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STOCHASTIC FRONTIER MODELS FOR PUBLIC TRANSPORT

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Abstract

In the Netherlands a study was carried out to identify factors which have an effect on the level of public transport subsidies to cities and regions and to examine whether inefficiencies exist in this sector. Stochastic frontier production and cost functions were estimated. The results suggest that structural characteristics such as address density play a role in explaining the operating cost. Indications for the existence of inefficiencies were found in all firms and regions.

INTRODUCTION

In the Netherlands, as in many other countries of the European Union, there is a growing concern for the need to improve efficiency in the allocation of scarce resources and to curtail government expenditures. In the field of transport planning, the payment of subsidy to support public transport is being hotly debated, particularly in the light of discussions over decentralisation, deregulation and possible privatisation. The Dutch Government is determined to allow market forces to play a major role. This policy is largely in line with the Directives issued by the European Commission which favours an open market in an enlarged EU. The efforts and the lessons learnt in the Netherlands will likely be beneficial not only to the EU countries but also to others. Results of the Dutch study can enhance our knowledge and provide a better understanding of using techniques that are not widely known, such as stochastic frontier models, as tools for the assessment of performance and the identification of inefficiencies.

The aim of this paper is twofold:

- to describe the research efforts in the Netherlands to determine which factors should be included in a new subsidy mechanism for the amount which cities and regions of various sizes will receive as operating subsidy payment from the central government; and
- to present the results and findings of a specific study using stochastic frontier models to estimate the extent of inefficiency at different levels of public transport operation.

In the paper we shall focus on the subsidy paid to support the operating cost for bus, tram and metro; for the investment cost (construction of new infrastructure) and the operating costs for railways separate subsidy mechanisms exist in The Netherlands. The present system (for 1997) for subsidising bus, tram and metro consists of two steps. The first step is the allocation of the dedicated central government budget to regional and local authorities and public transport companies. The second step is at the moment basically a shift from the regional and local authorities to public transport companies providing services in these areas. In the envisaged new system (some experiments using it have already taken place) the first step will only involve regional/local authorities. The second step will involve tender procedures in which several public transport companies compete for providing public transport on the regional/local networks.

The paper is divided into seven sections. Section 2 outlines the background leading to the research, together with a description of the goals and objectives of the study. Section 3 presents the stochastic frontier model and gives a brief review of its potency as an instrument for policy analysis in comparison with other performance appraisal techniques such as benchmarking and Data Envelopment Analysis. Section 4 describes the data that have been used in the study. Section 5 gives the estimation results when the model is applied to production functions. Section 6 provides the outcomes when the model is applied to cost functions. In Section 7 the paper concludes with an overview of the main findings and indicates to potential users how stochastic frontier models can be used to assist policy planning and project evaluation.

BACKGROUND AND STUDY AIMS

In 1997, revenue support (government subsidy) to finance the operational deficits in urban and regional transport in the Netherlands amounted to 1.9 billion guilders. In pursuit of sustainable growth and development, the Dutch Government recognised at an early stage the need to have an efficient public transport system. The main policy goals have been laid down in the Second Transport Structure Plan, namely: improved accessibility, guided mobility, quality environment and enhanced road safety. Over the years, the Dutch Government has invested in new infrastructures and made a substantial contribution to municipal authorities and operating companies to ensure adequate provision of public transport services.

More recently, changes in public attitudes to government spending have led to renewed efforts in the search for higher efficiency and greater savings. Research studies from ECMT suggest that subsidy on its own does not ensure customer satisfaction and that over-generous provision of revenue support might be counter-productive to the drive for efficiency. Economic rationality requires that available scarce resources should be used efficiently to provide quality services to meet the mobility needs of the general public and the special requirements of particular sections of the population.

In the Netherlands, the Brokx Commissions (1991-95) concluded that there should be more business-like relationships between the municipalities and the operators and recommended that market forces should play a stronger role and that periodic competitive tendering for regional networks should be introduced. The De Boer Commission (1993-94) gave support to this philosophy. It recommended that operators should strive to achieve a cost recovery ratio of 50% by the year 2004 and that the share of public transport in the modal split should increase to dampen the continuous rise in car use.

