Cost and Productivity of Major Urban Transit Systems in Europe

An Exploratory Analysis

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1. Introduction

In most European cities, public transport is regarded as a major element of city life and organisation. Transit systems tend to be more developed than in the United States and to rely more heavily on rail (underground rail or streetcar). Despite a substantial decline in patronage since the 1950s and 60s, supply levels have generally been maintained. This has been possible only through a large increase in subsidies which seem less and less sustainable in times of general public austerity.

Our purpose here is not to discuss specific solutions to the problems faced by public transit but rather to inquire about the cost of various transport modes in Europe (excluding Central and Eastern Europe), and to identify a few firms in the industry which exhibit remarkable productive performance. The focus will thus be on intermodal and intercity comparisons, with due attention to specific local conditions such as wages, vehicle speed and capacity, and network density.

We rely on two types of methodologies for our study. First, we compute some rough productivity and average cost measures for the largest firms. Second, we use regression techniques to estimate the impact of relevant variables on the cost of buses, streetcars and underground rail. As far as we know, this is the first attempt to compare systematically major European networks in such a disaggregated manner.

Economies of capacity, higher vehicle speed and density are identified. We also find a high correlation between costs and subsidies. Concerning intermodal comparisons, results suggest that streetcars do not fill a significant gap between buses and underground rail. We also try to identify some plausible 'role models' in the sector. Deregulated British firms are among the first on our list in terms of technical performance.

We start with a description of the data in Section 2. Section 3 discusses labour productivity and average cost measures. Section 4 presents the results from our regressions. Economies of capacity, density and higher speed are discussed in Section 5. Section 6 considers some plausible 'role models'. Finally, Section 7 draws conclusions.

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2. Description of the Data

To our knowledge, there is currently no comprehensive database on European transit firms. As we were mostly interested in major multimodal networks and needed detailed information, we had to rely partly on mail contacts for data collection. There was also a very good database from CETUR (1990) on most French networks, and a Swiss database for major Swiss cities. Some specific technical information was also available in JANE's (1993) and UITP (1985). The geographical structure of the sample is therefore a result of both the response rate to our mailing and the availability of national databases.

In most of continental Europe, transport services in cities are run by only one firm under the direct or indirect authority of a public body responsible for public transport. There are, however, some instances in which some of the services are operated by additional firms. This is typically the case for some bus lines in the suburbs. "Firm", "network" or city names will be used interchangeably hereafter and will generally designate all the transport services in the city as defined by the local public authority. Exceptions are for British cities where the data correspond to the dominant bus companies, and for Lisbon and Madrid whose underground rail is run by distinct companies (see also the discussion on contracted-out activities below and in the following section).

After discarding some firms for missing data (usually on speed or wages), we were left with 178 networks from 12 countries. Among them are 17 underground and 32 streetcar and/or light rail systems. The remaining networks are mostly medium or small French urban bus companies.

An effort was made to spot cases of contracted-out activities (which is important for computing labour productivity measures) and to homogenise information on capacity supplied. Indeed, most networks use different criteria for computing vehicle capacity. We chose to keep a common measure of four persons per square metre which is used in Germany. Concerning convoy- or train-km supplied, we also had to make some approximations for a few underground systems for which we only had information on car-km supplied and minimum and maximum train size.

For input prices and financial values, we relied on nominal exchange rates for comparisons and made some corrections for different years of observation (our sample is a cross-section but years differ: all of them are between 1988 and 1993). We have no reliable information on input prices other than wages and capital expenditures.

These problems and approximations clearly limit the scope of our analysis. The lack of data on some important variables, as well as the small number of rail systems, will not allow for very sophisticated estimation of the cost functions. It also restricts us to the study of *operating* costs. On the other hand, controlling adequately for vehicle speed, capacity and the modal structure of the network is seldom done and contributes to the interest of our findings.

3. Labour Productivities and Average Costs

We proceed here with some rough analysis of labour productivities and average costs for our 54 major networks. These measures should be heavily qualified as they do not control for differences in production environments, number of hours worked per employee, type of employee, modal split, input prices or network size. Yet, despite these limitations, they are interesting as a first exploratory tool. While they certainly do not provide a comprehensive picture of productive performance, they are still regarded as important descriptive statistics by most people working in transit firms.

3.1 Labour productivities

We compute labour productivities for two measures of output, namely convoy-km and seat-km supplied. These are supply-related measures as opposed to demand-related ones such as passengers transported or passenger-km. This choice is justified by the fact that demand depends on factors which are outside the firms' control and also by our purpose which is to compare the cost associated with the provision of different transit services.

A potential problem with technical measures such as labour productivities is the occurrence of contracted-out activities which could bias the results significantly (by more than 30 per cent for cities like Hamburg and Oslo). This is why the ratios reported are computed on the basis of in-house production. More precisely, sub-contracted lines are excluded from output when the labour figures corresponding to this additional supply are not reported (this correction is not made for computing average costs when the *expenditures* on sub-contracted activities are reported).

