



## **School of Economics and Management**

TECHNICAL UNIVERSITY OF LISBON

Department of Economics

**Carlos Pestana Barros, Jean-Pascal Guironnet, Nicolas Peypoch  
and William Roy**

***Heterogeneity in Technical Efficiency of the French  
Urban Transport: 1995 to 2002***

**WP 17/2008/DE/UECE**

---

**WORKING PAPERS**

ISSN N° 0874-4548



## **Heterogeneity in Technical Efficiency of the French Urban Transport: 1995 to 2002**

Carlos Pestana Barros<sup>a</sup>, Jean-Pascal Guironnet<sup>b</sup>, Nicolas Peypoch<sup>c</sup> and William Roy<sup>d</sup>

<sup>a</sup> Technical University of Lisbon, Portugal.

<sup>b</sup> LAMETA, University of Montpellier I, Department of Economics, France.

<sup>c</sup> GEREM, University of Perpignan, IAE, France.

<sup>d</sup> LET, University of Lyon 2, Faculté des Sciences Economiques et de Gestion, France.

**Abstract:** In this paper, we analyze the heterogeneity in the technical efficiency of a sample of French urban transport companies with a translog production frontier model. The model generates efficiency disentangling homogenous and heterogeneous variables. Our study concluded that outputs and inputs play a major role in transport efficiency and we find that the efficiency scores vary along the sample. Policy implication is derived.

**Keywords:** Urban Transport; France, Translog random Frontier Model and Decision-Making Unit.

## 1. Introduction

Since Aigner, Lovell and Schmidt (1977) established the stochastic frontier model; bus companies technical efficiency has been the focus of a growing number of empirical studies (Jorgensen *et al.* 1995, Viton 1998, Odeck 2003). For example, the study surveyed by Brons, Nijkamp, Pels and Rietveld (2005) showed mixed results among the bus companies analyzed, with some displaying high level of efficiency, while others lagged behind. The importance of analyzing efficiency in the bus industry derives from the need that bus companies have to maintain their effectiveness, performing well in relation to alternative means of transport and increasing their market share by upgrading their productivity. Bus transport policy, Barros and Prieto Rodriguez (2008) has to take into account technical efficiency. In this environment, identifying the inefficient unit is of paramount importance, particularly if it can suggest ways of improving performance and converging towards the “best practice” frontier.

Conceptually, it is useful to distinguish between different types of frontier: parametric, or stochastic frontier models (Kumbhakar and Lovell, 2000), vs. non-parametric, or DEA-Data envelopment Analysis (Charnes *et al.*, 1978). There are several generations of frontier models, namely the old homogenous frontier models (Coelli, Rao and Battese, 1998), and new heterogeneous frontier models (Greene, 2005). Our approach is original since it used for the first time, as far as we know, the random frontier model on bus transportation.

The motivation for the present research is as follows: firstly, past research has analyzed bus industry with either DEA models or stochastic homogenous frontier model. Therefore, the present paper enlarges previous research disentangling the variables in the production frontier in heterogeneous and homogenous (Greene, 2005). Second, the French bus industry provides transport to the population at a social price, which is lower than the costs incurred in its provision. Therefore, the local governments usually finance the deficits of bus companies. However, local organizing authorities are obliged to control public expenditure under the rules established by the national transport law<sup>1</sup> and the European Treaty<sup>2</sup>, forcing public-financed bodies to perform their tasks in a cost-controlling environment. In this context, improving efficiency would seem to be the best way forward (Gagnepain and Ivaldi 2002). Third, since these enterprises operate

---

<sup>1</sup> Loi d'Orientation sur les Transports Intérieurs (LOTI)

<sup>2</sup> Art. 76, 86 and 87, adapted to public transport services by regulation (EEC) n°1191/69, which should be upgraded in a close future by the regulation proposal COM(2005) 319 final.

exclusively in each urban area, they retain some monopoly power, which they cannot exploit because of the price setting that they are obliged to respect. The bus firm can, however, always shift costs from capital costs to operating costs in order to ask for a higher subsidy, or alternatively delay efficiency improvements in periods leading up to the introduction of new tariffs. In fact, the evaluation techniques used by the regulatory body are currently based only on financial reports (Quinet and Vickerman 2004). What it often proves difficult to clarify in an objective manner is the operational efficiency behind the financial reports, since these include no comment on, or analysis of operational performance. This is considered by management theory to be a vital component in a strategy designed to bring about improvements. Finally, two competing theories explain difference performance among firms operating in the same market. First, the strategic-group theory (Caves and Porter, 1977) justifies differences in efficiency scores as being due to differences in the structural characteristics of units within an industry, which in turn lead to differences in performance. Second, resource-based theory (Barney, 1991 and Rumelt, 1991), which justifies different efficiency scores on the grounds of heterogeneity in relation to the resources and capabilities on which the bus companies base their strategies. Which theory explains different efficiency among French urban transport operators? Finally, unobserved heterogeneity has been subject of concern and analysis in many recent works as Chesher (1984), Chesher and Santos Silva (2002) and McFadden and Train (2000). This type of model seems to be frequent in data concerning the behavior of different organizations, and neglecting it is likely to lead to inconsistent parameter estimates.

This paper is organized as follows: in the second section, we present the contextual setting, describing the French bus industry and its characteristics. In section 3, we present a literature review. In section 4, we present the hypothesis. In section 5, we present the data and results. In section 6, we discuss the results. In section 7, we present the contribution and limitations of the paper and finally, in section 8, we present the conclusions.

## **2. Contextual Setting**

The French urban transport is decentralised to local authorities (Kerstens, 1996). These urban authorities choose to provide transport services by its own operator ("régie"), or

alternatively delegates the operation to a private company or to a semi-public company ("société d'économie mixte"). The not 'in-house' operators are legally selected through tendering processes, but competition is not very pregnant when a semi-public company wants to succeed to herself (Roy and Yvrande-Billion 2007). Whenever an organising authority delegates the operation, it signs a contract with the operator. Contracts can be defined according alternative regulating rules (Gagnepain and Ivaldi 2002): (i) the net cost contract ("CFF: Compensation Financière Forfaitaire") which provides incentives on receipts and costs; (ii) the gross cost contract ("GPF: Gestion à Prix Forfaitaire") which allocates risks on costs to the operators and risks on receipts to the public authority and (iii) the management contract ("Gérance"), according to which all risks are borne by the public authority. Yvrande-Billon (2008).

