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Demand and revenue implications of an integrated public transport policy. The case of Madrid

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ABSTRACT

One of the most popular options for promoting public transport use is the provision of an integrated and high quality public transport system. This was the strategy adopted by the regional government in Madrid in 1986 and since then public transport patronage has increased by more than 50%. This paper has two objectives. The first is to identify the factors underlying the significant increase in the demand for public transport in Madrid. To do this we estimate an aggregate demand function for bus and underground trips, which allows us to obtain the demand elasticities with respect to the main attributes of public transport services and also to calculate the long-term impact of changes in those explanatory variables on patronage. The second objective is to evaluate the impact on revenue derived from the introduction of the travel card scheme, and to discuss the consequences on revenue of changes in the relative fare levels of different types of ticket without substantially affecting patronage. This latter issue is addressed by estimating a matrix of own and cross-price elasticities for different ticket types.

1. Introduction

In most urban areas, it is increasingly difficult for public transport to compete with the private car. An increase in real income has resulted in a higher level of car ownership and use, and the ongoing process of residential suburbanisation and employment decentralisation experienced in the largest cities has generated a pattern of travel that is more suited to the private car than to public transport. The changes observed in urban travel can be summarised by a growing number of motorised trips as well as an increase in the use of the private car.

In order to reverse this trend, local authorities have implemented several strategies to promote public transport use. The supply of an integrated and high-quality public transport system has been one of the most favoured options. Clear examples of such a policy are the integrated regional public transport systems in Germany, Austria and Switzerland documented in Pucher and Kurth (1996). Integration is a broad concept that includes several issues, such as the co-ordination of service levels, routes and timetables, and a common fare system. This is the strategy adopted by the regional government of Madrid with the main aim of promoting public transport use and shifting demand away from the private car. Since 1986, passenger transport infrastructure and services have been planned as a complete system. The most significant change was the creation in 1987 of an integrated fare system for the whole public transport network based on a travel card. At the same time, the quality of public transport has been improved, mainly through the extension of bus, underground and suburban rail networks. The number of passengers using public transport services has grown from 951 million in 1986 to 1549 million in 2001.

This paper has two objectives. The first is to identify the underlying factors behind the significant increase in public transport demand in Madrid. To do this, we estimate an aggregate demand function, which allows us to obtain the demand elasticities with respect to the main attributes of public transport services and additionally to calculate the long-term impact on patronage of changes in the explanatory variables. The second objective is to evaluate the impact on revenue derived from the introduction of the travel card scheme and to discuss the role of possible changes in relative fare levels for different ticket types in order to increase revenue without essentially affecting patronage. In fact, one of the most important concerns with the travel card is its negative impact on revenue. Theoretical and empirical work on this topic (for instance, White 1981, Doxsey 1984, Carbajo 1988) shows that the final impact will depend on the combination of fare levels for different ticket types, and on user distribution according to rates of use. On this matter, Carbajo (1988) concludes that the potential gains of non-uniform pricing will only be attained if operators depart from arbitrary pricing rules when setting fares for the different ticket types. In order to provide useful information about potential changes in fare structure which reduce the negative impact on revenue, we have estimated a matrix of own and cross-price elasticities for different ticket types.

This paper is structured as follows: section 2 provides an overview of supply and demand in the region of Madrid, section 3 explains the methodology and the data set while section 4 presents the estimation results of the aggregate demand model and the long-term effects of the explanatory variables. Section 5 is devoted, firstly, to the evaluation of the impact of the travel card on revenues and secondly to the estimation of demand elasticities with respect to ticket type. Finally, section 6 summarises the main conclusions.

2. Supply and demand of public transport in Madrid: an overview

The region of Madrid has more than five million inhabitants and is made up of 179 municipalities. About 56% of the people live in the city of Madrid and 44% in the rest of the region. In recent decades, there has been a clear process of suburbanisation; since 1975 the population of the city of Madrid has decreased, while that of the rest of the region has increased. The employment structure is dominated by the service sector, which accounts for 75% of total jobs (of which 35% are in the public sector). This dominance of services implies that so far jobs have remained heavily centralised in the city of Madrid. According to different estimations, around 70% of the jobs are located in the city and most of them in the city centre. The distribution of residential areas and employment centres gives rise to an urban structure that predominantly follows a monocentric model with radial trips from satellite settlements to the city centre. This structure makes Madrid well suited to public transport use.

The public transport supply in the Madrid region is summarised in table 1. Since 1986 the Consorcio de Transportes de Madrid (CTM), a regional public authority, has co-ordinated the services, networks and fares of the different modes of transport operating in the area. The underground company and the urban bus company (EMT) mainly operate within the boundaries of the Madrid municipality. The suburban railway and 357 lines of suburban buses serve the metropolitan area. Since its creation, CTM has been engaged in an active policy of improving the quality of public transport. The most relevant measures include the enlargement of the metro network to the outskirts as well as the improvement of its structure and connections, extension of the urban bus service network, together with better vehicles, significant improvements in the quality of the suburban railway, with more frequent and better trains, and finally an improvement in metropolitan buses and underground connections.

Table 1. Public transport supply and demand in the region of Madrid. 2001

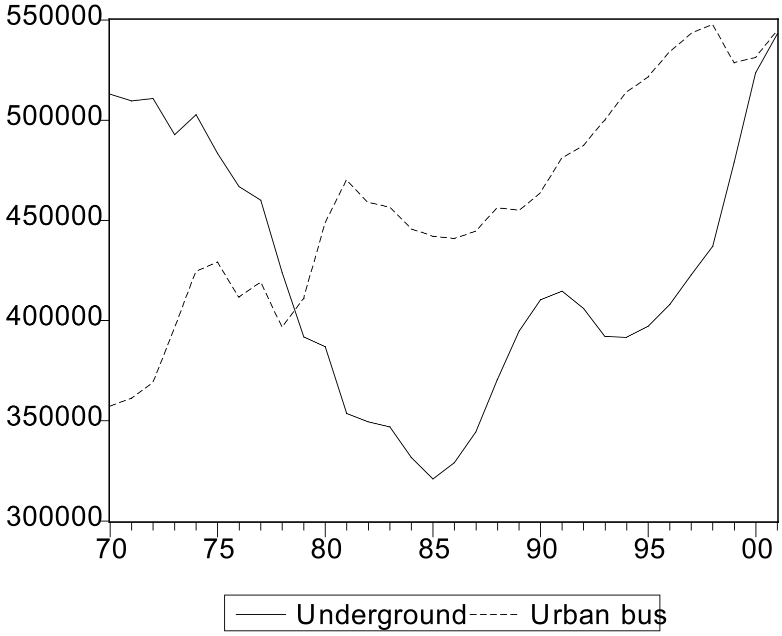
Operators	**Route length (km)**	**Vehicle*km (10^6)**	**Trips (10^6)**
Underground	171	122.4	543.0
Urban buses (EMT)	1531	95.9	544.7
Suburban rail	311	86.7*	176.5
Suburban buses	3345	135.9*	284.9

* Data for 2000
Source: Consorcio Transportes de Madrid

The annual number of trips is split among the different modes of transport as follows: underground 35%, urban bus 35%, rail 11% and suburban buses 19%. Unfortunately, it is not possible to obtain a homogenous time series for the suburban railways and buses. That is why the demand analysis will be based hereafter on data from the two main transport companies, underground and urban buses, which account for 70% of the market.

