). Thus, heteroskedasticity means that the model is not convergent[12], which makes it less robust.

To estimate the model's unknown parameters, we first of all used the Ordinary Least Square (OLS) method. But multiple regressions that include some or all of the structural variables are subject to heteroskedasticity problems. To deal with these, we used the Breusch-Pagan test and tHC (Student t heteroskedasticity-consistent test) (Greene, 1993; Maddala, 2008). The Breusch-Pagan test ascertains whether the estimated variance of the regression residues is dependent on the value of the independent variables. Under these circumstances, the results of the two tests must be significant for the model to be retained.

The retained model must also avoid the risk of autocorrelation of the errors between the explanatory variables. To avoid this risk, we have applied the Double Least Square (2SLS) method (Greene, 1993; Maddala, 2008). The 2SLS method makes it possible to identify the instrumental variables which are not correlated with the error term but only with one of the model's explanatory variables, which makes it possible to have an estimator which does not have any bias resulting from the error term.

As we decided to estimate two separate models for the car and public transport, we then examined the relationship between these two models. In other terms, we set out to verify that the residues of the two models do not have some variables in common. If this were the case, it would mean that these variables are not truly residual and that they should be shown more clearly in the model. We shall use the Seemingly Unrelated Regression (SUR) method which tests the autocorrelation of residues between equations (Maddala, 2008). We are therefore concerned with errors correlation in the cross-section units, represented here by the two equations. Following Maddala (2008, p. 579), in the SUR model, "the errors are independent over time but correlated across cross-section units".

As this technique does not change the level of the coefficients, we continued our analysis using the Three Least Square method (3SLS) which combines the 2SLS and the SUR methods (Greene, 1993; Maddala, 2008). This further increases the soundness of our estimations. As has been stated by Cervero and al., (2002, p. 475): "To obtain more efficient estimates, a third stage

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[11] Following Bourbonnais (2004), the basic hypotheses of the *log*-linear model are : $E(\varepsilon_t^2) = \sigma_\varepsilon^2$, the variance of the error is constant (∀t) (hypothesis of homoskedasticity); no collinearity between the explanatory variables; $Cov(x_{it}, \varepsilon_t) = 0$, the error is independent from the explanatory variables (no correlation between the explanatory variables, i.e. no multicollinearity), $E(\varepsilon_t, \varepsilon_{t'}) = 0$ when t ≠, the errors are not correlated (i.e. independent).

[12] Thus, the larger the sample size the more the model diverges.

of estimation was introduced that explicitly accounted for the cross-equation correlation of error terms as well as, unlike 2SLS, the presence of a right-hand side endogenous variable". In the three-stage technique, all the exogenous variables were used as instruments in estimating the endogenous variables. It is important to note that the use of these methods in addition to the OLS method does not result in major differences between the values of the coefficients.

As we have seen from the literature survey, there appear to be cross-country differences in travel behavior. We have therefore checked whether the creation of groups of countries with different travel practices produces instability in the selected models. To do this, we have compared our reference model, constructed for all the countries in the database with other models, constructed using subgroups of countries (North American, Developed Asian, European and other countries).

The following subgroups were constructed[13]:

- a "North American countries" group with a high level of economic development, low urban density and travel dominated by car trips;
- a "developed Asian countries" group with a high level of economic development, high urban density and considerable public transport use;
- a "European countries" group with a high level of economic development whose position is between that of the North American and Developed Asia groups with regard to urban density and modal split;
- an "other countries" group which gathers together all the other countries and whose characteristics are more difficult to identify.

We then applied a Chow test. This is a predictive test for stability as it tests the stability of the regression coefficients for the models (Maddala, 2008, p. 173-176 and p.313-316)[14]. It can be expressed as follows: is there a significant difference between the sum of the squares of the residues of all the countries and the addition of the sum of the squares of the residues calculated for the subgroups of countries?

This exercise nevertheless has limitations due to the small size of the sample for each of the subgroups (about twenty countries) and the rejection of urban GDP as a variable. As will be seen, it was necessary to abandon urban GDP when the differences in travel behavior could be explained by differences in income or development between the countries.