The main private companies are almost three international groups: Kéolis, Connex (Véolia) and Transdev. Data are collected under the responsibility of the CERTU (2003), a ministerial agency, and controlled by the GART (2002), a nation-wide association that gathers most of the local authorities in charge of an urban transport network. The unbalanced panel is composed of 135 French urban transport units, comprising all forms characterised above, including the cited three international groups.

### **3. Literature Review**

There has been relatively extensive research into the bus industry using a variety of methods, Badami and Haider (2007). Seth et al. (2007). Restricting the survey to frontier models, we can see that there are some papers that use the non-parametric DEA model, whilst there are others that use the parametric econometric frontier (De Borger, Kerstens and Costa, 2002).

Chu *et al.* (1992) adopted the DEA model to develop a single measure for the efficiency of a transit system in comparison with other agencies within the same peer group and suggested that the US had improved slightly over the period 1988-1992. Moreover, efficiency and effectiveness were found to be negatively correlated. Chang and Kao (1992) also adopted the DEA model to analyse municipal bus firms. Jorgenson, Pedersen and Solvoll (1995) analysed the efficiency of Norwegian bus firms with a homogenous stochastic frontier model. Kerstens (1996) analysed the efficiency of the French urban transit companies.

Holvad *et al.* (2004) analysed the Norwegian bus industry with a Multi-directional efficiency analysis,<sup>3</sup> concluding that part of the improvement potential for companies in coastal areas is caused by topographical factors beyond the management control. Karlaftis and McCarthy (1997) adopted the DEA model to analyse the US transit system, contradicting the findings of Chu *et al.* (1992) regarding efficiency vs. effectiveness. Jorgenson *et al.* (1997) estimated a homogenous stochastic cost frontier model for the Norwegian bus industry and found no significant differences between public and privately owned operators. Viton (1998) also analysed the US bus industry with DEA in order to develop a single measure of efficiency. Cowie and Asenova (1999) analysed the efficiency of the British bus industry with DEA. Odeck and Alkadi (2001) analysed the efficiency of the Norwegian bus industry with DEA. They find potential for improving efficiency in the sector by about 28%. Odeck (2003) again analysed the efficiency of the Norwegian bus industry with a DEA model. A Man-Whitney rank test was used to test efficiency differences. Karlaftis (2004) used a two-step procedure to analyse the efficiency of the US transit system. In the first stage, a DEA procedure was used to disentangle efficiency from effectiveness. In the second stage, goal programming was used to find economies of scale.

This bibliography is, in our view, relatively brief for what is such an important issue in the context of the bus market. With the present paper, we seek to enlarge upon the economics of transport and to draw the attention of other researchers to this neglected aspect of transport economics.

#### **4. Theoretical Framework**

Our framework is based on two strands of literature: models of industry efficiency and stochastic frontier models.

##### **4.1. Models of Industry Efficiency**

Two competing models of industry efficiency exist in the literature. Firstly, the strategic-group theory (Caves and Porter, 1977) justifies differences in efficiency scores as being due to differences in the structural characteristics of units within an industry, which in turn lead to differences in performance. In the case of bus

---

<sup>3</sup> Using almost the same data as Jorgenson *et al.* (1995) and Odeck and Alkadi (2001).

companies, units with similar asset configurations pursue similar strategies with similar results in terms of performance (Porter, 1979). Although there are different strategic options to be found among the different sectors of an industry, because of mobility impediments, not all options are available to each bus companies, causing a spread in the efficiency scores of the industry. Secondly, the resource-based theory (Barney, 1991; Rumelt, 1991), which justifies different efficiency scores on the grounds of heterogeneity in relation to the resources and capabilities on which the bus companies base their strategies. These resources and capabilities may not be perfectly mobile across the industry, resulting in a competitive advantage for the best-performing bus companies.

Purchasable assets cannot be considered to represent sources of sustainable profits. Indeed, critical resources are not available in the market. Rather, they are built up and accumulated on the bus's premises, their non-imitability and non-substitutability being dependent on the specific traits of their accumulation process. Thus, the difference in resources results in barriers to imitation (Rumelt, 1991) and in the bus managers' inability to alter their accumulated stock of resources over time. In this context, unique assets are seen as exhibiting inherently differentiated levels of efficiency; sustainable profits are ultimately a return on the unique assets owned and controlled by the bus companies (Teece *et al.*, 1997).

#### **4.2 Random Frontier Models**

In this paper, we adopt the stochastic cost econometric frontier approach. This approach, first proposed by Farrell (1957), came to prominence in the late 1970s as a result of the work of Aigner, Lovell and Schmidt (1977), Meeusen and Van den Broeck (1977).

The frontier is estimated econometrically and measures the difference between the inefficient units and the frontier by the residuals. This is an intuitive approach based on traditional econometrics. However, when we assume that the residuals have two components (noise and inefficiency), we have the stochastic frontier model. Therefore, the main issue is the decomposition of the error terms. Let us present the model more formally. The general frontier cost function proposed by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977) is the following:

$$C_{it} = C(X_{it})e^{v_{it}+u_{it}}; \quad i=1,2,\dots,N, t=1,2,\dots,T \quad (1)$$

where  $C_{it}$  represents a scalar cost of the decision-unit  $i$  under analysis in the  $t$ -th period;  $X_{it}$  is a vector of variables including the input prices and the output descriptors present in the cost function. The error term  $e$  decomposes into two components: first, the error term  $v_{it}$  is the one that is traditional of the econometric models, assumed to be independently and identically distributed, that represents the effect of random shocks (noise) and is independent of  $u_{it}$ . Second, the inefficient term  $u_{it}$  represents the technical inefficiencies and is assumed to be positive and distributed normally with zero mean and variance  $\sigma_u^2$ . The positive disturbance  $u_{it}$  is reflected in a half-normal independent distribution truncated at zero, signifying that each bus company's cost must lie on or above its cost frontier. This implies that any deviation from the frontier is caused by management factors controlled by the bus company.

The total variance is defined as  $\sigma^2 = \sigma_v^2 + \sigma_u^2$ . The contribution of the error term to the total variation is as follows:  $\sigma_v^2 = \sigma^2 / (1 + \lambda^2)$ . The contribution of the inefficient term is:  $\sigma_u^2 = \sigma^2 \lambda^2 / (1 + \lambda^2)$ . Where  $\sigma_v^2$  is the variance of the error term  $v$ ,  $\sigma_u^2$  is the variance of the inefficient term  $u$  and  $\lambda$  is defined as  $\lambda = \frac{\sigma_u}{\sigma_v}$ , providing an indication of

the relative contribution of  $u$  and  $v$  to  $\varepsilon = u + v$ .