The trend in urban public transport patronage is shown in figure 1. Since the mid seventies until 1985 the number of passengers decreased continuously, with patronage falling from 927 million trips in 1975 to 763 million in 1985. This decrease has been much more significant for the underground. The increase in bus passengers between 1979 and 1981 can be explained by the fact that the urban bus company (EMT) took over several private bus companies operating in the area. In sharp contrast to this, from 1986 until the present the trend has been reversed and patronage rose to 1088 million trips in 2001. Therefore, a remarkable increase in public transport use of more than 40% was observed. The turning point in demand coincides with the creation of the CTM but also with the recovery of the Spanish economy from a severe economic crisis. A significant part of this increase is attributed to the development in 1987 of an integrated fare scheme covering all modes of public transport in the region. The system is essentially based on a monthly travel card that permits unlimited travel across the entire network. Prices are set according to a zonal structure based on concentric rings around the central area[1]. After the introduction of the new fare scheme, passengers could choose between three different ticket types: ordinary tickets, multi-ride (ten-trip) tickets and a travel card[2].

Figure 1. Trips by public transport in Madrid (thousands)



The economic effects of travel passes have received substantial attention in the transport literature. With respect to the effects on passengers, (our main variable of interest), most studies agree that the introduction of a differentiated price scheme provides benefits to users[3] such as fare discounts (the average cost per trip is lower), reduction of interchange penalties and reduction in boarding and queuing time. Also, once the pass is purchased, it permits travel at a zero marginal cost. Therefore, the most likely impacts

[1] A more detailed explanation of this system is found in appendix 1.
[2] In appendix 2, the fare structure for bus and underground services is explained in more detail.
[3] White (1981) presents a detailed enumeration of the benefits of travel passes to operators, passengers, local authorities and employers.

of the travel card will be an increase in the number of trips made by previous travellers and a high probability of attracting new users. On the other hand, substitution of other ticket types may also be observed. Frequent users will change from single tickets to travel cards as soon as they find them worthwhile.

A preliminary analysis of data in Madrid shows that patronage has increased at an annual rate of 2.2% whereas significant changes in the share of each ticket type have occurred (table 2).

Table 2. Demand composition by ticket type. 2001

	Bus		**Underground**	
	1987	2001	1987	2001
Single	27.4%	4.3%	47.7%	4.5%
Multi-ride	56.8%	23.8%	36.7%	35.0%
Travel card	15.7%	71.9%	15.5%	60.4%
Ordinary	-	43.1%	-	47.0%
Young	-	14.1%	-	9.2%
Elder	-	14.7%	-	4.2%

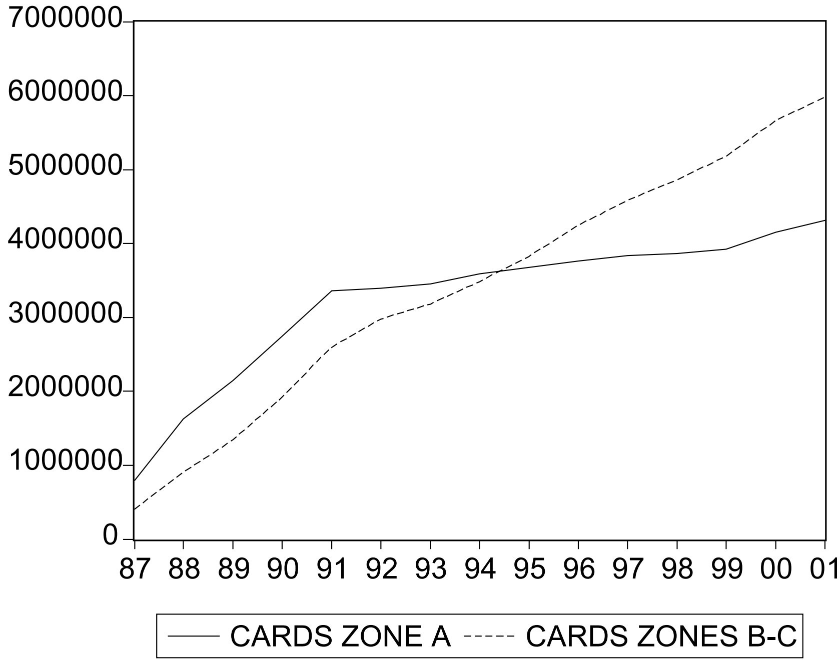
Source: Consorcio Transportes de Madrid

The use of single tickets has fallen to just over 4% for both modes of transport. It can also be observed that, the market share of multi-ride tickets among bus users dropped from 57% to 24% whereas in the case of the underground it has remained almost constant. This difference can mainly be explained by the fact that bus transfers are penalised in monetary terms whereas underground transfers are free; this implies that the break-even ratio between multi-ride ticket and travel card is lower for bus users. The market share for travel cards in 2001 exceeded 60%, which was the target figure when the integrated fare system was introduced. It is also interesting to note that there is a higher proportion of concessionary trips among bus users than among underground users. Such an extensive use of the travel card is not surprising. Following White's (1981) arguments, in those areas where flat fares are applied, as soon as a travel pass is attractive to the regular passenger a large proportion of users will also find purchasing it worthwhile. The market share of travel cards in Madrid is comparable with that of other cities in which there is a long tradition of travel passes. In Stockholm, travel passes represent on average 82% of all trips (Tegner et al. 1998), while there are figures of

92% in Vienna, 78% in Hamburg, 78% in Rhein-Ruhr, 54% in Zurich and 50% in Munich (Pucher and Kurt 1996).

In 2001, more than 13 million monthly travel passes were sold, of which 63% corresponded to ordinary holders, 16% to young holders and 21% to senior citizens[4]. Use of travel cards valid for two or more zones has increased at a higher rate than for those valid only for the central zone. Figure 2 shows that from 1987 to 1990 both series behave similarly, but after this date, the use of travel cards for zones B and C increased more sharply. This increase is explained by several factors, three of which are; firstly, the process of residential suburbanisation in the Madrid region; secondly, the improvement in the quality of the suburban rail and suburban bus services; and thirdly, the economical incentive that the travel card entails for long distance travellers. Travel cards valid for zones B and C are mainly used for radial trips, Madrid being the major attraction centre[5].

Figure 2. Number of monthly cards according to the zones



[4] In order to calculate the total number of cards sold, the annual cards are converted into monthly cards.
[5] For a review of the characteristics and effects on mobility of the tariff integration policy see Echevarría-Jadraque and Martínez-Sanchez (1997).