Results for convoy-km supplied by employee are reported in Table1 (column 1) and are quite straightforward. Companies providing only bus services tend to have a much higher productivity. The best performances are to be found in Lucerne (19,510), Sheffield (19,041) and Manchester (18,898). As expected, labour productivity is much lower for the two companies providing only metro services: 1,534 km/employee for Lisbon Metro and 2,794 km/employee for Madrid Metro. We have no companies providing only streetcar services but more disaggregated data for some multi-modal companies suggest productivities lower than for buses and higher than for underground rail.

The figures on the number of seat-km supplied per employee are more interesting (Table 1, column 2). There is no clear-cut relation between modal split and productivity. The worst results are for Lisbon Metro which runs an underground rail system (508,000 seat-km per employee) and for Lisbon Carris which runs buses and streetcars (614,000). The best performances are achieved by Munich (1,817,000), Manchester (1,701,000), Hannover (1,640,000), Edinburgh (1,661,000) and Barcelona (1,639,000). Munich and Barcelona have a fairly developed underground rail system, Manchester a lot of double-decker buses ('London buses'), and Hannover one of the largest light rail systems in Europe.

3.2 Average costs

Average costs are very easy to compute but are fairly sensitive to variations in input prices. This is why we also computed average costs (partly) deflated by wages. More precisely, for each network i, deflated costs are equal to $0.75C_i(\bar{w}/w_i) + 0.25C_i$, where C_i is the cost in network i, w_i the observed wage rate in network i, and $\bar{w}$ the average wage in the sample (which is equal to 1.2 million BF). The motivation behind this computation is the

Table 1
Partial Productivities, Average Costs and Efficiency Scores
(ranked by deflated costs per seat-km)

	1	*2*	*3*	*4*	*5*	*6*	*7*
*City (and Modes)**	*Labour Productivity†*		*Observed Costs§*		*Deflated Costs§*		*Regression*
	conv-km	*seat-km*	*conv-km*	*seat-km*	*conv-km*	*seat-km*	
Manchester (b)	18898	1701	68	76	79	88	1.31
Liège (b)	17587	1294	72	98	72	99	1.20
Barcelona (b,ur)	9073	1639	185	102	184	102	0.93
Hanover (b,sc,lr)	8843	1640	213	119	190	107	1.05
Helsinki (b,sc,ur)	11372	1590	192	137	152	108	0.99
Sheffield (b)	19041	1360	54	75	80	111	1.34
Madrid Metro (ur)	2794	1362	562	115	578	119	0.65
St Etienne (b,sc)	11823	1274	124	118	126	120	1.03
Munich (b,sc,ur)	7886	1817	286	156	222	121	0.82
Nuremberg (b,sc,ur)	8560	1468	257	163	199	126	0.84
Hamburg (b,ur)	7987	1359	208	143	185	127	0.76
Basle (b,sc)	13600	1579	230	204	146	130	1.42
Nantes (b,sc)	13458	1201	111	127	115	131	0.94
Cologne (b,sc,lr)	9044	1349	210	145	191	132	0.98
Winterthur (b)	15306	1347	179	204	118	134	0.91
Rotterdam (b,sc,lr,ur)	8319	1338	222	138	218	135	0.82
Lucerne (b)	19510	1565	161	200	110	137	0.95
Berlin (b,ur)	5384	1124	334	160	288	138	0.61
Oslo (b,sc,ur)	6210	1180	223	144	217	140	0.92
Valenciennes (b)	15500	1163	108	144	106	142	0.79
Grenoble (b,sc)	13377	1180	134	152	128	146	0.89
Lyons (b,ur)	12500	1099	135	154	128	146	0.85
Lille (b,sc,ur)	14153	1366	141	150	138	147	0.89
Düsseldorf (b,sc,lr)	9104	1124	203	164	186	151	0.88
Bonn (b,sc)	13608	1122	146	177	127	154	1.02
Toulon (b)	13878	1013	107	146	113	154	0.88
Rouen (b)	12885	991	125	162	124	161	0.77

* b = bus, sc = streetcar, lr = light rail, ur = underground rail.
† Convoy-km and seat-km per employee are in thousands.
§ Costs are in BF per convoy-km or 100 seat-km.

Table 1 Continued

Partial Productivities, Average Costs and Efficiency Scores

(ranked by deflated costs per seat-km)