The Dutch Parliament has endorsed these views and the cabinet places great importance on public accountability for any form of subsidy provided by the central government. Under the decentralisation process, there will also be a transfer of responsibilities from central to the lower tiers of government. To these ends, a new subsidy system will be introduced. As from January 1998, subsidy payment to urban and regional public transport will be on the basis of an agreed formula, taking account of achieved performance measured in terms of fare revenues received and standardised costs. At the same time, the Government is interested to seek out ways and means to rationalise the organisation of the public transport systems. The aim is to motivate radical changes in different transport and traffic regions such that the market will be the driving force for service improvements. There will be increased competition 'for the road' and tendering will introduce business discipline to ensure greater values for money for the passengers. The important question is what is the optimal level in service planning and in operation that will favour the pursuit for efficiency.

The Dutch Ministry of Transport and Public Works has the task to devise a new subsidy payment system based on the principle of rewarding regions according to achieved performance. In parallel with this action, the cabinet also decided in 1996 to inaugurate an Interdepartmental Policy Research Study (IBO) to investigate the financing of urban and regional transport as an integral part of strategic financial policy planning. The Ministry of Finance joined forces with 4 other ministries, including the Transport Ministry.

Four questions were raised:

1. Which part of subsidy is awarded on the basis of performance?
2. What factors should be used as indicators of performance?
3. How does the principle 'rewarding performers' work in practice?
4. How should the inefficiency that has been identified be treated?

In order to have an insight to these pertinent policy questions, it is considered necessary to have a better understanding of the working of the existing and proposed subsidy payment systems, in particular of the apportionment of central government subsidy between the beneficiaries, namely: the 7 'kaderwetgebieden' (agglomerations), 12 provinces and 36 municipalities which have legal responsibility over their own public transport system. The chosen approach is to undertake an econometric study and statistical analysis of the relationships in the recent past in order to identify the factors and to determine the extent to which they respectively influence the amount of subsidies to be apportioned to the different interest parties. The study is commissioned by the Study Group IBO and is supervised by a group of officials from the Finance and Transport Ministries. The consultant chosen is Hague Consulting Group.

Three types of factors are reckoned to have significant influence on the amount of subsidy received:

- 'agreed' performance measures such as the absolute amount of fare revenue received or passenger kilometres carried;
- structural characteristics, i.e. factors such as population density or total land area which will by nature increase operating costs, but are themselves not directly susceptible to the influence of the related interest parties;
- inefficiency, i.e. factors such as the wage rate and terms of employment which are in principle within the realm of influence of the operating company or of the responsible municipal authority and which do in practice contribute towards higher than minimum costs or lower than the maximum output; under the old system, higher inefficiency could lead to a call for more subsidy; in an 'ideal' subsidy mechanism, inefficiency would not be rewarded.

THE STOCHASTIC FRONTIER MODEL

The stochastic frontier model was introduced more or less simultaneously by Aigner, Amemiya and Poirier (1976), Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The best-known and most frequently used specification is that of Aigner, Lovell and Schmidt (ALS), which will be used in this paper as well.

The stochastic frontier model was first developed for estimating production functions, and has subsequently been generalised. A production function in economics is defined as the maximum output that can be produced using the available inputs (assuming constant technology). If one would estimate an equation explaining observed output as a function of observed inputs using standard least squares techniques, the outcome would not be maximum output but average output. In the ALS model, maximum production (the 'frontier') can be estimated, because of the stochastic specification of the model, which distinguishes between two disturbance terms.

$$y_i = f(x_i) + \varepsilon_i \,. \tag{1}$$

$$\varepsilon_i = v_i - u_i \,. \tag{2}$$

The index i represents observations (e.g. public transport companies); y_i stands for the output of firm i, x_i is a vector of inputs of firm i and ε_i is the disturbance term for observation i. v_i is the usual normally distributed disturbance term with mean 0 and variance σ^2_v. This error term is two-sided (positive and negative disturbances). u_i on the contrary is a one-sided disturbance term: $u_i \geq 0$. This disturbance term measures the technical inefficiency: to which extent does observed output y_i lie below the maximum that is given by the 'stochastic frontier' $f(x_i) + v_i$? The first disturbance term (the usual random noise component), represents factors which the firm cannot control and which can affect the frontier positively or negatively. It can also include errors of observation or measurement. The second disturbance term has a one-sided distribution: the observed output should lie on or below the frontier. The one-sided disturbance represents 'factors under the firm's control such as technical and economic inefficiency, the will and effort of the producer and his employees' (ALS, 1977, p. 25).