4. Results and the estimation of demand

4.1. Private car travel demand

For car travel, the results of regression with the OLS method show that the richer the city and the more roads it possesses, the higher the level of car travel. Conversely, high urban density and a high average user cost for car travel appear to limit car travel severely (see Table 1).

Table 1 :OLS Estimation of car travel for all the structural variables

	~ Log (p_{CAR})	~ Log (d_u)	~ Log (p_{PT})	~ Log (I)	~ Log (q_{CAR})

[13] See Bernick and Cervero (1997).

[14] Maddala (2008, p. 173-176) gives the following example: F-test = 0.80, thus at the 5% level we do not reject the hypothesis of stability ; F-distribution = 2.57, from the F-tables with df=15 and 11, we see that the 5% point is 2.72, then we cannot reject the hypothesis of stability of the coefficients.

Estimate	-0.74303	-0.6373	-0.40721	0.45298	0.14847
Std. Error	0.05819	0.0591	0.09826	0.04758	0.05577
t-value	-12.77	-10.78	-4.144	9.520	2.662
Pr(>|t|)	<2e-16 ***	<2e-16 ***	8.25e-05 ***	6.66e-15 ***	0.00934 **
(intercept)					
Estimate	*4.14507*	*2.7385*	*1.73620*	*-0.96009*	*-0.13989*
Std. Error	*0.30974*	*0.2379*	*0.36951*	*0.13753*	*0.16119*
t-value	*13.38*	*11.51*	*4.699*	*-6.981*	*-0.868*
Pr(>|t|)	*<2^{e}-16 ****	*<2e-16 ****	*1.04e-05 ****	*6.98e-10 ****	*0.38802*
Multiple R Squared	0.6654	0.5865	0.1732	0.525	0.07956
Adjusted R squared	0.6613	0.5814	0.1631	0.5192	0.06833

*Signif. codes: 0 '***' 0.001 '**' 0.01*

Moreover, and in contradiction with McFadden's first research, private car travel seems to decrease when the average cost of a public transport trip increases. Nevertheless, it is true that the context has changed and that McFadden was only concerned with the inhabitants of San Francisco Bay. At the time he was dealing with, 1970, the markets for cars and car travel were growing. This development was primarily an American phenomenon as has been shown by Dargay and Gately (1999, p.105): in 1970 the United States was the country with by far the highest car/population ratio or vehicle/population ratio. It retained this position subsequently, but other countries have drawn closer to them and the nature of the automobile market has changed, becoming much less "explosive" (graphic, p.106). In the case we are considering, as travel demand is sensitive to price variations, this negative correlation can be explained by the fact that changes in the price of public transport tend to be similar to changes in the price of transport in general. The existence of a positive correlation between the average user cost of a car trip and the user cost of a public transport trip (estimated value coefficient: + 0.5305, *t-value*: 5.143) supports this explanation. However, at the time McFadden did not test the correlation between the user cost of the car and public transport.

The car travel model which is not affected by heteroskedacity contains only two of the five structural variables: the average user cost of a car trip and urban density (Table 2). Unsurprisingly, the results show that car travel is greater when the average user cost of a car trip and the urban density are low. The value obtained for the elasticity of demand for car travel with respect to the user cost of a car is consistent with that obtained by McFadden in 1974 (depending on which model he used, McFadden obtained a value of between –0.32 and –0.47 - see McFadden p. 325 and 327).

The 2SLS method isolates the specific effects of both these variables and thereby completely avoids the problem of autocorrelation. The results are significant, but the estimated value of the coefficients changes: the effect of the average user cost of a car trip falls, while the effect of urban density rises (Table 2). The result for urban density lies within a range between –1.18 and –0.25, which is consistent with Giuliano and Dargay's results (2006, p.118).