Because estimation procedures of equation (1) yield merely the residual  $\varepsilon$ , rather than the inefficiency term  $u$ , this term in the model must be calculated indirectly (Greene, 2000). In the case of panel data, such as that used in this paper, Battese and Coelli (1988) used the conditional expectation of  $u_{it}$ , conditioned on the realized value of the error term  $\varepsilon_{it} = (v_{it} + u_{it})$ , as an estimator of  $u_{it}$ . In other words,  $E[v_{it} + u_{it} / \varepsilon_{it}]$  is the mean productive inefficiency for the  $i$  th bus company at any time  $t$ .

But the inefficiency can also be due to heterogeneity of the bus firms. For taking in account heterogeneity we consider the following random effects model:

$$c_{it} = (\beta_0 + w_i) + \beta' \mathbf{x}_{it} + v_{it} + u_{it} \quad (1)$$

where the variables are in logs and  $w_i$  is a time invariant, firm specific random term that captures company heterogeneity.



To estimate the model, the random coefficient model requires the identification condition that the random components of the coefficients be uncorrelated with the explanatory variables. A second issue concerns the stochastic specification of the inefficiency term  $u$ . For the latter, we assume the half normal distribution.

For the estimation of the parameters of this model, we construct the likelihood function using the approach proposed by Greene (2005). With the previous assumptions, the conditional density of  $c_{it}$  given  $w_i$  is:

$$f(c_{it} | w_i) = \frac{2}{\sigma} \phi\left(\frac{\varepsilon_{it}}{\sigma}\right) \Phi\left(\frac{\lambda \varepsilon_{it}}{\sigma}\right), \quad \varepsilon_{it} = c_{it} - (\beta_0 + w_i) - \boldsymbol{\beta}' \mathbf{x}_{it} \quad (2)$$

where  $\phi$  is the standard normal distribution and  $\Phi$  the respective cumulative distribution function. The parameters  $\lambda$  and  $\sigma^2$  were defined before.

Conditioned on  $w_i$ , the  $T$  observations for company  $i$  are independent and therefore the joint density for the  $T$  observations is:

$$f(c_{i1}, \dots, c_{iT} | w_i) = \prod_{t=1}^T \frac{2}{\sigma} \phi\left(\frac{\varepsilon_{it}}{\sigma}\right) \Phi\left(\frac{\lambda \varepsilon_{it}}{\sigma}\right) \quad (3)$$

The unconditional joint density is obtained by integrating the heterogeneity out of the density:

$$L_i = f(c_{i1}, \dots, c_{iT}) = \int \prod_{t=1}^T \frac{2}{\sigma} \phi\left(\frac{\varepsilon_{it}}{\sigma}\right) \Phi\left(\frac{\lambda \varepsilon_{it}}{\sigma}\right) g(w_i) dw_i \quad (4)$$

The log likelihood,  $\sum_i \log L_i$ , is then maximised with respect to the parameters  $\beta_0$ ,  $\boldsymbol{\beta}$ ,  $\sigma$ ,  $\lambda$  and any parameters appearing in the distribution of  $w_i$ . The integral in (4) will be intractable. However, if we take in account that equation (4) can be rewritten in the equivalent form:

$$L_i = f(c_{i1}, \dots, c_{iT}) = E_{w_i} \left[ \prod_{t=1}^T \frac{2}{\sigma} \phi\left(\frac{\varepsilon_{it}}{\sigma}\right) \Phi\left(\frac{\lambda \varepsilon_{it}}{\sigma}\right) \right] \quad (5)$$

We propose to compute the log likelihood by simulation. Averaging the function in (5) over sufficient draws from the distribution of  $w_i$  will produce a sufficiently accurate estimate of the integral in (4) to allow estimation of the parameters (see Train, 2002). The simulated log likelihood is,

$$\log L_s(\beta_0, \boldsymbol{\beta}, \lambda, \sigma, \theta) = \sum_{i=1}^N \log \frac{1}{R} \sum_{r=1}^R \left[ \prod_{t=1}^T \frac{2}{\sigma} \phi\left(\frac{\varepsilon_{it} | w_{ir}}{\sigma}\right) \Phi\left(\frac{\lambda \varepsilon_{it} | w_{ir}}{\sigma}\right) \right] \quad (6)$$

where  $\theta$  includes the parameters of the distribution of  $w_i$  and  $w_{ir}$  is the  $r$ -th draw for observation  $i$ .

## 5. Hypothesis

Consider a French bus company operating in a city. Based in previous research, Roy and Yvrande-Billon (2007), Gagnepain and Ivaldi (2002), the frontier model allows the definition of the following null hypotheses:

*Hypothesis 1 (public vs. private):* Public companies are less efficient than private companies. This hypothesis is based on the traditional hypothesis related to private versus public property in markets (Williamson 1979). This is a traditional assumption in transportation markets (Chang and Kao 1992, Roy and Yvrande-Billon 2007). Reasons to support this hypothesis is that with private ownership the rewards and costs of the activity are more directly concentrated in the stockholders restricting the principal-agent relationship (Jensen and Meckling 1976). However, there are some research that found no evidence that private operators are more efficient than public operators (Caves and Christensen 1980), justifying the present hypothesis. This hypothesis will be tested by the variables public and private (managed, net and gross).

*Hypothesis 2 (Private companies managed by cost plus contract):* Private companies with cost plus contract perform efficiently. This hypothesis is based in the theory of transaction costs and property rights (Grossman and Hart, 1986). This theory is based in two critical assumptions: first, the firms cannot write complete contracts concerning their transport allocation based in the cost-plus rule; second, investments are specific to firms' assets so that the same investment is less valuable with different assets. When both assumptions hold, the theory predicts that firms under-invest because they are afraid that their relationship with the other firm may end at same point. To minimise under-investment, firms allocate dedicated asset specificity (Williamson, 1981), which refers to investment that take place with the prospects of selling a significant amount of product to a particular customer. Therefore, assuming the asset specificity strategy, private companies managed by cost plus contract that are assumed to be efficient. This hypothesis will be tested with the variable managed.