	1	*2*	*3*	*4*	*5*	*6*	*7*
*City (and Modes)**	*Labour Productivity†*		*Observed Costs§*		*Deflated Costs§*		*Regression*
	conv-km	*seat-km*	*conv-km*	*seat-km*	*conv-km*	*seat-km*	
Bordeaux (b)	12821	987	126	163	125	162	0.76
Stuttgart (b,sc,ur)	8551	1235	283	196	236	163	0.79
Geneva (b,sc)	10708	1132	261	247	175	166	0.74
Vienna (b,sc,lr,ur)	6803	1195	300	171	294	167	0.75
Bremen (b,sc)	10104	1136	216	192	189	168	0.83
Fribourg (b)	12808	993	183	237	134	173	-
Marseilles (b,sc,ur)	8959	964	193	182	185	174	0.67
Essen (b,sc,lr)	9420	1008	231	220	183	174	0.83
Zurich (b,sc)	10590	1269	304	253	210	175	0.83
Berne (b,sc)	10348	1060	274	268	181	177	0.83
Brussels (b,sc,ur)	7133	839	250	213	216	183	0.88
Strasbourg (b,sc)	11347	828	141	193	136	187	0.71
Amsterdam (b,sc,lr,ur)	7182	953	253	191	250	188	0.80
Florence (b)	12766	919	174	241	140	194	0.70
Antwerp (b,sc)	10127	762	157	209	146	195	1.30
The Hague (b,sc)	8429	892	210	199	206	195	0.94
Duisburg (b,lr)	9480	810	195	229	169	197	1.01
Mannheim (b,sc)	10404	963	216	233	187	203	1.12
Toulouse (b)	11858	853	141	195	146	203	0.69
Milano (b,sc,ur)	6992	942	350	260	275	204	0.62
Nice (b)	11004	825	162	216	158	210	0.68
Lausanne (b,sc)	10348	877	256	302	179	212	0.56
Genoa (b)	9962	697	150	214	151	215	0.71
Lisbon (Carris) (b,sc)	8742	614	96	136	171	243	0.82
Dresden (b,sc)	8622	1017	142	120	328	278	0.93
Lisbon (Metro) (ur)	1534	508	533	161	961	290	-
Edinburgh (b)	16616	1661	68	68	-	-	-

* b = bus, sc = streetcar, lr = light rail, ur = underground rail.
† Convoy-km and seat-km per employee are in thousands.
§ Costs are in BF per convoy-km or 100 seat-km.

following: the average wage share in the sub-sample of 54 firms is 70 per cent which, after taking into account sub-contracted activities, implies that local labour costs account for around 75 per cent of operating costs in most networks. We thus found it relevant — as a first approximation — to control for differences in wages by deflating that share of costs by the ratio between observed wages and the average wage in the sample. The main differences between average costs and deflated average costs are for Swiss networks where wages are very high and for Lisbon and Dresden where they are very low.

Focusing on the deflated values (see Table 1, columns 5 and 6), one sees that the lowest costs per convoy-km are found, as one would have expected, for bus networks (72 BF per km to 100 or more). Madrid Metro shows 578 BF per km and Lisbon Metro shows 961 BF. On a seat-km basis, firms providing bus services like Liège (99 BF per 100 seat-km), Manchester (88 BF) and Sheffield (111 BF) are still very cheap, but some other companies providing rail services also are doing well, such as Hanover (107 BF), Helsinki (108 BF), Barcelona (102 BF), and Madrid Metro (119 BF).

4. Statistical Analysis

4.1 Motivation and brief review of the technologies for the different modes

In recent years, econometric analysis of the transit sector has become more and more widespread and sophisticated. Flexible stochastic frontiers have replaced the first linear OLS studies. While this approach has contributed to a better understanding of scale economies and elasticities of substitution in the industries under consideration, it has also reduced the prospects for a clear understanding of some basic realities of transit operations. Degrees of freedom have often been used to study the substitution possibilities between labour and fuel rather than to control for speed or capacity, and few studies have compared different transport modes.

The approach followed here departs from current trends and goes back to very simple analysis. Instead of going for flexibility, we will impose cost functions suggested by accounting studies, assume constant returns to scale, and leave no room for factor substitution. This will allow us, despite data limitations, to focus on the most important environmental factors affecting costs: vehicle speed, vehicle capacity and network density, and also to make some intermodal comparisons. Such a procedure is not as bold as it may at first appear, since most studies based on translog cost functions have concluded that there are very small elasticities of substitution and limited returns to scale for buses (see Berechman 1993).

Before turning to statistics, we briefly summarise our basic understanding of transit technologies for buses, streetcars and underground rail.

Bus technology

In order to provide bus services, a transit firm must support different types of expenditures. The most important cost items are (in approximate order): driving (more than 50 per cent of operating costs for low speeds); maintenance (around 20 per cent of costs); fuel and tyres (around 10 per cent); administration (10 per cent or more); and capital cost (essentially for rolling stock, around 10 per cent of total costs). These estimates are based on an internal document from a bus company in Belgium (SNCV, 1990) which have been reported in Wunsch (1994). Typical average total costs for standard buses are around 100 BF per km travelled.

Some cost allocation models have been devised to estimate marginal changes in costs brought about by modifications in a network, such as changes in frequencies, creation or withdrawal of lines. They generally distinguish between costs proportional to the *number of km travelled*, costs proportional to the *number of vehicle hours*, and finally some *fixed or semi-fixed costs* (Savage, 1989). In short, fuel and part of maintenance costs are linked to the number of km travelled; driving costs depend on the number of vehicle hours; other maintenance costs, insurance and garage costs depend on the number of vehicles; and finally, administration costs are a function of 'the size of the network', which includes number of employees, number of vehicles, number of passengers, and so on.