Table 2 :The results for the different estimation methods for the car travel model

	Estimation OLS (1)		Estimation 2SLS (2)		Estimation 3SLS (3)	
	Log (p_{CAR})	Log (d_u)	Log (p_{CAR})	Log (d_u)	Log (p_{CAR})	Log (d_u)
Estimate	-0.52185	-0.39080	-0.8623	-0.2300	-0.521847	-0.390797
Std. Error	0.04920	0.04495	0.2132	0.1118	0.049196	0.044947
t-value	-10.607	-8.695	-4.045	-2.057	-10.60744	-8.69459
Pr(>|t|)	< 2e-16 ***	3.19e-13 ***	1.189^{e}-04	4.292e-02	0 ***	0 ***
*t*HC	-9.772747	-7.050781	-	-	-	-

	(1)	(2)	(3)
(intercept)			
Estimate	*4.51598*	*5.6756*	*4.51598*
Std. Error	*0.22816*	*0.7520*	*0.228164*
t-value	*19.793*	*7.547*	*19.792655*
Pr(>|t|)	*< 2e-16 ****	*5.813e-11*	*0 ****
tHC	*15.879866*	-	-
Breusch-Pagan test	BP = 19.2, p-value = 6.827e-05, df =2		
Multiple R square	0.8269		0.826908
Adjusted R square	0.8226		0.822634

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 (1) Residual standard error: 0.3116 on 81 degrees of freedom, F-statistic: 193.5 on 2 and 81 DF, p-value: < 2.2e-16 (2)* Residual standard error: 0.3931 on 81 degrees of freedom *and Instrumental Variables: ~ log (d_u) + log (SURF) + log (DISTCAR) (3)* Residual standard error: 0.311628 on 81 degrees of freedom, Number of observations: 84 Degrees of Freedom: 81, SSR: 7.866068 MSE: 0.097112 Root MSE: 0.311628, *Instruments: ~ Log (p_{CAR}) + Log (d_u)+ log (DISTCAR) + log (SURF)*

4.2. Public transport travel demand

OLS regression of public transport demand reveals the following: while public transport travel is encouraged by an increase in the average user cost of a car trip, the urban density or *per capita* public transport supply, it is reduced by an increase in the user cost of public transport and a reduction in urban GDP (Table 3).

Table 3 :OLS estimation of public transport travel for all the structural variables

	~log (p_{CAR})	~ log (p_{PT})	~log (I)	~log (d_u)	~ log (q_{PT})
Estimate	0.3546	-0.2228	-0.05216	0.49432	0.33690
Std. Error	0.1102	0.1232	0.08003	0.09181	0.04247
t-value	3.219	-1.810	-0.652	5.384	7.933
Pr(>|t|)	0.00184 **	0.074	0.516382	6.78e-07 ***	9.48e-12 ***
(intercept)					
Estimate	*-2.8478*	*-0.1610*	*-0.84446*	*-2.92330*	*-0.62409*
Std. Error	*0.5863*	*0.4631*	*0.23131*	*0.36954*	*0.08414*
t-value	*-4.857*	*-0.348*	*-3.651*	*-7.911*	*-7.417*
Pr(>|t|)	*5.63e-06 ****	*0.729*	*0.000459 ****	*1.05^e-11 ****	*9.84^e-11 ****
Multiple R Squared	0.1122	0.0384	0.005154	0.2612	0.4342
Adjusted R squared	0.1014	0.02667	-0.006979	0.2522	0.4273

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

However, the Student test shows, unexpectedly, that urban GDP is not significantly correlated with levels of public transport travel (*t*-value: -0.652). This result confirms our doubts about the way this variable has been constructed in the IUTP database and leads us to exclude it from the model. Use of purchasing power parity adjusted urban GDP seems to be a better indicator of a conurbation's wealth as it provides a better comparison because it eliminates differences in price levels and exchange rates between cities. However, it was not this variable which was used in the database.

Once we have excluded urban GDP, the model that remains correlates public transport travel to the three following variables: the rise in the average user cost of a car trip, urban density and the reduction in the user cost of public transport (Table 4).