3. The model and data

3.1. Model specification

To explain the increase in public transport patronage in the city of Madrid, a demand model for bus and underground services is estimated. Two different equations are estimated, allowing for substitution effects between the underground and the bus. Ideally, in order to properly account for relationships of complementarity and substitutability, a complete system of demand equations should be estimated. Unfortunately, the lack of data on car usage makes such an analysis impossible.

This study relies on time series data. Therefore, the estimated equations should be interpreted as aggregate demand functions. It is well known that the aggregate demand function is based on certain restrictive assumptions about consumer behaviour. Nevertheless, it allows for an approximation of the behaviour of an aggregate group of individuals and is useful for given purposes. In our case, the estimation of an aggregate demand equation allows us to offer an approximation of the underlying factors behind changes in transport demand and to the corresponding demand elasticities.

The demand for transport services can be assumed to depend on the attributes of each mode, the competing modes of transport and on the socio-economic characteristics of the population. The competing modes considered as feasible transport alternatives in the city of Madrid are bus, underground and car[6]. The relevant characteristics that define the modes of transport are basically monetary costs and quality of service variables. Monetary cost for public transport modes has been approximated by a fare index explained below in section 3.2. In order to estimate cross-price elasticities between transport modes, both bus and underground fares should be included as explanatory variables in each demand equation. However, the evolution of the changes in bus and underground fares was increasingly similar over the period 1981-1989 and has been exactly the same since 1990. The high correlation index for these two variables (0.97)

[6] For those travelling outside the city of Madrid, suburban rail and suburban buses become relevant options. Unfortunately, no data is available for supply characteristics of these modes of transport for a long enough period.

has precluded including both variables in the equation. Therefore, only the own mode fare enters the equation and elasticities should be interpreted as conditional (for equi-proportional fare changes). Monetary cost of car use is approximated by the price of petrol. All monetary costs are deflated by the Retail Price Index (RPI).

Service quality variables are limited by the aggregate nature of the data and by the time period considered. In this study, service quality is captured by route length for both the bus and the underground. Alternatively, the commonly used measure of vehicle-kilometres was tested. However, it was discarded because from 1982 until 1989 the bus company undertook a process of route rationalisation with the aim of reducing spare bus kilometres without essentially affecting the quality of the service. Additionally, other variables such as the average speed of buses and average frequency were tested but none of them showed to be significant and were therefore omitted.

A dummy variable was included to take into account the full development of the integrated fare scheme. As explained in appendix 1, the travel card was first introduced in 1987 and subsequently expanded. In 1988 concessionary passes and annual travel passes were created and in 1989 the system was extended to its present limits. Accordingly, a step dummy variable was introduced that takes value 0 before 1987, 0.33 in 1987, 0.66 in 1988 and 1 thereafter.

Transport demand depends on the socio-economic and demographic characteristics of the area. The variables considered are: population, suburbanisation index, employment level, income and car ownership. Due to the lack of data on regional household disposable income before 1986, this variable has been approximated by real GDP (Gross Domestic Product) in the Madrid region. Although underground and urban bus services operate mainly in the city of Madrid, the catchment area is the Madrid region. For this reason, all variables refer to a regional level. As expected, there is a high correlation between GDP and car ownership (0.99). In fact, car ownership positively depends on income per capita. Our decision was to include only GDP as an explanatory variable, bearing in mind that it expresses the effects of both variables; a positive effect which reflects the increase in activities and therefore mobility, and a negative effect of an increase in car ownership.

The demand equations can be expressed as follows:

$$Y_{it} = h(f_{it}, c_t, r_{it}, d_t, p_t, s_{t,} e_t, g_t) \tag{1}$$

where,

i= bus, underground

Y_{it}=passenger trips in mode i and period t

f_{it}=fare index in mode i and in period t

c_t= private car fuel costs in period t

r_{it}=route length in mode i and period t

d_t=dummy variable that reflects the change in fare structure

p_t=population in period t

s_t=suburbanisation index in period t

e_t=employment level in period t

g_t=real GDP in period t

The demand equations are estimated using a double log specification. As is well known, this functional form is often criticised for the constant elasticity assumption[7]. However, the double log form has the advantage of permitting a clear interpretation of the corresponding coefficients in terms of elasticities. The assumption of the constant elasticity model was tested by the estimation of both a linear specification and a semi-log specification. The selection among these alternative functional forms was based on their goodness of fit. The results showed that the double-log was statistically the best option[8]. Additionally, the reliability of the selected model was evaluated according to the usual econometric practice, testing the lack of disturbance autocorrelation (if the functional form were mis-specified this would be manifested in autocorrelation of the disturbances) and the structural constancy of coefficients, using recursive estimation techniques. On this basis, the model is not rejected by the data. Therefore, we consider that the double logarithmic specification offers an adequate approximation, at least in the neighbourhood of actual data.

[7] Additionally, the adding-up restriction is not fulfilled by the double-log specification. However, this problem is less severe when it does not apply to a complete system of equations. In this case, the double-log functional form can be defended at least for a restricted range of data.

[8] The criterion used was based on the likelihood function according to the Box-Cox (1962) suggestion.

The demand equation is estimated in levels[9]. To allow for dynamic effects, the starting specification includes lags of the dependent and the explanatory variables. The search for the final specification followed a general to specific process. After simplifying the model with restrictions that were not rejected by the data, a partial adjustment equation was selected. Lagged explanatory variables were not significant and do not appear in the final model. The equations to be estimated can therefore be expressed as follows:

$$\ln(Y_{it}) = \alpha + \beta_{1i}\ln(f_{it}) + \beta_{2i}\ln(c_t) + \beta_{3i}\ln(r_{1t}) + \beta_{4i}\ln(r_{2t}) + \beta_{5i}\ln(d_t) + \beta_{6i}\ln(p_t) + \beta_{7i}\ln(s_t) + \beta_{8i}\ln(e_t) + \\ + \beta_{9i}\ln(g_t) + \gamma_i \ln(Y_{it-1}) + \varepsilon_{it} \qquad (2)$$

3.2. The data

Demand equations are estimated using annual data for the period from 1979-2001. Although passenger data has been compiled since 1970, the breaks in the series in the years leading up to 1979 preclude the possibility of extending the analysis[10]. Demand has been measured as the number of registered trips. A trip is registered every time a mode of transport is boarded and so two links of the same journey are counted as two different trips. This is so except for transfers between underground lines. Data on alternative and more consistent measures of demand is not available[11]. Table 3 shows the percentage variation in bus and underground passenger trips that has already been commented in section 2.

[9] In order to select between estimating in levels or in differences, we estimate the static equation in levels and given that the D.W. statistic showes no autocorrelation among the error terms we proceed with the demand model specified in levels. Given the low number of available observations the application of formal unit roots and cointegration test is not advisable.

[10] Different corrections need to be made to the passenger data in order to construct a homogenous time series. The most important one is the correction of the effect of strikes in 1990, 1991 and 1992 according to the companies' own estimations.

[11] The way trips are registered inflates the number of passengers using buses with respect to those using the underground. The use of the total number of trips as the measure of demand can introduce distortions in the historical time series if the total number of transfers per trip has changed over time. This might well be the case when demand shifts from single tickets to travel cards.