As for environmental factors influencing costs, speed is one of the most obvious. Driving costs are proportional to the inverse of speed and other costs such as maintenance or fuel consumption also tend to increase on a km basis at very low speeds. Vehicle load, vehicle capacity, vehicle age and the peak-base ratio are other variables correlated with costs.

Streetcar technology

The most striking difference between buses and streetcars is of course the fact that the latter run on tracks which have to be paid for and maintained. Other differences are the generally bigger capacity of streetcars and the electric propulsion system. The extent to which these factors have an important impact on the cost structure is not clear. Can the conclusions regarding returns to scale and factor substitution for buses be extrapolated to streetcars? We have no definite answer to this question but a fixed factor technology seems to make sense at first glance, except for economies of density associated with track use. In any case, the preceding remarks about the impact on bus cost of speed, capacity, vehicle age and the like should be relevant for streetcars.

A micro study for Brussels (Borremans, 1994) suggests average total costs of around 350 BF per km for relatively small streetcars (average size of 108 seats). Driving costs account for about 20 per cent of costs, maintenance for more than 25 per cent, fuel for 5 per cent, track maintenance for 17 per cent, vehicle costs for more than 10 per cent, and finally administration (including line agents) for about 20 per cent. If one looks at operating costs per km of track (two way), a gross approximation would be around 3 million BF/km/year. Note also that vehicles are very expensive: 66 million for the new Brussels streetcars versus about 6.5 million for a standard bus (which is about 50 per cent smaller and whose lifetime is about half that of a streetcar).

Underground rail technology

The important factor here is the existence of a very significant infrastructure. A study by CETUR (1989) on French undergrounds (Lille, Lyons and Marseilles) suggests that station maintenance can account for 22 to 34 per cent of operating costs. Track maintenance is less important (6.5 to 7.5 per cent of costs). On a cost-per-station basis, numbers vary from one million to two million FF in 1986, which roughly corresponds to 6 to 12 million BF. Costs per km of track are between 3.5 and 5 million BF.

Another important aspect that one should have in mind is that underground rail technology is far less homogeneous than bus or even streetcar technologies. In addition to very segmented markets for rolling stock, one observes that station size, manning and decoration differ significantly from one network to another (Jung 1993). Differences in the number of agents per station is partly a result of crime prevention policies which have little to do with the efficiency or inefficiency of the network. This implies that any result from econometric studies on subways will have to be interpreted with caution, unless very disaggregated information is available.

4.2 Basic structure of the model to be estimated

Following the preceding discussion, we restrict ourselves to a very simple estimation of average costs for each transport mode, with corrections for some technical parameters and wages. Our 'model' is therefore essentially descriptive in nature and has no pretention of providing a detailed analysis of the economic behaviour of transit firms.

We assume that, for each mode, the cost per km travelled is equal to the sum of:

(1) a constant which does not depend on wages (fuel, spare parts, some contracted-out activities);
(2) a constant which depends on wages (administration cost);
(3) costs that depend on the inverse of speed and wages (essentially drivers costs);
(4) costs that depend on vehicle capacity and wages (essentially maintenance costs).

In addition to these costs, one should include track maintenance for streetcars and undergrounds, as well as station maintenance for undergrounds. The latter are also supposed to depend on local wages. Formally, we have for each mode j and network i:

$$C_i^j = \alpha^j + \left[\beta^j + \beta_c^j \, cap_i^j + \beta_{sp}^b \left(\frac{1}{sp_i^b}\right) + \beta_t^{t,s} \frac{tracks_i^{t,s}}{km_i^{t,s}} + \beta_{st}^s \frac{stat_i^s}{km_i^s}\right] w_i \tag{1}$$

where $j = b$ for bus, t for streetcar and s for underground rail; $i = 1$ to n observations; w_i is the wage in network i, C_i^j is the cost per km travelled for mode j in network i; *cap* stands for vehicle capacity, *sp* for speed, *tracks* for the number of km of tracks and *stat* for the number of underground stations. The last two are both divided by the number of kilometers travelled.

Note that multiplying the technical variables (speed, capacity) by the wage rate implies that the βs should be interpreted as measures of labour requirements. As it stands, the equation thus assumes a fixed factor technology which varies with vehicle speed and capacity. Under this formulation, wages are not expected to be correlated with productivity and should have no impact on factor demand. All terms in equation (1) can then be divided by wages to avoid heteroscedasticity problems linked to variations in the latter:

$$CW_i^j = \frac{C_i^j}{w_i} = \alpha^j \frac{1}{w_i} + \beta^j + \beta_c^j \, cap_i^j + \beta_{sp}^b \left(\frac{1}{sp_i^b}\right) + \beta_t^{t,s} \frac{tracks_i^{t,s}}{km_i^{t,s}} + \beta_{st}^s \frac{stat_i^s}{km_i^s} \tag{2}$$