*Hypothesis 3 (Private companies with Net cost Contract):* Private companies with net cost contract perform efficiently searching for profits. This hypothesis is based on previous research on transportation and on the strategic-group theory (Caves and Porter,

1977) which justifies differences in efficiency scores as being due to differences in the structural characteristics of units within an industry. In the case of bus companies, units with similar asset configurations pursue similar strategies with similar results in terms of performance (Porter, 1979). Although there are different strategic options to be found among the different sectors of an industry, because of mobility impediments, not all options are available to each bus companies, causing a spread in the efficiency scores of the industry. Therefore it is assumed that French private bus companies, with net cost contract, adopt this type of contract because it corresponds to a strategy inherent to an efficient drive. This hypothesis will be tested by the variable Net.

*Hypothesis 4 (private companies with gross cost contract):* Private companies with gross cost contract perform efficiently searching for profits. This hypothesis is based on previous research on the resource-based theory (Barney, 1991; Rumelt, 1991), which justifies different efficiency scores on the grounds of heterogeneity in relation to the resources and capabilities on which the bus companies base their strategies. These resources and capabilities may not be perfectly mobile across the industry, resulting in a competitive advantage for the best-performing bus companies. Purchasable assets cannot be considered to represent sources of sustainable profits. Indeed, critical resources are not available in the market. Rather, they are built up and accumulated on the bus's premises, their non-imitability and non-substitutability being dependent on the specific traits of their accumulation process. Thus, the difference in resources results in barriers to imitation (Rumelt, 1991) and in the bus managers' inability to alter their accumulated stock of resources over time. In this context, unique assets are seen as exhibiting inherently differentiated levels of efficiency; sustainable profits are ultimately a return on the unique assets owned and controlled by the bus companies (Teece *et al.*, 1997). This hypothesis is tested with the variable Gross.

These hypotheses will be tested with the random frontier model.

## **5. Data and Results**

To estimate the production frontier, we used panel data on French urban transport companies for the years 1995 to 2002 (8 years, 135 units resulting in an unbalanced panel data of 981 observations). The data was obtained from two sources, a ministerial agency,

CERTU,<sup>4</sup> and a nation-wide professional organisation that gathers most of the local authorities in charge of an urban transport network, GART.<sup>5</sup>

Frontier models require the identification of inputs (resources) and outputs (transformation of resources). Several criteria can be used in their selection. One empirical criterion is available. For the applicability of the model's results and its management, it is important to "buy in" to the process that the measures of inputs and outputs are relevant and adequately measurable, and that appropriate archival data are available. Usually this latter criterion is used, since it encompasses the other two already mentioned criteria. Secondly, the literature survey is a way of ensuring the validity of the research and therefore constitutes another criterion that needs to be taken into account. The final criterion for measurement selection is the professional opinion of managers. In this paper, we follow the first two criteria.

Table 1 presents the characteristics of the variables used in the analysis. We transformed the variables according to the description column. We adopted the traditional log-log specification to allow for the possible non-linearity of the frontier.

**Table 1: Descriptive Statistics of the Data 1995-2002**

Variable	Description	Minimum	Maximum	Mean	Standard deviation
Log (Vehicle-Km)	The number of kilometers cover by vehicles	5.251	7.056	6.169	0.445
Log (Labour1)	The number of equivalent employees-drivers	1.945	6.537	4.118	1.063
Log(Labour2)	The number of equivalent employees non-drivers	-0.693	4.036	2.997	1.562
Log (Energy)	The quantity of diesel m3 consumed	1.799	6.779	4.777	1.659
Log (Vehicles)	The number of vehicles	1.609	4.127	3.819	2.103
Log (network length)	The total lines length	2.639	5.319	4.790	0.805
Log Journey	The number of journey <sup>6</sup>	5.153	10.553	8.170	—
<i>Public</i>	Public company	0	1	0.065	—
<i>Managed</i>	Private company operating under management (cost-plus) contract	0	1	0.145	—
<i>Net</i>	Private company with net cost contract	0	1	0.326	—
<i>Gross</i>	Private company with gross cost contract	0	1	0.253	—

<sup>4</sup> Centre d'Etude et de Recherche sur les Transports Urbains.

<sup>5</sup> Groupement des Autorités Responsables du Transport.

<sup>6</sup> A trip usually involves more than one single journey. Typically, if somebody travel in two different buses to reach her destination (a unique trip), the number of journey counted is two.

The variable Semi-public is not considered in the analysis to avoid perfect collinearity with public and private variables (Gujarati, 2003, page 302). In this condition the constant will represent the mean value of the semi-public.

## 5.1 Results

The translog is flexible functional form that provides a second order approximation to any arbitrarily twice differentiable function. The production function does not employ separability and homogeneity hypothesis; neither assumes constant or unitary elasticity of substitution between inputs. Rather, the separability and homogeneity assumptions can be tested and the values of elasticity of substitution vary for every data point in the input space. Although the translog functional form has these advantages, there are some limitations. First, the translog function does not always provide a good approximation over a wide range of observations. The curvature conditions of the production function (monotonicity and quasi-concavity) can be violated, even though the approximating function fits the data very well. This however, does not necessarily imply the absence of an underlying profit-maximizing process of the production function, but simply reflects the inability of the functional form to approximate the true function over the range of the data. Secondly, if used as an exact form, the translog functional forms are inflexible in providing a second-order approximation to an arbitrarily weakly separable function, Blackborby et al. (1977).

In this study, we estimate a stochastic Translog production function with four inputs (Labour, Energy, Vehicles, Network Length), one output descriptors (Journey) and contextual variables (Public, Semi-public, Managed, NET, GROSS).

$$\begin{aligned}
 \log(\text{Vehicle} - Km_{it}) &= \tau_0 + \tau_1 t + \frac{1}{2} \tau_2 t^2 + \sum_{k=1}^m \alpha_k \ln Y_{kit} + \sum_{j=1}^n \beta_j \ln X_{jit} + \\
 &\frac{1}{2} \left[ \sum_{k=1}^m \sum_{r=1}^m \pi_{kr} \ln Y_{kit} \ln Y_{rit} + \sum_{j=1}^n \sum_{s=1}^n \delta_{js} \ln X_{jit} \ln X_{snt} \right] + \sum_{k=1}^m \sum_{j=1}^n \theta_{kj} \ln Y_{kit} \ln X_{jit} + \\
 &+ \eta \text{Public}_{it} + \kappa \text{Semipublic}_{it} + \varsigma \text{NET} + \zeta \text{Gross} + (V_{it} - U_{it})
 \end{aligned} \tag{1}$$