Table 3. Percentage growth of the variables in the model

	1979-1986	1986-2001	1979-2001
Trips			
Bus	7.2	23.6	32.5
Metro	-16.0	65.0	38.6
Fare index			
Bus	19.7	21.0	44.8
Metro	73.5	19.2	106.8
Route length			
Bus	17.9	21.9	43.8
Metro	57.4	57.4	147.8
Vehicle-km			
Bus	-	15.2*	-
Metro	11.6	51.8	69.5
Fuel price	-10.9	-5.0	-15.3
Population	4.1	12.4	17.0
Suburbanisation	19.5	24.8	49.1
Employment	0.0	50.2	50.2
Real GDP	22.5	62.9	100.3

* 1989-2001

An aggregate price index has been constructed trying to properly reflect both changes in fare levels and structure. This is not a straightforward task when several ticket types are in use. The alternative chosen here is similar to that used by London Transport (1993). The fare index is a weighted average of the changes in individual ticket prices, where the weights used are the number of trips made using each ticket in the base period. This index measures the changes in fares that would result if people's ticket buying behaviour were unchanged after the revision. A problem arises when a new ticket type is introduced, as was the case in 1987 with the introduction of the travel card scheme. The solution adopted was to use the change in average revenue as an approximate measure of the fare change in that particular year[12]. According to this index, real fares increased markedly over the whole period and particularly for the underground between 1979 and 1986. It has to be mentioned that the fare's level in the starting year was very low. Moreover, since 1987, frequent users could switch to the travel card, which permitted travel at a lower price per trip. The noticeable increase in bus and mainly underground route length shows the active policy followed to promote public transport.

[12] Different alternative solutions were tried with no significant effect on the estimated coefficients of the demand equation.

The population in the Madrid region has risen at an annual rate of 0.7%, although its growth rate is higher after 1986. This growth is the result of a steady decrease in the population of the city of Madrid, which is compensated by a larger increase in the rest of the region. This change in residential population is reflected by the continuous increase of the suburbanisation index, which is the ratio of population in the rest of the region to the total population. Annual increase in GDP was lower in the first period, although economic recovery started in 1985. Finally, with respect to the employment level it has to be noted that there has been a significant increase since 1986, after 11 years of severe economic crisis. Figure 3 shows the clear synchronisation between employment and the demand for the underground with a correlation coefficient equal to 0.96.

Figure 3. Underground passenger trips (thousands) and employment in Madrid region

4. Estimation and results

4.1. Demand equations and elasticities

The equation system has been estimated by applying the seemingly unrelated regression (SUR) method, instead of ordinary least squares (OLS), in order to take into account contemporaneous correlation in the errors across equations and therefore to increase efficiency. It is very likely that some factors not included in the equation may affect both bus and underground patronage. It therefore seems reasonable to allow correlation of the disturbance across modes of transport.

The general model estimated according to equation 2 is presented in table A.1 in the appendix. In the bus equation, the coefficients related to the characteristics of the modes of transport have the expected sign and have been estimated with a high degree of reliability. In the underground equation only its own attributes appear as significant. In both equations the coefficients of the socio-economic variables are estimated with high standard errors (as a result of the high degree of multicollinearity observed among them[13] and the relatively small sample size) and none of them appear to be clearly significant. In order to increase the efficiency of the estimates we proceed by excluding some of the non-significant variables from the equation. We should consider that some of these variables express the same phenomenon. For instance, given that demand is measured as the total number of trips, the population and GDP variables express the region's growth. Although from a statistical point of view the population coefficient has a slightly higher degree of significance, from a conceptual point of view, GDP is a more relevant variable. Therefore, on those grounds we decided to exclude population and maintain GDP in the demand equations. In the restricted model, the socio-economic variables that appear to be significant in the bus equation are GDP and the suburbanization index whereas the level of employment is the key economic variable explaining underground demand. The hypothesis of equal GDP elasticity for bus and underground trips was not rejected by the data and so the model was estimated in accordance with this assumption. The results of the restricted model are presented in table 4[14]. It has to be emphasised that moving from the general to the restricted model does not significantly affect the coefficient of the transport variables, our main variables of interest, while their estimated variance is smaller.

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[13] The correlation matrix is:

	GDP	Population	Suburbanization	Employment
GDP	1.000	0.984	0.975	0.963
Population	0.984	1.000	0.970	0.947
Suburbanization	0.975	0.970	1.000	0.895
Employment	0.963	0.947	0.895	1.000

[14] According to the likelihood ratio test the restricted model was not rejected by the data; the calculated chi-square was 13.09, while the tabulated value for 7 degrees of freedom at 5% significant level is 14.1.

Table 4. Estimation results of demand equations for bus and underground. 1979-2001

Dependent variable:	log (bus trips)		log (underground trips)	
Explanatory variables	Coefficient	t-statistic	Coefficient	t-statistic
Constant term	6.528	5.73	5.152	10.89
Log (bus fare)	-0.208	-3.52	n.a.	
Log (underground fare)	n.a.		-0.369	-9.44
Log (bus network)	0.479	6.26	n.s.	
Log (underground network)	-0.210	-7.96	0.245	5.82
Log (petrol price)	0.155	6.46	n.s.	
Log (bus trips (-1))	0.298	4.28	n.a.	
Log (underground trips (-1))	n.a.		0.399	8.30
Log (GDP)	0.148	2.74	0.148	2.74
Log (employment)	n.s.		0.305	3.18
Log (suburbanisation)	0.397	2.71	n.s.	
Step dummy variable	0.034	2.74	0.053	4.07
Number of observations	23		23	
R-square	0.992		0.994	
Adjusted R-square	0.987		0.992	
S.E. regression	0.009		0.012	
h-test	-0.22		-0.69	

n.a. not applicable
n.s. not significant

The estimated coefficients are highly significant, the level of fit is high and no correlation is detected in the disturbances according to Durbin's *h* statistic. Given the double-log specification, the estimated coefficients can be interpreted as short run elasticities and, as can be observed, they are in line with the standard literature[15]. In our study, short run is defined as the effect on demand occurring within one year of a change in the relevant variable. Bus fare elasticity is equal to –0.21. This value is similar to that estimated by Dargay and Hanly (2002) for English Metropolitan areas (excluding London). The underground's fare elasticity equals to –0.37; the evidence in this case is sparser but reviewed papers show a range of –0.2 to –0.4[16]. On average, underground users appear to be more price-sensitive than bus users. The explanation for this result might be the higher market share of travel cards in the bus market, which, as is argued in section 5.2, appear to be the least sensitive to price. The elasticity of bus demand with respect to the price of petrol is equal to 0.16 and is clearly significant. However, the price of petrol has no significant effect on underground patronage.

[15] See Oum et al. 1992, Goodwin, 1992, Nijkamp and Pepping 1998 and Dargay and Hanly 1999.
[16] Gilbert and Jalilian 1991, Oum et al. 1992, London Transport 1993.