At this stage, we should stress that almost none of our data on costs are disaggregated by mode but they are total operating costs for each network. We had therefore to estimate the cost per km travelled in each network (total operating costs/total convoy-km) as a weighted average of the costs for each mode, the weights being defined as the shares of each mode in the total supply of convoy-km. The assumption here is that there are no economies of scope: total operating costs in a network are equal to the sum of the costs per convoy-km computed for each mode, multiplied by the relevant productions. Formally, and for each network i, total operating costs *per km* are given by:

$$CW_i = S_i^b \bullet CW_i^b + S_i^t \bullet CW_i^t + S_i^s \bullet CW_i^s + \varepsilon_i \qquad (3)$$

where bus, streetcar and underground costs are defined as in equation(2); output shares S_i^j are independent (observed) variables; ε_i is a random disturbance; and total cost per km (CW) is the dependent variable. This characterisation amounts to multiplying the independent variables in (2) by the relevant mode shares in each network. It allows us to estimate the coefficients α^js and β^js in one regression.

4.3 Specific data on underground rail and wage expenditures

Information on some specific cost items is often included in the estimation of cost or production functions. For instance, sets of equations with data on input shares have been estimated for different industries. (See De Borger, 1984, for an application to mass transit and Johnston, 1984, pp.330-38, for a general discussion.) In the same spirit, but for demand analysis, Bauwens *et al.* (1994) have incorporated some data from direct-metering in models of appliance consumption. These procedures are intended to improve the quality of the fit as more relevant information is added to the regression.

Two kinds of disaggregate data are available to us: expenditure on labour costs and specific cost estimates for most underground systems in the sample. The latter come from micro studies or from our own computations based on reported labour requirements. They should be regarded as imperfect since there are some joint costs in the networks (mainly administrative costs) that are difficult to allocate between modes. The data on labour costs are probably more reliable from a pure accounting point of view. However, they should be used with some caution for our purpose due to the existence of sub-contracted activities. Indeed, we decided to exclude from the labour cost estimates the firms whose wage share was below 65 per cent for this reason. Those firms operate under a different 'input mix' and would have biased the results (by forcing higher α^js).

The different data were grouped into one regression as follows:

$$\begin{aligned} CW_i = {} & S_i^b\left[\alpha^b\frac{1}{W_i} + \beta^b + \beta_c^b cap_i^b + \beta_{sp}^b\left(\frac{1}{sp_i^b}\right)\right] \\ & + S_i^t\left[\alpha^t\frac{1}{W_i} + \beta^t + \beta_c^t cap_i^t + \beta_{sp}^t\left(\frac{1}{sp_i^t}\right) + \beta_t^t\frac{tracks_i^t}{km_i^t}\right] \\ & + S_i^s\left[\alpha^s\frac{1}{W_i} + \beta^s + \beta_c^s cap_i^s + \beta_{sp}^s\left(\frac{1}{sp_i^s}\right) + \beta_t^s\frac{tracks_i^s}{km_i^s} + \beta_{st}^s\frac{stat_i^s}{km_i^s}\right] + \varepsilon_i \end{aligned} \qquad (4a)$$

$$L_l = S_l^b\left[\beta^b + \beta_c^b cap_l^b + \beta_{sp}^b\left(\frac{1}{sp_l^b}\right)\right] + S_l^t\left[\beta^t + \beta_c^t cap_l^t + \beta_{sp}^t\left(\frac{1}{sp_l^t}\right) + \beta_t^t\frac{tracks_l^t}{km_l^t}\right] + S_l^s\left[\beta^s + \beta_c^s cap_l^s + \beta_{sp}^s\left(\frac{1}{sp_l^s}\right) + \beta_t^s\frac{tracks_l^s}{km_l^s} + \beta_{st}^s\frac{stat_l^s}{km_l^s}\right] + \varepsilon_l \tag{4b}$$

$$K_k = \left[\alpha^s\frac{1}{w_k} + \beta^s + \beta_c^t cap_k^s + \beta_{sp}^s\left(\frac{1}{sp_k^s}\right) + \beta_t^s\frac{tracks_k^s}{km_k^s} + \beta_{st}^s\frac{stat_k^s}{km_k^s}\right] + \varepsilon_k \tag{4c}$$

where $i = 1$ to 177 observations on operating costs per km (CW), $l = 1$ to 102 observations on labour costs per km (L), and $k = 1$ to 15 observations on underground costs per km (K). 294 observations are therefore used in the regression. Note that the α's are dropped for the estimation of the labour costs in equation (4b). This is indeed the only cost item which is not related to labour use. Similarly, independent variables unrelated to underground rail are dropped from equation (4c).

4.4 Correcting for heteroscedasticity and covariances

Concerning the variance of the disturbance terms, there are two remaining reasons for suspecting heteroscedasticity. First, networks with rail systems are likely to have higher average costs per km, which should translate into a higher variance of the disturbance. Second, labour costs (in 4b) are, by definition, smaller than total operating costs (in 4a) which again should lead to some heteroscedasticity.