This is depicted in Figure 1. On the horizontal axis are several public transport companies (here with labels A to P), on the vertical axis is output (e.g. in terms of distance travelled). The order in which the firms A to P are represented is arbitrary; the horizontal distances have no meaning, but the vertical distances between the functions do. The maximum output $f(x_i)$ on the basis of the inputs is given by ❍. Around these points (above and/or below) are the disturbances v_i. They represent the fact that because of company-external factors output can turn out to be higher or lower. This causes the stochastic frontier $f(x_i) + v_i$ to lie above or below the maximum, depending on v_i being positive or negative. The stochastic frontier is given by the ●. The vertical distance between ● and ❍ is equal to v_i. The difference between the stochastic frontier ● and observed output ♦ is equal to u_i (this is always greater than or equal to 0) and is caused by inefficiency.

ALS use a half normal distribution for u_i: $u_i \sim |N(0,\sigma^2_u)|$. Another possibility they mention (and use) is an exponential distribution for u_i. Later authors have used other distributional assumptions, such as a normal distribution truncated at 0 (Stevenson, 1980). Both disturbance terms are assumed to be independent from each other.

Except for production functions, there also is an ALS model for cost functions. The cost function gives the minimal cost that are necessary to produce a given output level y_i. Here too, there are two disturbance terms (one two-sided, the other positive), but now we have, instead of eqn (1) and (2):

$$k_i = f(y_i) + \varepsilon_i. \quad (3)$$

$$\varepsilon_i = v_i + u_i. \quad (4)$$

This implies that the minimal cost to produce given output will always be on or below the observed cost k_i. The inefficiency measures the difference between observed and minimal cost.

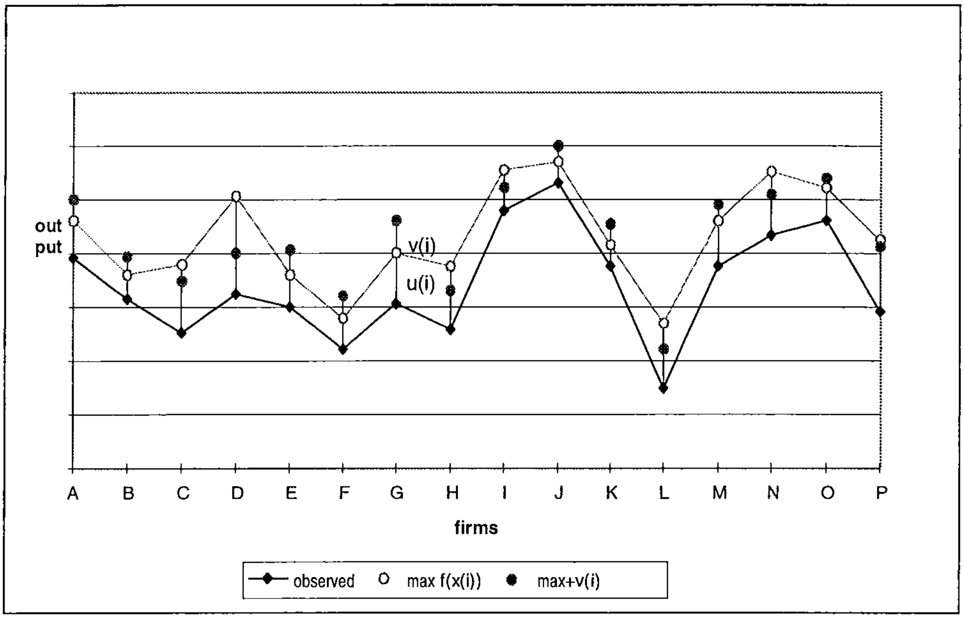

Figure 1 - Observed and maximum output for several hypothetical firms

The stochastic frontier model can be estimated by Maximum Likelihood methods. In fact the likelihood function is very similar to the likelihood function of the tobit model or the Heckman sample selection model, which have been used in transport to model car ownership and use simultaneously (e.g. Train, 1986; de Jong, 1990).

After having estimated a production function according to the ALS specification, it is possible to determine the average technical inefficiency and the inefficiency per firm. The average technical inefficiency in the model with a half normal distribution is $\sigma_u\sqrt{(2/\pi)}$. For the expectation of the technical inefficiency per firm a formula was derived by Jondrow, Lovell, Materow en Schmidt (1982); It is conditional on the outcome for ε_i: $E(u_i | \varepsilon_i)$.

The above discussion focused on one of the two basic approaches of efficiency analysis: the econometric approach (Greene, 1993). This approach assumes a functional form for the shape of the production function and distributions for the various disturbance terms. This is the approach that has been used in most empirical studies in efficiency analysis. The other approach is Data Envelopment Analysis (DEA). DEA (Ali and Seiford, 1993; Viton, 1997) originated in mathematical programming. Contrary to the econometric approach it does not try to identify the theoretical production function, but it derives a 'best-practice; frontier from the observed decisions made by the firms under study. DEA is non-parametric (it uses piecewise-linear functions) and deterministic. The econometric approach is parametric and stochastic.