Service quality measured in terms of route length is found to have a positive impact on public transport patronage, although the effect on the bus market doubles that of the underground[17]. Given that in aggregate studies a very crude proxy for the quality of service is used, it is difficult to give an adequate interpretation of the estimated elasticities and, therefore, evidence of service elasticity is less conclusive. It is interesting to note that bus users are sensitive to the quality of the underground service, while there is no evidence of the reverse effect. This result suggests that the underground is a relevant option for bus users but not vice versa. This might well be the case for commuters who place a higher value on time costs and reliability, in which case the underground is a better option.

The coefficient estimated for the dummy variables that capture the non-pecuniary effects of the travel card indicates a growth in bus and underground patronage of 3.4% and 5.3% respectively. These figures proved highly robust under different specifications of the dummy variables. The higher percentage for the underground can partially be explained by the introduction in 1987 of a multi-ride ticket at an advantageous price, while this ticket has only been a feasible option for the bus since 1979.

According to the dynamic structure of demand, the long-term effects are around 1.4 times those of the short-term for the bus and 1.7 times for the underground. Again the values found agree with other empirical evidence. The period of adjustment is relatively short, with about 60% of the effects experienced within the first year and 95% completed within three years.

Income elasticity is positive and equal to 0.15. This value agrees with the values found by Asensio et al (2003) for a range of Spanish cities. These authors show that in small cities, where the relative quality of public transport tends to be worse, car ownership levels are more income elastic, and public transport services have characteristics of inferior good. On the contrary, in larger cities, where the relative quality of public transport is usually better, public transport is regarded as a substitute for private transport by a larger share of population and its use is less sensitive to changes in income. Nonetheless, our finding differs from the negative income elasticity found in

[17] It has to be noted that when in the underground equation the quality of service was measured in terms of vehicles-kilometre, the estimated elasticity was nearly identical.

other studies, for example, in the UK[18]. One possible explanation for this difference is the higher population density of Spanish cities, which makes them better suited to public transport use than to car use. This argument is suggested in Webster et al (1986), who verify that "in Spanish towns public transport is used on average a little more than in British towns, but in car-owning households the rate of public transport use is nearly half as much again as in Britain ".

The level of employment appears to be a significant variable to explain underground demand but not bus demand. This result confirms what was shown in figure 3 and suggests that commuters represent a higher proportion of users in the case of the underground than in that of buses. The role that employment plays in the demand equation in Madrid is similar to the one found by London Transport (1993). The estimation of a demand equation for bus and underground services in London showed that employment was a significant explanatory variable in the underground equation but did not explain changes in bus demand.

4.2. Long-term impact on patronage of changes in explanatory variables

As stated earlier, one of the objectives of this study was to quantify the causes of the significant increase in public transport use in the region of Madrid since 1986. The estimated equations allow us to disentangle the effect on patronage as a result of the applied transport policy (fares and service quality) from the effect of other exogenous variables. Taking into account the dynamic effects, we have evaluated the change in patronage from 1986 to 2001 that can be attributed to the change in each explanatory variable[19]. Table 5 shows the change in the explanatory variables and the corresponding impact on patronage.

[18] See, for instance, Dargay and Hanly (1999).

[19] In order to calculate the impact on demand that can be attributed to variable X we used the following procedure. First, from the demand equation, the total number of trips in 2001 has been forecast under the assumption that variable X has remained constant all over the period and equal to its value in 1986. Second, the contribution of variable X to the change in the number of trips has been calculated as the difference between the observed number of trips in 2001 and the predicted number of trips assuming variable X has remained constant. This procedure has been repeated for each variable in the model.

Table 5 . Estimated effect on patronage of changes in explanatory variables 1986-2001 (percentage change)

Bus market

Explanatory Variable	Percent change in the explanatory variable	Impact on patronage (%)
Fare index	21.0	-5.5
Bus route length	21.9	16.3
Underground route length	57.4	-16.1
Petrol price	-5.0	-0.4
Travel card	-	7.1
GDP	51.8	12.8
Suburbanisation	24.8	15.4

Underground market

Explanatory Variable	Percent change in the explanatory variable	Impact on patronage (%)
Fare index	19.2	-15.8
Underground route length	57.4	27.1
Travel card	-	14.9
GDP	51.8	18.7
Employment	50.2	29.3

As far as the bus market is concerned, our research shows that the growth in real fares has reduced demand by more than 5%. Secondly, it can be observed that the extension of the bus network has had a significant impact on demand, which has, however, been practically offset by the enlargement of the underground network. The final effect of the introduction of the travel card is slightly higher than 7%. The impact on patronage of the two exogenous variables included in the equation has proved to be positive. Real GDP growth leads to an increase of nearly 13% of total trips while suburbanisation has expanded demand by an additional 15%. The impact of the last variable has to be interpreted with caution. As was explained in section 2, the largest increase in travel coupons corresponds to those valid for two or more zones; that is, in users travelling from the rest of the region to the city of Madrid (or vice versa). However, this growth has not occurred without the influence of an integrated fare system. Hence, it is possible that the impact of suburbanisation reflects part of what is really due to the impact of the travel card. It was not possible to further disentangle the effects of these two variables. In relation to the underground, the long-term effect of underground extensions and the travel card are 27% and 15% respectively, which have been partially offset by the increase in real fares. Employment and GDP growth have contributed by 29% and 19%, respectively, to the increase in patronage.

The impact of the travel card on patronage falls in the range of values reported by other studies. FitzRoy and Smith (1998), estimate that the introduction of two heavily discounted travel cards in the city of Freiburg increased the number of bus trips per capita by 9.4% and 13.9%, respectively. FitzRoy and Smith (1999) report that the impact of the introduction of a season ticket scheme in four Swiss cities on the total number of bus passenger trips had the following results: Geneva, 16%, Bern 14%, Basel 5,4% and Zurich 4,5%. However, the impact of the travel card in Madrid is below that estimated for London. London Transport (1993) quantifies the impact on patronage of the May 1983 fare revision and introduction of the Travelcard as a growth of 33% for underground passenger-miles and 20% for bus passenger-miles from 1982/83 to 1990/91.

5. Impact on revenue and price elasticity with respect to different ticket types

5.1. Impact on revenue

In this section, we want to evaluate the consequences for revenue derived from the changes in the level and structure of the fare system. An analysis of the related literature leads to the conclusion that the implementation of a non-uniform price scheme does not necessarily imply an increase in financial support. From his theoretical analysis, Carbajo (1988) concludes that the effect of different combinations of fares on revenue will depend on how users are distributed according to their intensity of use. Doxey (1984), working under the assumptions of price-inelastic demand and wide dispersion of individual demand at any fare level, concludes that travel pass sales will have a negative impact on revenue. However, as FitzRoy and Smith (1998) state, Doxey's argument ignores the potential generation effect of travel cards. On the other hand, White (1981) argues that although a travel card pricing policy does not necessarily imply an increase in deficit in the long run, the common policy followed in the short-term of setting a low price for travel cards in order to achieve high market penetration involves an increase in financial support. This result seems to be confirmed by empirical evidence. Pucher and Kurth (1996) conclude that for five case studies analysed (Hamburg, Munich, Rhein-Ruhr region, Vienna and Zurich) the service improvements and the integrated fare system required substantial government subsidies. On the other hand, FitzRoy and

Smith (1998) show that the low cost travel cards introduced in Freiburg have not deteriorated the operating deficit of the transport company. Nonetheless, the authors suggest that this outcome is perhaps exceptional. Similarly, LT (1993) presents a significant positive effect of travel cards on underground revenue and a smaller positive effect on bus revenue, due to the large increase in patronage.