We relied on a two-step approach to deal with the issue. OLS results for the model in equation (4) suggest an average cost per km of 87 BF for buses, 265 BF for streetcars and 391 BF for subways. Now, after regressing the OLS residuals (in absolute value) on the mode shares in total convoy-km, coefficients of 12.6 for buses, 23 for streetcars, and 70 for underground rail were obtained. As for the labour costs estimates, the ratio of the standard errors of the OLS residuals in equations (4b) and (4a) is equal to 0.727, which is consistent with the labour share figures. Altogether, this means that the standard error of the disturbance is more or less proportional to the costs. We therefore constructed the following indices for each observation:

$$I_{i,k} = \{1.S_i^b + 2.5.S_i^t + 5.S_{i,k}^s\} \text{ and } I_l = 0.727\{1.S_l^b + 2.5.S_l^t + 5.S_l^s\} \tag{5}$$

The first index applies for equations (4a) and (4c) and the second for equation (4b). The indices were then used to build the diagonal of the variance-covariance matrix for a GLS estimator.

Controlling for the covariances between the residuals from identical firms in the different equations in (4) was also done on the basis of the OLS residuals. Our GLS estimator is thus very similar in spirit to a SURE estimator, except that the number of observations is not the same in the different sub-equations, and that all coefficients were restricted to be equal across equations.

Table 2
Results of the GLS Estimator
(n = 294)

Variable	*Coefficient*	*Standard Error*	*t-statistic*	*Significance*
α^b	27.52	1.504	18.29	0.00000000
α^t	125.9	15.72	8.00	0.00000000
α^s	66.88	40.86	1.636	0.102
β^b	10.22	13.14	0.777	0.437
β^t	72.03	44.66	1.612	0.107
β^s	22.23	102.22	0.217	0.827
β^b_c	0.359	0.145	2.476	0.0138
β^t_c	0.364	0.198	1.829	0.0683
β^s_c	0.402	0.133	3.015	0.00279
β_{sp}	598.23	113.04	5.291	0.0000024
β^t_t	2.985	1.680	1.776	0.0767
β^s_{st}	14.14	6.200	2.281	0.0232
β_{fr}	−17.31	4.938	−3.505	0.000530

$R^2 = 0.312$

4.5 Results of the GLS estimator

The results reported in Table 2 correspond to the model discussed above. One minor difference is that we included the own financing rate as an independent variable (β_{fr}). Indeed, the argument has often been made that subsidies tend to allow for an increase in costs (see, for instance, Pucher *et al.*, 1983; Bly and Oldfield, 1985). Another difference is that the coefficient on speed was restricted to be equal for the different modes. Note finally that Lisbon's metro was deleted from the database as it systematically biased the results on the impact of wages.

Note first that an R^2 of 0.312 is good for this type of analysis where all size effects have been controlled for (the R^2 is equal to 0.88 for the OLS estimator). Most coefficients are also very significant and all have the predicted sign.

The element of costs independent of wages (α^j) is estimated to be 27.5 BF for buses, 126 BF for streetcars and 67 BF for underground rail. In relative terms, that is 26.5 per cent for buses, 32.4 per cent for streetcars, and 13 per cent for underground rail. These results are consistent with what we expected, except for underground rail for which the coefficient is not very significant ($t = 1.64$).

Capacity seems to be cheap for all modes, less than 0.50 BF for an additional unit of capacity (see the β^j_c). Recall here that these estimates were computed for costs deflated by wages, or to put it differently, that they should be interpreted for an annual wage of one million BF. Concerning the inverse of speed, a β_{sp} of 598 should be interpreted as the cost associated with one vehicle-hour. Track maintenance for streetcars costs about 3 million BF per km of track and station maintenance more than 14 million BF (β^t_t and β^s_{st}). Finally, the own financing rate β_{fr} is found to have a significant and quite large impact on costs. An increase of 50 per cent in this rate is associated with a decrease in costs of about 8.6 BF per km for buses, 2.5 and 5 times more for streetcars and underground rail respectively.

5. An Examination of the Results

5.1 Economies of higher capacity

Capacity is relatively cheap for the different modes with estimates around 0.30-0.40 BF per additional seat of capacity. These results were robust to various specifications and have relatively small standard errors (below 0.20). Figure 1 shows costs per seat-km for the various modes as vehicle capacity increases. Variables other than capacity are equated to sample means and the capacities considered are the observed ones (it is meaningless to estimate the cost of a bus with a capacity of 500).

Results are quite obvious, the marginal cost of capacity is much lower than the average cost for all modes. Interestingly enough, streetcars — whose capacity is bigger than that of buses — are more expensive on a seat-km basis. This is also true but less striking for light rails. Underground rail costs are comparable to articulated buses from a capacity of 300 to 450 and are cheaper for very large trains.

Cost elasticities (marginal cost of capacity/average cost of capacity) are low: 0.301 for buses, 0.177 for streetcars and 0.484 for underground rail.