Both the stochastic production function frontier approach and DEA relate to measuring technical inefficiency. A firm is technically inefficient if it can reduce its inputs and still produce the same amount of output, or if it can increase its output at the same input levels. In economics there is also the concept of allocative efficiency. This concept also takes account of the prices of the inputs. A firms is allocatively inefficient if it can reduce total costs by purchasing more of one input and less of another, while still producing the same output level. Allocative efficiency can be separated out by estimating a system, consisting of a cost function and derived input demand functions (e.g. using translog functions). An advantage of all of these methods over the much simpler and very popular method of benchmarking is that they do not assume that for each criterium one firm (the benchmark) is fully efficient. Especially in the stochastic approach, all firms may be inefficient.

Both methods of efficiency analysis have been used before in transport studies, though rather infrequently and mainly in the United States. Greene (1993) and Sickles et al (1986) used the econometric approach to study efficiency in the airline industry. Kim (1987) used similar methods to study US railroads. Deterministic non-parametric methods, including DEA, were used by Kerstens (1996) to study the technical efficiency of French urban transit companies. Viton (1997) applied DEA in a study of US bus transit firms. Obeng and Azam (1997) estimated a system of cost and input demand functions to investigate the same bus sector.

DESCRIPTION OF THE DATA USED

In this study, stochastic frontier models have been estimated both on data for individual public transport companies and on data for recipients of central government subsidies. The latter data have also been used for estimating regression equations with subsidy per beneficiary as the dependent variable, using ordinary least squares.

Data on firms

Data used for the individual public transport companies have been provided, specially for this project, by the Dutch Ministry of Transport an Public Works (the so-called URS data). We also make use of balance sheets from the annual reports of the public transport companies. Data items include passenger kilometres carried, number of employees, number of vehicles and energy use. In total, the following data were available for public transport companies (giving 33 observations):

- 2 years (both 1994 and 1995) for 14 companies
- 1 year (either 1994 or 1995) for 5 companies.

The data set for firms is of the 'unbalanced panel' type. Of those 19 companies 8 are providers of urban public transport only. The other 11 are regional public transport companies that may also operate in urban areas under contract to the responsible municipal authority.

Data on regions and cities

In the present system of subsidies for public transport in The Netherlands, the following recipients can be distinguished:

- 10 regional authorities
- 36 cities
- a number of public transport companies (15 in 1996, 13 in 1997).

The future system of central government subsidies will only involve regional and local authorities. Moreover we want to include geographical attributes in the analysis, which are only available for regions and cities. Therefore, the data on public transport companies were distributed between regions. The resulting data set includes 55 areas:

- 19 regional authorities (7 agglomerations and 12 provinces)
- 36 cities.

This data set is a cross section. For the 55 areas, we have data on central government subsidy for public transport, passenger kilometres carried in public transport and public transport fare revenues for 1996, based on published statistics of the Dutch Ministry of Transport and Public Works. We also have data on geographical attributes (e.g. address density: the number of postal delivery points in an area within a radius of 1 kilometre) based on statistical information provided by the Dutch Central Bureau of Statistics.

OUTCOMES FOR PRODUCTION FUNCTIONS

All stochastic frontier models were estimated using the econometric software package LIMDEP.

A number of different production functions was estimated on data for public transport companies (33 observations). The following distinctions can be made:

- whether the model accounted for the fact that for most firms there are 2 observations in the data set (1994 and 1995). In a panel model this is taken into account: the term u_i that represents the inefficiency of firm i cannot in 1995 be entirely different from its 1994 value; in principle this term is the same in both years, and this is what the panel model (in this case a 'random effects' panel model) assumes.
- the assumption that is being used for the statistical distribution function of the one-sided error term u_i: half Normal distribution or exponential distribution.
- the choice of input variables: several combinations of labour input, vehicle input and energy use.

The production function giving the best 'fit' (in terms of loglikelihood value) is presented below. This is a panel model with an exponential distribution for the one-sided error term. The production function is specified as follows:

$$\ln Y = \beta_0 + \beta_1 \ln L + \beta_2 \ln P + \beta_3 \ln E + v - u \,. \tag{5}$$

Y: output, measured as passenger kilometres carried by all the firm's local and regional lines (bus, tram and metro)
L: labour input (vehicle staff, technical support staff and indirect staff)
P: the sum of the number of places (seated and standing) in the vehicles in local and regional routes
E: energy use for the traction (measured in money-units).