The results from the 2SLS method are significant in all cases, but lead to considerable changes in the values of the coefficients (Table 4). The new elasticity coefficients show an increase in the influence of the user cost of the car and public transport and reduction in the influence of urban density. The value of the coefficient for the elasticity of public transport demand with respect to user cost of a car (+0.91) thus becomes almost identical to that identified by McFadden in 1974 (depending on the model McFadden used, he found a value between +0.81 and +0.97 - see McFadden p. 325 and 327). Moreover, Bresson and *al.* (2004, p.274) have estimated the minimum long term fare elasticity of public transport[15] at –1.56. Our figure, i.e. a fare elasticity for public transport of –1.7 is fairly close to this.

In this estimation, the combined action of the user cost of the car and urban density cannot counteract the negative impact of a rise in the user cost of public transport on public transport travel.

Table 4 :Results of the different estimations for the public transport travel model

	Estimation OLS (1)			Estimation 2SLS (2)			Estimation 3SLS (3)		
	log (p_{CAR})	log (p_{PT})	Log (d_u)	Log (p_{CAR})	Log (p_{PT})	Log (d_u)	Log (p_{CAR})	Log (p_{PT})	Log (d_u)
Estimate	0.35296	-0.52756	0.43146	0.9118	-1.7030	0.3989	0.363881	-0.550524	0.430821
Std. Error	0.11681	0.11040	0.09539	0.3727	0.7057	0.1495	0.115426	0.103772	0.095381
T value	3.022	-4.779	4.523	2.4466	-2.4131	2.6683	3.152505	-5.305133	4.51684
Pr(>|t|)	0.00337 **	7.88e-06 ***	2.09e-05 ***	0.016614	0.018102	0.009227	0.002279 **	1e-06 ***	2.1e-05 ***
*t*HC	1.709982	-2.528109	2.638667	-	-	-	-	-	-
(intercept)									
Estimate	-2.58959			-1.0709			-2.559916		
Std. Error	0.50454			1.1821			0.502191		
T value	-5.133			-0.9059			-5.097497		
Pr(>|t|)	1.96e-06 ***			0.367705			2e-06 ***		
*t*HC	-3.993859			-			-		
Breusch-Pagan test	BP = 10.5268, p-value =0.01458,			Df =3					
Multiple R Squared	*0.4306*						*0.430252*		
Adjusted R squared	*0.4092*						*0.408886*		

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 (1) Res. standard error: 0.661 on 80 degrees of freedom, F-statistic: 20.16 on 3 and 80 DF, p-value: 7.93e-10 (2) Res. standard error: 1.0276 on 80 degrees of freedom,* Instr.: ~ log (p_{CAR}) + log (LGROADH) + log (SURF) + log (d_u) (3) Res. standard error: 0.661175 on 80 degrees of freedom, Number of observations: 84 Degrees of Freedom: 80, SSR: 34.972213 MSE: 0.437153 Root MSE: 0.661175, Instruments: ~log (p_{CAR}) + log (p_{PT}) + log (d_u) + log (LGROADH) + log (SURF)

4.3. Relationship between the two demand models

The results obtained with the SUR and 3SLS methods in Table 2 and Table 4 do not alter the significance of the results; the new coefficients are very similar to those given by the OLS estimation.

4.4. The stability of demand models

The Chow test is significant for both models (car travel: F-test=0.34 and for public transport travel F-test=0.83)[16]: we therefore do not reject the hypothesis H_0 of the stability of the demand models (Table 5). The stability of the two models shows that the variables that act on mobility are independent of which group a country belongs to.

This result is mainly explained by the fact that we have decided to reject urban GDP as a variable. However, in most cases these differences in travel practices can be explained by cross country differences in income or development.

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[15] Elasticity for the semi-log data for France in the period 1975-1995.

[16] F-test = 0.34, thus at the 5% level we do not reject the hypothesis of stability, from the F-tables with df=15 and 66, we see that the 5% point is 1.84, then we cannot reject the hypothesis of stability of the coefficients. F-test = 0.83, thus at the 5% level we do not reject the hypothesis of stability, from the F-tables with df=24 and 56, we see that the 5% point is 1.79, then we cannot reject the hypothesis of stability of the coefficients.