For the two municipal companies that operate bus and underground services in Madrid we have calculated the effect of the change in ticket types on revenue by breaking down the components of total revenue. The results are presented in table 6 in percentage terms. For the bus company, revenue has increased at a rate lower than the inflation rate, patronage and the real fare index have had a positive effect, while the increase in the market share of ticket pass holders has clearly reduced revenue. According to the results presented in table 5, this reduction has been weakly offset by the generation effect due to cheap travel passes. The corresponding figures for the underground company show a significant increase in total revenue in real terms, which is mainly explained by the increase in the total number of passengers. Again, the travel pass has had a negative impact on revenue only partially offset by the attraction of new users by the travel cards. It should be remembered that the extension of the underground network explains a significant increase in demand with the corresponding effect on total costs. In order to find the net financial effect of the transport policy applied since 1986 it would be necessary to calculate the impact on total costs and, therefore, on operating deficit. However, this task goes beyond the scope of this study.

Table 6. Impact of travel card on company revenues. 1986-2000

	Revenues	Inflation	Passengers	Real fares index	Change in ticket types
BUS	78.4%	83.8%	18.9%	16.9%	-35.3%
UNDERGROUND	124.2%	83.8%	58.8%	14.6%	-38.2%

5.2. Price elasticity with respect to ticket type

The change in fare structure has resulted in a negative impact on revenue, which might not be sustainable in the long run. According to the aforementioned authors, it is possible to find a combination of fare levels for different ticket types that reduces this negative effect. In order to find the appropriate direction for this change, we have estimated the own and cross-price elasticities of demand for the three main ticket types.

The number of available observations forces us to rely on some simplifying assumptions and to estimate a simple model structure. Although this is probably not the best option, it provides useful insights into demand behaviour. The model has been estimated only for underground data in order to avoid counting bus transfers twice. Pensioner concession trips have been excluded due to their different sensitivity to factors influencing demand.

The model has been specified as in the aggregate equation, i.e. the demand equations have been estimated in levels, using a double-log form and according to a partial adjustment model. The model consists of three equations, one for each ticket type (single, multi-ride and travel card) and it can be expressed as follows:

$$y_{it} = h(f_{it}, r_t, e_t, d_t)$$

Where:

i = single fare, multi-ride fare or travel card

y_{it}= passenger trips with fare type i in period t

f_{it}= real price of fare type i in period t

r_t=route length in period t

e_t=employment level in period t

d_t=dummy variable that reflects the change of fare structure in 1998

The explanatory variables included in the equation are those that proved significant in the aggregate model. A dummy variable has been added to take into account the unification of the multi-ride ticket for bus and underground in 1998, which implied a substitution of single ordinary tickets with multi-ride tickets. The sample period is from 1990 to 2001, the starting year being that in which the travel card scheme could be considered complete.

Figure 4 summarises the changes in fares in real terms for the three ticket types. The introduction of the travel card was accompanied by a sharp increase in the price of single ticket fares, which continued until 1992. In 1993, the pricing policy was reversed and single fares decreased in real terms until 2000. Between 1987 and 1991, the prices of the travel card and multi-ride tickets were held constant in monetary terms with a break-even number of trips equal to 73 per month. This ratio fell to an equivalent of 59 in 1993 and thereafter it increased gradually until it reached 65 in 2001. As shown in figure 5, passengers reacted strongly to the change in price level and structure. Trips using travel cards show a continued increase since its introduction even after its relative price had been raised.

Figure 4. Fare index for the three ticket types (1987=100)

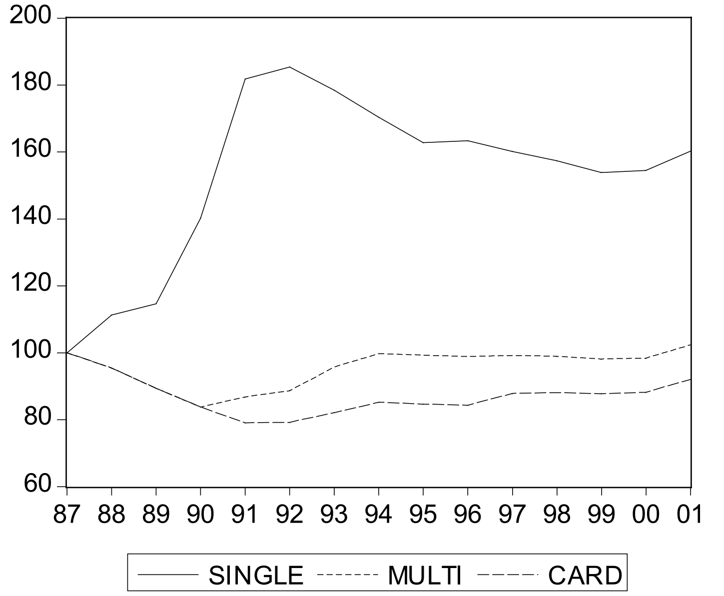
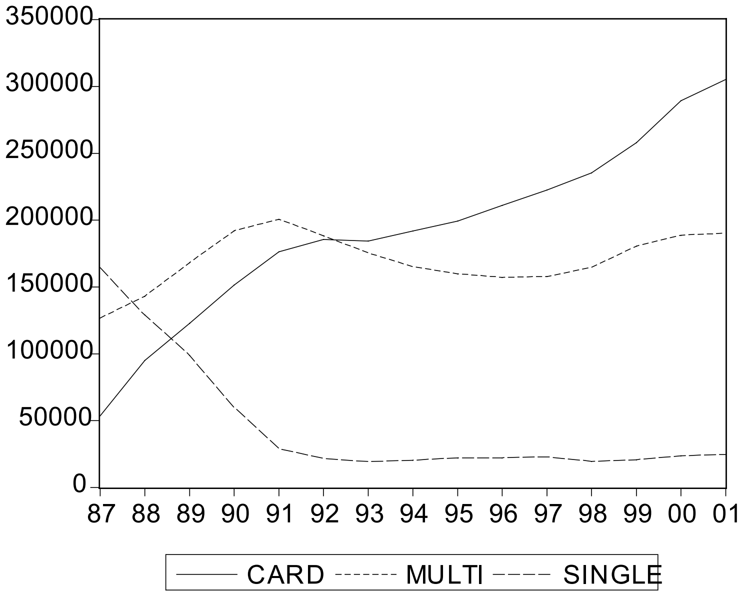


Figure 5. Underground passenger trips by ticket type



The equation system has been estimated by applying the SUR method. We proceed from the general to the restricted model by omitting those variables that were found to be non-significant[20]. The final equation (table 7) shows a good overall level of fit and all coefficients take the expected sign and are highly significant. In order to increase the degrees of freedom it was assumed that the coefficient of the lagged dependent variable takes the same value in the three equations. This constraint was not rejected by the data.