Table 1 - Estimates for production function for companies (n=33)

Coefficient	estimated value	t-ratio
β_0	2.3712	4.787
β_1	0.0419	0.271
β_2	0.4652	1.970
β_3	0.5818	1.737
σ^2_v	0.0004	
σ^2_u	0.0154	

The estimated sign for all inputs is positive, as expected. The estimated coefficient for L is not significant, whereas those for P and E are marginally significant. The coefficients for L, P and E are elasticities: they tell us how a percentual change in the inputs is translated into a percentual change in output. The sum of the exponents $\beta_1 + \beta_2 + \beta_3$ is greater than 1. This means that there are economies of scale in production: an increase in all inputs with some percentage k will lead to an output increase in excess of k. The average technical inefficiency, calculated using the method of Jondrow et al. (1982), is 20%.

The main outcomes from the estimation using different specifications of production functions for public transport companies are:

- the average technical inefficiency is between 5% and 22%
- in most specifications the regional public transport firms are on average more efficient than the urban public transport firms, and the firms in the 4 largest cities (Amsterdam, Rotterdam, The Hague and Utrecht) are more efficient than the urban public transport firms in the smaller cities.

OUTCOMES FOR COST FUNCTIONS

Cost functions for public transport companies

On the same data for public transport companies (n=33), stochastic frontier cost functions have been estimated, with the operating cost on public transport routes as the dependent variable and as explanatory variables: output (passenger kilometres carried on bus, metro and tramlines), a constant intercept and two error terms. These functions also point at the existence of economies of scale and give an average inefficiency of 13-27%. In the case of a cost function, the inefficiency tells how far the cost exceeds the minimum cost that is attainable at a certain output level (at given input factor prices). Here the inefficiency is lowest in regional public transport and highest in urban public transport in the 4 largest cities. Possible explanations are the relatively high running cost of trams (only Amsterdam, Rotterdam and The Hague have trams in The Netherlands) and the civil servant status of employees of the urban public transport companies (the employees of the regional firms are not civil servants, and have lower wage costs)

Outcomes for regions/cities

As for the firms, simplified cost functions were estimated on the data for 55 regions/cities, using passenger kilometres carried as regressor variable at given input prices. These regions and cities receive central government subsidy for public transport. They do not produce public transport services, so the relationship between cost and output is of a more indirect character. On the other hand these cost functions for regions and cities can be very useful to answer questions about the influence of output, regional attributes and inefficiencies on the allocation of central government subsidies. This information is needed to evaluate the present allocation system and to devise an efficient and fair allocation mechanism for future years.

Logarithmic cost function on kilometres, n=55

This model is a cost function with an exponential distribution for u_i. The specification is:

$$\ln K = \beta_0 + \beta_1 \ln Y + v + u \,. \tag{6}$$

K: operating costs (according to the data of the Ministry of Transport and Public Works)
Y: passenger kilometres carried on all bus and tram routes and metro lines

The estimation results are given in Table 2.

Table 2 - Estimates for logarithmic model on kilometres for 55 regions/cities

Coefficient	Estimated value	t-ratio
β_0	1.5057	8.195
β_1	0.7916	41.918
σ^2_v	0.0174	
σ^2_u	0.0283	

The estimated parameter for passenger kilometrage is very significant. The elasticity is almost 0.8, whereas using the data for firms it was almost 0.9. Again we find economies of scale. The average technical inefficiency according to this model is 17%. As was the case with the data for firms, the highest inefficiencies are found in the 4 largest cities (in the data for regions and cities these are 4 agglomerations).

Logarithmic cost function on revenues, n=55

In this model ln Y from the previous model has been replaced by Ln O; output is being measured here in terms of revenues from passengers instead of distance travelled; everything else is the same. Estimation results are given in Table 3.

Table 3 - Estimates for logarithmic model on revenues for 55 regions/cities

Coefficient	Estimated value	t-ratio
β_0	2.4088	25.521
β_1	0.8493	70.241
σ^2_v	0.0124	
σ^2_u	0.0158	

The estimated β's here are highly significant. For raising the revenues by 10%, 8.5% extra costs are needed, indicating economies of scale. The average technical inefficiency is 13%; the highest values again are to be found in the 4 largest cities.