This is the production frontier model, known as the error components model in Coelli, Rao and Battese (1998) where  $\log(\text{Vehicle} - Kms_{i,t})$  is the natural logarithm of the output);  $\log X_{jit}$  is the natural logarithm of the  $j^{\text{th}}$  input (Labour, Energy, Vehicles,

Network Length) from bus company  $i^{\text{th}}$  in period  $t$ ;  $\log Y_{kit}$  is the natural logarithm of the  $k^{\text{th}}$  output descriptor (Journeys) from the bus company  $i$  in period  $t$ . Public, Semi-public, Net and Gross are dummy variables to account for the property role in the technical change and  $\tau_0, \tau_1, \tau_2, \alpha_k, \phi_k, \beta_j, \psi_j, \pi_{kr}, \delta_{js}, \theta_{kj}, \eta, \kappa, \zeta, \zeta$  are coefficients to be estimated. The usual symmetry restrictions are imposed in estimating the model, following Young's theorem that requires the symmetry restrictions, which correspond to:

$\pi_{kr} = \pi_{rk}$  for all  $k$  and  $r$ , and  $\delta_{js} = \delta_{sj}$  for all  $j$  and  $s$ . These restrictions reduce the number of parameters to be estimated, Cornes (1992).

Table 2 presents the results obtained for the stochastic frontier adopting a half-normal distribution specification for the costs function frontier. For comparative purposes, a non random frontier model alongside a traditional cost function is estimated. A Gauss program was used.

**Table 2: Stochastic Translog panel cost frontier  
(Dependent variable: Log Vehicle-Km)**

Variables	Translog Random Frontier model	Translog Non Random Frontier Model
Non-random parameters	Coefficients (t-ratio)	Coefficients (t-ratio)
Constant	6.128 (4.238)*	8.132 (5.218)*
Trend	1.035 (3.678)*	1.532 (3.156)*
log Labour 1	0.016 (3.182)	0.052 (2.932)*
log Labour 2	0.021 (4.218)*	0.085 (3.219)*

log energy	0.021 (4.129)*	0.018 (5.543)*
log Vehicles	0.052 (4.219)*	0.061 (3.693)*
log Network Length	—	0.205 (3.128)*
log Journey	—	0.071 (4.125)*
1/2 Trend*Trend	-0.052 (2.316)	-0.123 (2.127)
1/2 log Labour1* log Labour1	0.238 (1.179)	0.073 (3.183)*
1/2 log Labour2* log Labour2	0.145 (2.217)	0.176 (1.045)
1/2 log energy* log energy	0.650 (1.844)	0.082 (4.126)
1/2 log Vehicles * log Vehicles	0.282 (4.052)*	0.015 (1.021)
1/2 log Network Lengh * log Network Length	0.321 (1.732)	0.285 (2.318)
1/2 log Journey * log Journey	0.125 (3.218)	0.218 (2.715)
Trend*log Labour1	0.313 (5.210)*	0.0214 (2.892)
Trend*log Labour2	0.163 (1.219)	0.094 (2.056)
Trend*log Energy	0.032 (0.032)	0.0321 (2.967)
Trend*log Vehicles	0.021 (3.328)*	0.162 (2.167)
Trend*log Network Length	-0.018 (-2.218)	-0.021 (3.127)*
Trend*log Journey	0.579 (2.626)*	0.417 (3.219)*
Log labour1*log Labour2	1.345 (4.218)*	1.046 (3.285)*
logLabour1*log Energy	1.076 (2.229)*	1.217 (3.128)
Log Labour1*log Vehicles	-0.024 (-0.025)	0.158 (3.892)*
Log Labour1* log Network Length	-0.257 (-2.783)	0.281 (2.837)*
Log Labour1*log Journey	0.217 (3.129)	0.521 (3.674)
Log labour2*log Energy	0.567 (4.789)*	0.674 (3.852)
Log Labour2* log Vehicles	0.357 (3.185)	0.289 (4.219)
Log Labour2*log Network length	0.178	0.135

	(2.954)	(3.078)
Log Labour <sup>2</sup> *log Journey	0.578 (3.976)	0.843 (2.986)
Energy*Vehicles	0.052 (3.742)*	0.072 (3.219)
Energy*Network Length	0.014 (1.236)	0.027 (3.218)
Energy*Journeys	0.975 (2.413)*	1.127 (2.893)
Vehicles*Network Length	-0.032 (-2.521)	-0.032 (-3.894)
Vehicles*Journey	0.085 (2.021)	0.073 (1.218)
Network Length*Journey	0.328 (5.218)	0.518 (2.453)
Public	-0.031 (-3.156)*	-0.025 (-2.218)
Managed	0.041 (3.217)*	0.032 (2.931)
Net	0.014 (3.232)*	0.027 (2.127)
Gross	0.018 (3.532)*	0.015 (3.112)
Mean of Random parameters		
Log Network length	0.219 (3.217)*	—
Log Journeys	0.082 (4.321)*	—
Scale Parameters for Dists. of Random Parameter		
Log Network Length	0.352 (3.892)*	—
Log Journeys	0.129 (4.521)*	—
$\sigma = [\sigma_V^2 + \sigma_U^2]^{1/2}$	0.105 (3.628)*	0.258 (3.892)*
$\lambda = \sigma_U / \sigma_V$	0.112 (3.521)*	0.281 (2.837)*
Log likelihood		
	1252.343	1200.128
Chi Square with 2 degrees of freedom (prob.)	2504.66 (0.000)	—
Observations	981	981

*t* statistics in parentheses are below the parameters; those followed by \* are significant at 1% level.

A first step in the estimation procedure was to check the sign of the third moment and the skewedness of the OLS residuals associated with the sample data (Waldman, 1982). The



third moment for the terminal frontier was  $-0.181$ , the negative sign implying that the residuals possess the correct pattern for the implementation of the maximum likelihood estimation procedure used in the frontier models. In the literature survey, we find out that for the most part, the papers on bus efficiency use the traditional Cobb-Douglas model. A conventional reason for using this model is the data span used in the analysis. An additional reason stems from statistical tests (usually a likelihood test which compares the likelihood function value for each model). However, it is recognised that the Cobb-Douglas model possesses several restrictive characteristics that make it undesirable, particularly if we have a data span that allows the estimation of a less restrictive model, such as the Translog. Among these undesirable characteristics, the Cobb-Douglas assumes that all bus companies have the same production, scale elasticities and unitary elasticities of substitution. The Translog model overcomes all these restrictions, being a more flexible functional form. However, the final decision between Translog and Cobb-Douglas is based on the likelihood test of both functional forms, with the Translog doing a better job in explaining variations in the sample data used in this paper compared to the Cobb-Douglas function. These problems become more serious when excluded inputs are unobservable to the researcher, but observable to the producer. This situation influences the input mix and causes the explanatory variable matrix to be correlated with the error vector (Fuss *et al.*, 1978). The Translog frontier model was estimated without the traditional share equations in order to not introduce further restrictions into the estimated parameters (Khumbhakar and Lovell, 2000). The use of share equations in frontier models allows the desegregation of overall cost inefficiencies into technical and allocative components, but it is subject to a restrictive hypothesis, which makes them almost unusable for efficient analysis (Kumbhakar and Lovell, 2000). To allow direct interpretation of the first order Translog parameters as elasticities evaluated at the sample mean, every series was divided by its average (Coelli *et al.*, 2003, page 33).