Table 7. Estimation results of underground demand according to ticket type. 1990-2001

Dependent variable:	log(single trips)		log(multi-ride trips)		log(travel pass trips)	
Explanatory variables						
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
Constant term	9.211	7.87	9.147	8.92	-0.752	-0.85
log(single fare)	-1.481	-9.85		n.s.		n.s.
log(multi-ride fare)		n.s.	-1.074	-13.38	0.217	2.58
log(pass fare)		n.s.	0.313	2.46		n.s.
log(network)	0.647	4.70	0.249	5.83	0.160	1.73
log(trips(-1))	0.507	22.16	0.507	22.16	0.507	22.16
log(employment)		n.s.		n.s.	0.622	4.07
Dummy98	-0.259	-5.65				
Observations		12		12		12
R-squared		0.984		0.974		0.994
Adjusted R-squared	0.975		0.959		0.990	
S.E. of regression		0.049		0.018		0.021
h-test		0.12		-1.50		-1.04

n.s. not significant

The results related to price elasticities with respect to different ticket types show that, firstly, price sensitivity decreases as we move from single tickets to the travel pass. This is a common result in the literature on that subject (de Rus 1990, Hensher 1998, Tegner et al. 1998). Secondly, users are highly sensitive with respect to single and multi-ride fares with elasticity values equal to –1.5 and –1.1, respectively. These values have been estimated with a high degree of confidence and prove highly robust in the model specification. It is difficult to compare these results with other empirical evidence given the wide range of observed variation. Our results are in line with those obtained by Tegner et al. (1998), de Rus (1990) and García-Ferrer et al. (2002) who also used time

[20] The variables found to be non-significant are the following. In the single ticket equation: multi-ride fare, travel card price and employment level; in the multi-ride ticket equation: single fare and employment level and in the travel pass equation: single fare and its own price. According to the likelihood ratio test the restricted model was not rejected; the calculated chi-square was 6.33, while the tabulated value for 9 degrees of freedom at 5% significant level is 16.9.

series data. Tegner et al. (1998) estimated a price elasticity equal to –1.8 for single ticket and -0.8 for pre-paid coupons. For a sample of Spanish cities, de Rus (1990) obtained a price elasticity for single fares of between –0.73 and –1.16, and for multi-ride tickets between –0.27 and –2.25. García-Ferrer at al (2002) have estimated demand elasticity with respect to ticket type for the same area and period as ours. They present a price elasticity for single fares that is similar for buses and the underground at around –1.1, while for multi-ride tickets the elasticity is equal to –2.4 for the underground and –0.5 for buses. However, Hensher (1998) reported much lower values for choice elasticities using micro data.

Thirdly, no elasticity statistically different from zero could be identified for the use of the travel pass with respect to its own price. This result is also found by García-Ferrer et al. (2002) and can be explained by the fact that relatively low changes in the breakeven ratio between the travel card and multi-ride tickets have little effect on travel card sales. Regarding this, White (1981) provides some arguments for elasticity being lower than single ticket elasticity. The main reason is that when the price of a travel card is raised, travel card holders do not reduce their trip frequency unless the price rises above a critical threshold at which the user switches to single tickets at a much lower trip rate. Additionally, given that an increase in card price encourages less frequent users to abandon purchasing cards, it can be expected that total trips made by travel cards are less price sensitive than the number of card holders[21]. The empirical evidence available for travel card price elasticity tends to support low values. White (1981) suggests negligible or very low price elasticity for moderate increases in the price of travel cards. Hensher (1998) estimates a value of –0.1 and Tegner et al. (1998) an elasticity of –0.2 for a monthly pass. However, there is also evidence of higher elasticities for travel passes. Dargay and Pekkarinen (1997) obtained an elasticity equal to –0.5 in the short run for bus trips in two regional areas of Finland. However, in this case, the authors suggest that a possible explanation for the large elasticity found could be the small market share of travel cards with respect to total bus trips. Preston (1997) in a literature review reports a wide range of variation, from very inelastic demand (-0.10) to very elastic demand (-2.40). The differences can be explained by the nature of the data, the specification of the demand model, the characteristics of travel passes and the definition of the dependent variable.

With respect to cross-elasticities, it can be observed that once the effects of the new travel card scheme have been established, single ticket users are sensitive only to their own price, whereas positive and significant cross-price effects appear between multi-ride and travel card users.

The estimated own and cross-price elasticities suggest that there is scope for change in relative fare prices if revenue needs to be increased. The negligible sensitivity with respect to travel card prices supports moderate increases in their prices without a significant effect on patronage. However, further increases in the price of single and multi-ride tickets will probably affect demand negatively given the high estimated elasticity values.

Finally, in order to check the robustness of the elasticities reported in table 7, it is interesting to see that when multiplied by the share of each ticket type, they result in values very similar to the aggregate underground elasticities obtained previously (table 5). The market shares are set to be equal to the average value in the sample (single ticket 9%, multi-ride ticket 31% and travel passes 50%). The overall price elasticity assuming an equiproportional price variation is equal to –0.33 whereas the overall service elasticity is equal to 0.24.

$$\varepsilon_f = -1.48*0.09 + (-1.07+0.31)*0.41 + 0.22*0.50 = -0.33$$
$$\varepsilon_s = 0.65*0.09 + 0.25*0.41 + 0.16*0.50 = +0.24$$

6. Conclusions

The results of the estimated demand equations prove that the introduction of an integrated fare system for the whole region and the improvement in bus and underground networks have succeeded in reversing the declining patronage trend of public transport in Madrid. However, we should take into account the fact that the economic recovery which started in 1985 also played a significant role in increasing public transport use. This happens to be the case mainly for the underground with a

[21] This result is found in Dargay and Pekkarinen (1997).

higher proportion of commuters among its users. In the long run, the introduction of a travel card system has increased underground trips by nearly 15% and bus trips by more than 7%. The positive impact of travel cards in Madrid is in line with that found in German and Swiss cities although below that estimated for London. The results confirm the essential role of an integrated fare scheme for those cities that seek to increase public transport use.

According to the results, bus users are sensitive to price and quality variables but also to the underground network, implying a substitution effect between these modes of transport. This substitution relationship allows for a rationalisation of the bus network without a negative impact on total patronage. On the other hand, underground users are only sensitive to underground characteristics. This can be partially explained by the predominance of commuter trips that place a high value on variables such as time and reliability that cannot be matched by bus supply. It can also be concluded that the price of petrol should not be ignored as an element of the pricing policy given the statistically significant, although small, impact on bus demand.