Concerning the high cost of streetcars on a seat-km basis, we should stress that these are average estimated costs. It is possible that streetcars are cheap for some values of the parameters for track density or speed. Other factors should also be considered such as comfort, pollution levels, road surface requirements, and capital costs which are significant for streetcars and huge for underground rail. One km of underground line costs about 2 billion BF which corresponds to 60 million per km every year if one assumes a real interest rate of 3 per cent and an infinite horizon. This suggests *total* costs per seat-km of more than 2 BF for underground rail.

We do not want to push these comparisons too far, but excessive capital infrastructure for urban transport has been highlighted by others. Small (1992) notes that there is "widespread suspicion among economists of policies favouring new rail systems. The evidence is strong that in all but very dense cities, equivalent transport can be provided far more cheaply by a good bus system, using exclusive right of way when necessary, to bypass congestion" (p.106).

5.2 Economies of higher speed

Drivers' costs are obviously smaller on a km basis when vehicles are faster. Our coefficient on the inverse of speed would imply a cost of 598 BF per vehicle hour. Now, if one assumes a yearly work load of 1920 hours (40 hours a week times 48 weeks a year) and a wage of 1 million BF, the expected cost is 520 BF per vehicle-hour. The difference between the two figures could be interpreted as time spent off line, 15 per cent in our case (598/520).

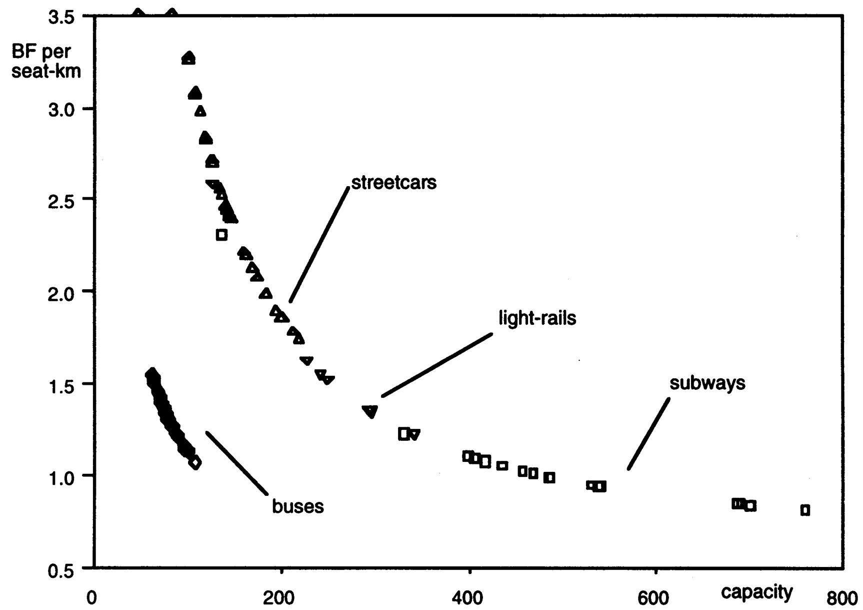

Figure 1
Relation Between the Cost Per Seat-km and Vehicle Capacity

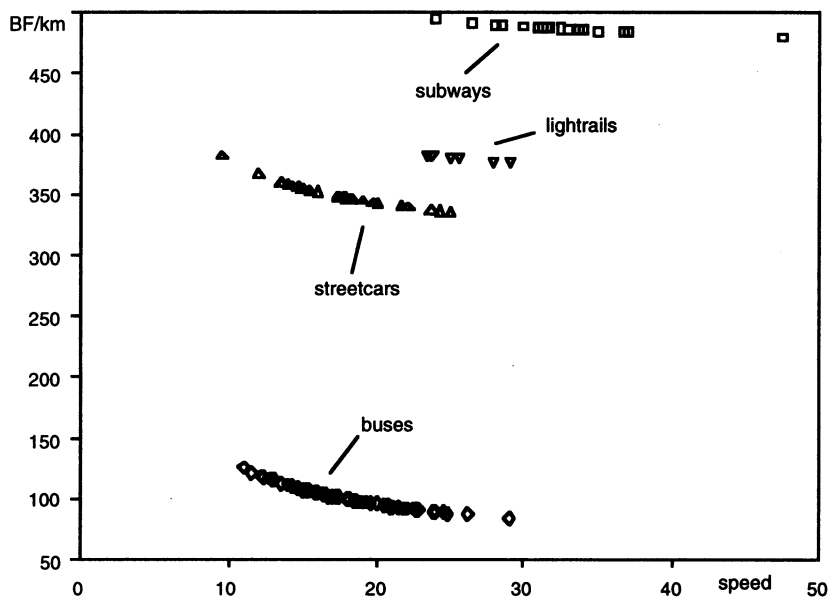

Figure 2
Relation Between Speed and Cost Per Convoy-km

Figure 2 shows costs per convoy-km for different speeds. Other parameters are at sample mean.

The relative impact of speed on costs is much higher for buses than for the other modes. Cost elasticities with respect to speed — which can be interpreted as the share of drivers costs — are equal to –0.392 for buses, –0.121 for streetcars, and –0.047 for underground rail. This confirms the high share of drivers' costs for buses and the much smaller one for streetcars and underground rail.