Table 5 :Chow test results for the two models

Coefficients	Car travel model (1) Estimate	Std. Error	t value	Pr(>|t|)	Public transport travel model (2) Estimate	Std. Error	t value	Pr(>|t|)
p_{CAR}	-0.52502	0.05459	-9.618	-6.85e-15 ***	0.3779	0.1084	3.487	0.000811 ***
d_u	-0.32375	0.06350	-5.098	2.34e-06 ***	0.2975	0.1229	2.421	0.017848 *
p_{PT}	-	-	-	-	-0.3530	0.1151	-3.067	0.002984 **
North American Group	4.42137	0.30869	14.323	< 2e-16 ***	-3.2404	0.6731	-4.814	7.23e-06 ***
Developed Asian Group	4.08017	0.41149	9.916	1.83e-15 ***	-2.2224	0.8757	-2.538	0.013173 *
Group of other countries	4.25635	0.43713	9.737	4.05e-15 ***	-3.1204	0.9340	-3.341	0.001290 **
European Group	4.21887	0.36260	11.635	< 2e-16 ***	-2.5248	0.7535	-3.351	0.001250 **
	F = 0.34 Test de Chow (pf) = 0.012 (df1=15, df2=66) Test de Chow (1-pf) = 0.988 (df1=15, df2=66) Test de Chow (qf 0,95) = 1.82 (df1=15, df2=66)				F = 0.83 Test de Chow (pf) = 0.31 (df1=24, df2=56), Test de Chow (1-pf) = 0.69 (df1=24,df2=56), Test de Chow (qf 0,95) = 1.71 (df1=24,df2=56)			

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 (1) Residual standard error: 0.3071 on 78 degrees of freedom, Multiple R-Squared: 0.8532, adjusted R-squared: 0.8419 , F-statistic: 75.57 on 6 and 78 DF, p-value: < 2.2e-16 , Car mobility model formula ~ log (p_{CAR}) + log (d_u) + groupe - 1 (2) Residual standard error: 0.5828 on 77 degrees of freedom, Multiple R-Squared: 0.8163, Adjusted R-squared: 0.7996, F-statistic: 48.89 on 7 and 77 DF, p-value: < 2.2e-16, Formula for the public transport mobility model ~ log (p_{CAR})+ log (d_u)+ log (p_{PT}) + groupe – 1*

5. Conclusion

To give us an idea of the nature of the city of the future and to foresee difficulties as accurately as possible, we have estimated an urban travel demand model that was constructed using structural factors of travel identified in the literature.

Our findings show that only statistically significant variables are the cost of the transport mode and urban density. Urban car travel increases when the average user cost of a car and the urban density fall. Conversely, an increase in these two variables combined with a reduction in the average user cost of public transport encourages public transport use.

Our results were obtained with a robust by yet rarely used econometric method. They concur with the findings in the literature.

These results plead for combined analysis of transport and space in the context of travel estimation, with, in particular, a consideration of the optimum size of cities, as highlighted by Venables (2007). In order to reduce car use, it is, of course, true that we can wait for an increase in the user cost of the car which will arise partly as a result of a rise in fuel prices. But there are other quantitative or pricing instruments. For example, it is possible to introduce an alternating number plate ban for car use or parking. Another possible solution would be to increase charges on vehicle use, either for parking or with urban tolls (Raux and Souche, 2004). Moreover, this solution would have the double advantage of reducing pollution and providing new revenue for funding public transport.

Finally, with regard to the stability of the model, our results (the Chow test) do not allow us to validate the hypothesis that there is a difference in travel practices between countries according to which of the four groups they belong (North American, Developed Asian, European, other). We have, however, suggested this somewhat unexpected result may be due to the fact that we have not considered GDP in our model. This would highlight the importance of a satisfactory evaluation of the income effect in order to take account of the differences between countries as well as possible.

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