However, the adoption of these transport policies tends to require an increase in financial support that is not always available. In the case of Madrid, the high market penetration of the low cost travel card has had a negative effect on company revenues, as occurred in the five case studies (Hamburg, Munich, Rhein-Ruhr region, Vienna and Zurich) analysed by Pucher and Kurth (1996). The estimation of separate equations for different ticket types provides interesting implications for fare policy. Firstly, the results confirm White's suggestion that card holders do not seem to be very sensitive to moderate increases in price. Secondly, given the high value of price elasticities with respect to single and multi-ride fares and the low value for cross-elasticities, further increases in the price of these tickets would generate a loss of patronage. Therefore, the results support the argument that there is scope for a more efficient non-uniform pricing policy with positive effects on demand while minimising the negative effects on revenue.

The experience of Madrid shows that a declining trend in public transport ridership can be reversed through an active public transport policy based on low cost travel passes and improvements in the quality of services. The same result has been observed in other

European cities. Among these are the well known cases of Austrian, German and Swiss cities reported by Pucher and Kurth (1996). Therefore, an integrated public transport system seems to be an advisable policy. However, several drawbacks need consideration. First, although it has been proved that the public transport policy observed by CTM has achieved a significant increase in patronage, there is not enough information to understand the impact on modal shifts from car to public transport, which is, in fact, the main goal of the urban transport policy. Therefore, more information would need to be available in order to evaluate the success of the policy implemented. Second, those policies addressed to improve public transport service usually have a significant impact on costs. Therefore, a careful evaluation of benefits and costs of such policies is needed.

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Appendix

1. The characteristics of the travel card[22]

In 1987, the regional transport authority (CTM) developed an integrated ticket system covering all modes of public transport in the region. The scheme is based on a monthly travel card that allows for unlimited travel across the entire network. Concessionary cards are available for young people (30% discount) and those over 65 (more than 70% discount). An annual card was later introduced for ordinary and youth tickets for the same price as 11 monthly passes. A zonal structure has been designed based on concentric rings around the central area. The central area, zone A, corresponds to the municipality of Madrid and is served by metro and urban bus companies. The rest of the region is divided into five zones (B1,B2,C1,C2,C3) that are served by private bus companies and suburban railways. The system was systematically extended to all the municipalities in the Madrid region. In 1990, the fare scheme was available for more than 95% of the inhabitants of the region and is presently being extended outside the Madrid region.

Prices are set according to the number of zones travelled through. In 1987 the monthly card for zone A was priced at an equivalent of 97 single trips using the next cheapest fare for busses and 73 trips for the underground. This ratio was progressively reduced to 65 in 2001 for both modes of transport. This may appear to be a high price for the travel card, but there are two factors to be considered; first, the cheapest fare is a single-mode fare, so for those journeys that imply a transfer (even between two different buses belonging to the same company) the break-even ratio is much lower, and second, the price ratio is much more attractive for those travelling across more than one zone. Moreover, this figure is similar to that observed in other cities. For instance, White (1981) reports a mean value of 80 trips per month for most travel card holders in Western European cities when different stages of a single journey are recorded as an additional trip.

2. Fare structure on bus and underground services

Until 1986, underground and bus operators had a different fare structure and level. For the bus operator there were four different types of fare: ordinary single ticket, multi-ride ticket, annual and quarterly passes and a concessionary ticket. The multi-ride ticket is a ten-trip ticket offering a discount of nearly 40% with respect to the ordinary single ticket. The concessionary ticket is also a ten-trip ticket offering a discount of 90% with respect to the single ticket. People eligible for the concessionary fare are those older than 65 or those below that age who are disabled with a monthly income below €425 (2000). Tickets issued by the bus operator are valid for only one bus trip and do not cover transfers between buses. For the underground, four ticket types were also in use: single tickets, day return tickets, multi-ride tickets and monthly and annual passes. The day return ticket was only in use until the end of 1987 and offered a 30% discount with respect to the single ticket. The multi-ride ticket was introduced in 1985 as a ten-trip

[22] For an explanation of concessionary fare policy and its design see Cos Blanco and Zaragoza 1990.

ticket but without any discount. It was not until August 1987 that a discount of 18% was offered. From that date and until 1990, the price of the single ticket was increased while the price of the ten-trip ticket was held constant in monetary terms; in 1990 the discount reached 46%. Transfers in the underground network are not penalised.

In 1987, the integrated zonal fare system was introduced while the previous fare structure for each mode of transport practically remained unchanged. In 1998, multi-ride tickets for busses and the underground were unified and the same strip could be used in either transport mode. However, transfers are still penalised when single and multi-ride tickets are used. Finally, since 1990 all fares for both modes of transport have been set at the same level.

3. Estimation results of the general model

Table A.1 Estimation results of the general model

Sample: 1979 2001
Included observations: 23
Total system (balanced) observations 46

	Coefficient	Std. Error	t-Statistic	Prob.
BUS EQUATION (bus trips)				
Constant term	-5.988462	6.085580	-0.984041	0.3349
log(bus fare)	-0.217801	0.085670	-2.542333	0.0179
log(bus route length)	0.536775	0.094332	5.690294	0.0000
log(underground route length)	-0.222807	0.039314	-5.667429	0.0000
log(petrol price)	0.112044	0.045159	2.481122	0.0205
Step dummy variable	0.027897	0.015385	1.813273	0.0823
log(bus trips(-1))	0.335390	0.088716	3.780478	0.0009
log(GDP)	0.062698	0.195106	0.321353	0.7507
log(suburbanisation)	0.246769	0.210944	1.169829	0.2536
log(population)	0.804857	0.394465	2.040376	0.0525
log(employment)	-0.024255	0.119689	-0.202649	0.8411
UNDERGROUND EQUATION (underground trips)				
Constant term	-1.715508	10.48184	-0.163665	0.8714
log(underground fare)	-0.321186	0.117775	-2.727108	0.0118
log(bus route length)	0.185212	0.163810	1.130647	0.2694
log(underground route length)	0.180620	0.088823	2.033473	0.0532
log(petrol price)	0.030213	0.083074	0.363689	0.7193
Step dummy variable	0.063938	0.026609	2.402844	0.0244
log(bus trips(-1))	0.351732	0.142053	2.476072	0.0207
log(GDP)	0.258348	0.270976	0.953400	0.3499
log(suburbanisation)	-0.415547	0.338206	-1.228680	0.2311
log(population)	0.316527	0.833484	0.379764	0.7075
log(employment)	0.343237	0.188957	1.816478	0.0818
Determinant residual covariance		3.13E-09		

BUS EQUATION			
R-squared	0.993956	Mean dependent var	13.08589
Adjusted R-squared	0.988920	S.D. dependent var	0.084868
S.E. of regression	0.008933	Sum squared resid	0.000958

h-Durbin	-1.09		
UNDERGROUND EQUATION			
R-squared	0.995599	Mean dependent var	12.88395
Adjusted R-squared	0.991931	S.D. dependent var	0.136995
S.E. of regression	0.012306	Sum squared resid	0.001817
h-Durbin	-2.30		

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