It can be verified that the production function specified above fits the data well, as both the R-squared value and the overall F-statistic from the initial ordinary least-squares estimation used to obtain the starting values for the maximum-likelihood estimation are high. Having estimated two competing models, the homogeneous Translog frontier model and the heterogeneous Translog frontier model, the Likelihood test enables the selection of the most adequate functional form, which is the heterogeneous frontier model in the present case. The likelihood test is a statistical test of goodness of fit between two competing models. It compares models with different number of parameters. Comparing the models, the Likelihood test has a chi-square distribution with 2 degree of freedom and, in the present

case, its value is 1252.343, with a critical value for  $p=0.01$  equal to 8.991. Therefore, it is concluded that the Heterogeneous frontier model describes better the data set than the Translog model.

We also compute the chi-square statistics that serve as a general specification test of adding variables to model. Based on the estimated values, it can be concluded for a critical value for  $p=0.000$  that the chi-square is equal to 2504.66. Therefore, it is concluded that the addition of variables by the heterogeneous frontier model is supported by the test, signifying that the heterogeneous frontier better describes the data set. Finally, the Sigma square and lambda variables of the frontier models are statistical significant, which means that a traditional cost function is unable to capture adequately all dimensions of the data set. Both variables are statistical significant. The value of parameter lambda is positive and statistically significant in the stochastic inefficiency effects.

We also verify that the coefficients of the variables have the expected signs, with the production growing with the trend signifying technological improvement during the period. Moreover, the production increases at decreasing rate according the trend square variable, signifying that technological improvement increases at decreasing rate.

Finally, the production increases with all variables with the exception of the output descriptor of managerial practice: Public company. The rationality for this negative values are that public companies under cost contracts shrink their production to ensure adequate profits, which is a sound economic transport policy, that may results in lower quality and decreasing production. Moreover, network length and journeys parameters are random parameters, meaning that they vary along the sample. The identification of the mean values of random parameters means that the number of networks and journeys are heterogeneous through the sample. Therefore, a policy to increase production has to take into account this heterogeneous characteristic of the sample. Thus, a common policy can be defined for the sample based on the average values of the homogeneous variables, but no common policy can achieve all clusters identified in heterogeneous variables. Different policies for the different segments companies by network length and journey are needed. The model does not identify how many clusters exist in the sample and identifies only their heterogeneous nature. However, other techniques can be applied to identify the clusters (Orea and Kumbhakar, 2005). The scale parameters of the heterogeneous variables are small but statistical significant, meaning that the heterogeneity of the variables is statistical supported.

## 6. Economic Implications of the Study

This paper has proposed a simple framework for the evaluation of urban transit companies and the rationalisation of their management activities, taking into account the traditional input and output descriptors of transport activity. The analysis is based on a random stochastic production frontier model, allowing for the incorporation of contextual variables. Since the paper uses an unbalanced data set, it cannot present efficient scores for each company.

How do we interpret these results? The main result of the present paper is that random frontier models better describe French bus companies than homogeneous frontier models. The implication of this result is that a common government policy towards French bus companies is unable to reach all companies, since heterogeneity exists relative to the network length and journeys obtained. Therefore any economic policy targeting any of these heterogeneous variables has to be tailored by clusters.

What is the rationality of this result? This is an intuitive result, since bus companies are not homogeneous. There are small, large and medium companies defined by network length and the journeys performed. These visible characteristics translate into different performances obtained in the market, resulting in different clusters in the market. These clusters are distinguished from each other based on network length and journey. This result also signifies that French bus companies are relatively homogeneous on the labour, energy and vehicles. With regard to labour, this means that competition over resources drives the market and translates into homogeneous dynamics in the labour market. Additionally, in the case of vehicles and energy, it signifies that a certain level of investment in capital is a pre-requisite in this market, which translates into homogeneous behaviour.

Another result is that the trend is positive: the production increases over time. This is an expected result for this industry. Bus industry is driven by technology improvements, based on intense competition observed in the market; therefore a positive sign is expected for the production frontier. Moreover the trend is at a decreasing rate. Third, the lambda inefficient parameter signifies that on average 28.1% of the costs are imputable to inefficiency according to the homogenous frontier. The blurring of heterogeneity with inefficiency is therefore a generic characteristic of homogenous stochastic frontier models. However, this value translates into 11.2% in the heterogeneous frontier, signifying that heterogeneity translates into inefficiency in the homogenous frontier models. Moreover the sigma is smaller in the random frontier model, signifying that the average homogenous inefficiency includes heterogeneity.

How do these results compare with the findings in similar research? The main conclusion is that the inefficient parameters are relatively low, when compared with similar results of Jorgenson *et al.* (1997). However, the period of analysis is different and this fact may explain the different efficient scores. In the period analysed competition among different transport modes has increased at European level forcing bus companies to adopt efficient procedures. Consequently, this phenomenon should be reflected in better performance, lower customer prices and improved service quality. Competitive pressures force every bus company to be close to the frontier of best practices. This signifies that these companies work under more, or less, similar managerial procedures and allocation rules. This rule forces the companies to converge to the frontier displaying a small lambda. Mergers and acquisitions are expected to follow a deregulation process, Odeck (2008).

What is the policy implication of the present research? The main policy implication, based on the result of labour variable, is that the competition by resources drives the market and translates in homogenous dynamics. Additionally, the results of capital and vehicles variables signifies that a certain level of investment is a pre-requisite in this market translating into homogenous behaviour. Having invested, the French bus companies display different dimensions measured by the value of the assets, and different locations. This dimension defines network length and the population served, which translates statistically in heterogeneity. Heterogeneity represents characteristics that influence the cost of the French bus companies analysed, which are not measured or observed but are displayed in the measurement errors.