5.3 Economies of density

Tracks and underground stations generate fixed costs that can be amortised over a low or high number of km. This implies economies of density so that increasing the supply of convoy-km while keeping the infrastructure unchanged results in short-run elasticities of around 0.680 for underground rail and 0.863 for streetcars. Note that these figures are consistent with the ones cited in subsection 4.1 on the share of infrastructure maintenance in costs, and that they are 'average' values — elasticities are not constant for a linear average cost function.

6. Network Comparisons and Role Models

We now return to our network comparisons, but this time controlling for relevant variables. We again concentrate on major networks. Regression scores in Table 1 (column 7) correspond to the ratio of expected to observed costs. Expected costs are fitted values from equation (4) computed for observed independent variables, except for the financing rate which was put at one for each firm. In other words, we controlled for all the variables in the model except subsidies, which were excluded as we found it sensible to compare firms to *average estimated practice in the absence of subsidies.*

The best companies are now, in decreasing order: Basle (1.42), Sheffield (1.34), Manchester (1.31), Antwerp (1.30), Liège (1.20), Mannheim (1.12) and Hanover (1.05). Note that the two British firms are found to be about 30 per cent above average practice which, interestingly enough, is precisely the estimated gain from deregulation mentioned in a micro study by Heseltine and Silcock (1991) for Great Britain!

Looking at the different measures reported in Table 1, we now suggest the names of a few firms that are plausible role models for their peers. One should interpret this with caution as our results depend crucially on data quality. The small number and heterogeneity of underground systems also makes comparisons difficult for some large cities. Finally, one should recall that we only discussed productive performances and did not consider demand arguments.

With this in mind, the first two names that should appear on the list are probably Manchester and Sheffield, whose performances seem remarkable. Labour productivities are high and costs are low before and after controlling for relevant variables. These results are achieved through a combination of cheap mode choice — double-deckers, standard and mini-buses — and high efficiency. Actually there are also LTR systems in Manchester and in Sheffield, but they are managed by different companies from the ones on which we had data.

Other good bus networks are Liège, Winterthur and Lucerne. St.Etienne, Nantes, and to a lesser extent Grenoble, also provide fairly inexpensive services with mostly buses and a few streetcars on the busiest lines (15 to 21 per cent of capacity supplied). Basle and Bonn are only slightly more costly with a bigger share of streetcars in capacity supplied. Antwerp, Mannheim, Dresden and Duisburg appear as very efficient when looking at scores from the regression but are nevertheless expensive due to their mode choice in favour of (small) streetcars.

For bigger networks with a larger share of rail, very good results are achieved by Hanover and Helsinki. The former has a well developed light rail system with large and fast trains. The latter combines buses, streetcars and a very fast underground line. Lyons and Lille are inexpensive with a mix of buses and underground rail (plus a small streetcar for the latter).

Finally, among the very large cities with big underground systems, Barcelona appears as the most efficient. Hamburg, Madrid Metro and Munich are also cheap on a capacity basis.

7. Conclusions

This paper relied on different methodologies for evaluating the productive performance of most major urban transit systems in Europe. The focus was on intermodal and intercity comparisons with some specific attention paid to the impacts of speed, capacity and network density on costs.

Concerning intermodal comparisons, results suggest that streetcars do not fill a significant gap between buses and underground rail. More specifically, most streetcar systems are more expensive than buses even on a seat-km basis, and despite the fact that we considered solely operating costs. Only very large vehicles running at a high speed on densely used tracks could prove economical. While one should include other considerations such as pollution and comfort before making any definite judgment, we believe that there is a strong case against small and slow streetcars. Good light rail systems are likely to be the best future for surface rail in urban areas.

Turning to intercity comparisons, we have identified a few networks that could be useful ‘role models’ for other cities. Admittedly, one has to be very cautious here as this type of judgment is highly sensitive to data quality as well as to the methodologies used. We have nevertheless taken the risk of naming some cities, if only to spur the debate.

The impact of environmental or technical factors on costs are generally well estimated in our regressions. Capacity seems to be cheap for all modes. Speed has a major impact on bus cost but a smaller one on streetcars and underground rail, for which expenditures on drivers are relatively less important. Strong economies of density are associated with the use of tracks and underground stations.

Another point worth mentioning is the important impact of subsidies on costs. This has been highlighted in other studies and is definitely confirmed by our analysis. Along the same line of argument, it appears that the two British firms in our database are far more productive than the average firm in the sample. As we have reason to believe that they are not atypical for Great Britain, it suggests a very significant impact of deregulation on technical efficiency. Orders of magnitude of about 30 per cent mentioned in the literature (Heseltine and Silcock, 1991) are consistent with our findings.

To conclude, we would like to point to the relatively good fit of our estimations. This makes the introduction of some form of yardstick competition (Shleifer, 1985) in the sector of urban public transport very relevant, especially if better data become available.

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