How do we interpret the hypothesis? We accept hypothesis 1, validating that the private enterprises are more efficient than public enterprises. This validation results directly from the results, with the public dummy decreasing production, while all other private characteristics (managed, net, gross) increase production. This result is validated by previous research in this field, Yvrande-Billon (2007), Roy and Yvrande-Billon (2007). Moreover, we accept hypothesis 2 since managed is positive and statistically significant. This result is supported by the competition supported by cost-plus private companies in the market. Furthermore, we accept hypothesis 3, because Net is positive and statistically significant. Finally, we accept hypothesis 4, because Gross is positive and statistically significant. This result is in line with Roy and Yvrande-Billon (2007) signifying that private enterprises are organizational focused on performance, Brewer and Hensher (1998), and differences may arise in quality, Hensher and Stanley (2003) which we could not take into account.

Which theory (strategic group theory vs. resource based theory) explains differences in efficiency among French bus companies? Both theories explain a part of the reality analysed. Difference in structural characteristics (for example public and private) leads to differences in performance, validating the strategic group theory, (Caves and Porter, 1977). Differences in human and material resources results in heterogeneity in performance, validating the resource based theory (Barney, 1991 and Rumelt, 1991). The general conclusion is that competition is that heterogeneity is a main issue in French bus companies.

## **7. Contribution, Limitations and Extensions of this Study**

In the light of the extensive literature on productivity in the bus industry, it is useful to consider the potential contributions of the current research. Based on the literature survey, we estimated a random stochastic frontier model for urban transport efficiency. Moreover, we adopted the error component model proposed by Coelli *et al.* (1998), which takes into account efficiency that is due to the enterprise. Finally, our stochastic production frontier model lends support to similar works by Jorgensen *et al.* (1995), Jorgensen *et al.* (1997).

However, it is worth noting that our construct has a stronger theoretical foundation, since it takes into account the heterogeneity, Chesher (1984), Chesher and Santos-Silva (2002), McFadden and Train (2000). Heterogeneous behavior is commonly observed in the market; not to take it into account is likely to lead to inconsistent parameter estimates or more importantly, inconsistent policy definitions. Therefore any transport policy has to take this heterogeneity in account when defining a public policy towards the French bus companies. The homogeneity of the bus companies used in the previous research is questionable, since it compared units of different characteristics.

A variety of extensions can be made to this paper. Firstly, based in the heterogeneity identified a latent production frontier (Orea and Kumbhakar, 2004) can identify endogenous segments. Second, a cost frontier model could be applied in order to identify economies of scale and scope.

## **8. Conclusion**

This article has proposed a simple framework for the evaluation of public transport companies and the rationalisation of their operational activities. The analysis is based on a production frontier model that allows for the incorporation of multiple inputs and outputs in determining relative efficiencies. The disentangling of homogenous and heterogeneous variables was achieved. Several interesting and useful managerial insights and implications arise from the study. The general conclusion is that the heterogeneity exists in the some variables and, therefore, homogenous transport policy is unable to achieve in a symmetric way all companies. Homogenous stochastic frontier models blur heterogeneity with inefficiency, Greene (2005). Therefore, the present result is an improvement in the measurement of organizational technical efficiency.

The results suggest that labour, energy and vehicles are the main determinant factors of efficiency in this sector. A management policy for improving efficiency should take these results into account. Further research is needed to confirm the present research.

## References

- Aigner, D.J., Lovell, C.A.K. and Schmidt, P. (1977). "Formulation and Estimation of Stochastic Frontier Production Function Models". *Journal of Econometrics*, 6, 21-37.
- Badami, M. and Haider, M. (2007) An analysis of public and Transit performance in Indian Cities. *Transportation Research Part A*, 41, 10, 961-981.
- Blackborby, C.; Primont, D. and Russell, R.R. (1977) On testing separability restrictions with flexible functional forms. *Journal of Econometrics*, 5, 195-209.
- Barney, J. (1991). "Firm Resources and Sustained Competitive Advantage". *Journal of Management*, 17, 99-120.
- Barros, C.P. and Prieto Rodriguez, J. (2008). "A Revenue-Neutral Tax Reform to Increase Demand for Public Transport Services". *Transportation Research Part A: Policy and Practice* (forthcoming)
- Battese, G.E. and Coelli, T.J. (1988). "Prediction of Firm-Level Technical Efficiencies with a Generalised Frontier Production Function and Panel Data". *Journal of Econometrics*, 38, 387-99.
- Brewer, A.M. and Hensher, D.A. (1998) The importance of organizational commitment in managing change: Experience of NSW private bus industry. *Transportation Research Part E*, 34,2, 117-130.
- Brons, M., P. Nijkamp, E. Pels and P. Rietveld (2005). "Efficiency of Urban Public Transit: A Meta Analysis". *Transportation*, 32, 1-21.

- Caves, D.W. and L.R. Christensen (1980), "The Relative Efficiency of Public and Private Firms in a Competitive Environment: The Case of Canadian Railroads". *Journal of Political Economy*, 88, 958-76.
- Caves R. and Porter M.E. (1977). "From Entry Barriers to Mobility Barriers: Conjectural Decisions and Contrived Deterrence to New Competition". *Quarterly Journal of Economics*, 91, 241-61.
- CERTU, (2003). *Transport Collectifs Urbains- Evolution 1997-2002*. Lyon.
- Chang, K.P. and Kao, P.H., (1992). "The Relative Efficiency of Public versus Private Municipal Bus Firms: An Application of Data Envelopment Analysis". *Journal of Productivity Analysis*, 3, 67-84.
- Charnes, A., Cooper, W.W. and Rhodes, E. (1978). "Measuring the Efficiency of Decision Marketing Units". *European Journal of Operational Research*, 2, 6, 429-44.
- Chesher, A. (1984). "Testing for Neglected Heterogeneity". *Econometrica*, 52, 865-72.
- Chesher, A., and J. Santos-Silva (2002). "Taste Variation in Discrete Choice Models". *Review of Economic Studies*, 69, 147-68.
- Chu, X., Fielding, G.J., Lamar, B.W. (1992). "Measuring Transit Performance using Data Envelopment Analysis". *Transportation Research*, 26A, 3, 223-30.
- Coelli, T.J., Rao, P., Battese, G.E., (1998). *An Introduction to Efficiency and Productivity Analysis*. Kluwer Academic Press.
- Coelli, T.; Estache, A.; Perelman, S. and Trujillo, L. (2003) A primer on efficiency measurement for utilities and transport regulators. Washington, World Bank.
- Cornes, R. (1992) *Duality and Modern Economics*. Cambridge: Cambridge University Press.
- Cowie, J. and Asenova, D. (1999). "Organisational Form, Scale Effects and Efficiency in the British Bus industry". *Transportation*, 26, 3,231-48.
- De Borger, B.; Kerstens, K. and Costa, A. (2002). "Public Transit Performances: What does one Learn from Frontier Studies?". *Transport Reviews*, 22, 1, 1-38.
- Farrell, M.J., (1957). "The Measurement of Productive Efficiency". *Journal of the Royal Statistical Society, Series A*, 120, 3, 253-90.
- Fuss, M., McFadden, D. and Mundlak, Y. (1978). *A Survey of Functional Forms in the Microeconomic Analysis of Production*. In *Production Economics: A Dual Approach to Theory and Applications*, M. Fuss and D. McFadden, eds., Amsterdam: North-Holland.
- Gagnepain, P. and Ivaldi, M. (2002). "Incentive Regulation Policies: The case of Public Transit Systems in France". *Rand Journal of Economics*, 33, 4, 605-29.
- GART (2002). *Les Chiffres de références des transports publics*. Paris.
- Greene W. (2000). *Econometric Analysis*. (4<sup>th</sup> ed.), London, Prentice Hall.
- Greene, W. (2005). "Fixed and Random Effects in Stochastic Frontier Models". *Journal of Productivity Analysis*, 23, 7-32.
- Grossman S. J., and O. D. Hart, (1986). "The Cost and Benefit of Ownership: A Theory of Lateral and Vertical Integration," *Journal of Political Economy*, 94, 691-719.

- Gujarati, D.N. (2003). *Basic Econometrics*. Macgraw Hill, N.Y. (4<sup>th</sup> edition).
- Hensher, D. and Stanley, J. (2003) Performance based quality contracts in bus service provision. *Transportation Research Part A*, 37,6, 519-538.
- Holvad, T.; Hougaard, J.L.; Kronborg, D. and Kvist, H.K. (2004). "Measuring Inefficiency in the Norwegian Bus Industry using Multi-Directional Efficiency Analysis". *Transportation*, 31, 3, 349-69.
- Jensen, M.C., Meckling, W., (1976). "Theory of the Firm: Managerial Behaviour, Agency Costs and Capital Structure". *Journal of Financial Economics*, 3, 305-60.
- Jorgensen, F., Pedersen, P. and Solvoll, G. (1995). "The Cost of Bus Operators in Norway", *Journal of Transport Economics and Policy*, 29, 253-62.
- Jorgensen, F.; Pedersen, P.A., Volden, R., (1997). "Estimating the Inefficiency of the Norwegian Bus Industry from Stochastic Cost Frontier Models", *Transportation*, 24, 421-433.
- Karlaftis, M.G., (2004). "A DEA Approach for Evaluating the Efficiency and Effectiveness of Urban Transit Systems", *European Journal of Operational Research*, 152, 354-64.
- Karlaftis, M.G. and MaCarthy, P.S., (1997). "Subsidy and Public Transit Performance: A Factor Analytic Approach", *Transportation*, 24, 253-70.
- Kerstens, K., (1996). "Technical Efficiency Measurement and Explanation of French Urban Transit Companies". *Transportation Research, A*, 30, 431-52.
- Khumbhakar, S.C. and Lovell, C.A.K. (2000). *Stochastic Frontier Analysis*. Cambridge University Press, N.Y.
- McFadden, D., and K. Train, (2000). "Mixed MNL Models of Discrete Response". *Journal of Applied Econometrics*, 15, 447-70.
- Meeusen, W. and van den Broeck, J. (1977). "Efficiency Estimation from a Cobb-Douglas Production Function with Composed Error". *International Economic Review*, 18, 435-44.
- Odeck, J., (2003). "Ownership, Scale Effects and Efficiency of Norwegian Bus Operators: Empirical Evidence", *International Journal of Transport Economics*, 30, 3, 305-25.
- Odeck, J. and Alkadi, A., (2001). "Evaluating Efficiency in the Norwegian Bus Industry using Data Envelopment Analysis", *Transportation*, 28, 211-32
- Odeck, J. (2008) The effects of merger on efficiency and productivity in public transport services. *Transport Research Part A* (forthcoming).
- Orea, L., Kumbhakar, S., (2004). "Efficiency Measurement using a Latent Class Stochastic Frontier Model". *Empirical Economics*, 29, 169-83.
- Porter, M.E. (1979). "The Structure within Industries and Companies' Performance". *The Review of Economics and Statistics*, 61, 214-27.
- Quinet, E. and Vickerman, R. (2004). *Principles of Transport Economics and Policy*. Edward Elgar, Cheltenham.



- Roy, W. and Yvrande Billon, A. (2007). "Ownership, Contractual Practices and Technical Efficiency: The Case of Urban Public Transport in France". *Journal of Transport Economics and Policy*, 41, 2, 257-82.
- Seth, C.; Triantis, K. and Teodorovic, D. (2007) Performance evaluation of bus routes: A provider and passenger perspectives. *Transportation Research Part E*, 43, 4, 453-478.
- Rumelt, R. (1991). "How much does Industry Matter?". *Strategic Management Journal*, 12, 2, 167-85.
- Teece D.; Pisano G. and Shuen A. (1997). "Dynamic Capabilities and Strategic Management". *Strategic Management Journal*, 18, 7, 509-33.
- Train, K. (2002). *Discrete Choice: Methods with Simulation*, Cambridge University Press.
- Viton. P.A., (1998). "Changes in Multi-Mode Bus Transit Efficiency, 1998-1992", *Transportation*, 25, 1-21.
- Waldman, D. (1982). "A Stationary Point for the Stochastic Frontier Likelihood". *Journal of Econometrics*, 18, 275-9.
- Williamson, O.E. (1981). "The economics of organization: The transaction cost approach". *American Journal of Sociology*, 87, 548-77.
- Williamson, O.E. (1979). "Transaction-Cost Economics: The Governance of Contractual Relations." *Journal of Law and Economics*, 22, 233-26.
- Yvrande-Billon, A. (2008). "Combining Competitive Tendering with Formal and Informal Ex Post Mechanisms - Evidence from the French Urban Public Transport Sector". *Transport Reviews*, forthcoming.