Logarithmic cost function on kilometres, n=19

This model is a cost function with an exponential distribution for u, in which the 55 regions and cities have been aggregated into 19 observations (7 agglomerations and 12 provinces). The 36 cities have been added to their respective provinces. The specification is otherwise identical to the model with 55 observations. We have to remark that 19 observations is a rather limited number for estimation of a regression equation (with 4 parameters). The outcomes are in Table 4.

Table 4 - Estimates for logarithmic model on kilometres for 19 regions

Coefficient	Estimated value	t-ratio
β_0	-2.3477	-4.653
β_1	1.1151	27.714
σ^2_v	0.0049	
σ^2_u	0.0219	

Again the estimated coefficient for distance travelled is highly significant, although less significant than in the model with 55 observations. The elasticity is 1.1; an increase in kilometrage causes a relatively greater increase in costs After aggregation to 19 regions we find diseconomies of scale, whereas with 55 regions we found economies of scale (elasticity of 0.8). The optimum number of regions in the allocation of the central government subsidy in this respect apparently lies between 19 and 55. Linear interpolation using the elasticity values at 19 and 55 regions gives an optimum number of about 30 regions. Similar numbers for the optimal number of recipients have been found in other analyses in The Netherlands. The average technical inefficiency in this model is 15%, slightly lower than in the same model for 55 regions/cities (17%). The agglomerations usually have higher inefficiencies than the provinces.

Linear cost function on kilometres, n=15

This model follows a linear specification:

$$K = \beta_0 + \beta_1 Y + v + u\ . \qquad (7)$$

A subsidy allocation system that is linear in kilometres or revenues is not only simpler than a logarithmic system, but it also is supposed to give the correct incentives for maximising output (measured either in kilometres or revenues). A logarithmic allocation rule would have decreasing incentives at increasing output. Cost is by definition the sum of subsidies and revenues. For these reasons we have investigated linear cost functions with a stochastic frontier. First, we estimated simple functions on output only. After this we included geographical attributes of the regions in the cost function. The number of regions is further reduced to 15: 3 agglomerations (regions around Amsterdam, Rotterdam and The Hague) and 12 provinces. All other recipients of central government subsidy were added to the respective provinces. This categorisation in 15 regions is interesting from a political point of view: it forms the highest level of aggregation of regions that might be used in a future allocation system. Of course 15 observations provides a rather weak basis for estimation; in drawing conclusions from the outcomes, we shall have to be extra careful. The estimation results are in Table 5.

The estimated parameter for passenger kilometrage in this linear model is still very significant. This parameter can no longer be interpreted as an elasticity, as in the logarithmic models. The average inefficiency percentage, calculated at the average cost level , is 10%. A linear cost model for n=15 with revenues, a constant term and two error terms as independent variables was tested in estimation, but the estimation process did not converge.

Table 5 - Estimates for linear model on kilometres for 15 regions

Coefficient	estimated value	t-ratio
β_0	-58144	-2.688
β_1	0.5968	16.878
σ_v	21700	
σ_u	20161	
Loglikelihood	-175.2208	

Linear cost function with geographical attributes, n=15

The easiest way to introduce geographical attributes to the stochastic frontier cost function is the following specification, with kilometres and address density (OAD):

$$K = \beta_0 + \beta_1 Y + \beta_2 OAD + v + u \,. \qquad (8)$$

Address density measures the number of addresses (i.e. postal delivery points) in an area within a radius of 1 kilometre. This variable was found to be an important explanatory variable in earlier regressions explaining the amount of public transport subsidy per beneficiary. This model was tested in estimation, but it did not produce an estimated stochastic frontier cost model. There also is no economic interpretation or justification for introducing address density as an additive variable in the cost function: a cost function can have output and input factor prices as arguments, but no variables such as OAD. An additive model in which output is measured in terms of revenues did not give estimation results for a stochastic frontier cost function either.

Another way of introducing geographical attributes is the multiplicative specification. The cost function now is (with GOAD being the national average OAD):

$$K = \beta_0 + \beta_1 Y + \beta_2 Y\,(OAD - GOAD) + v + u \,. \qquad (9)$$

This cost function does have an economic interpretation. OAD now is not a term that should represent output or prices of inputs, but $\beta_1+\beta_2$ (OAD-GOAD) is the function that determines the coefficient for the output variable Y. The specification is similar to the 'random coefficients' model for taste variation. The estimation results for this multiplicative specification are in Table 6.

Table 6 - Estimates for linear model on kilometres with OAD for 15 regions

coefficient	Estimated value	t-ratio
β_0	-14450	-0.633
β_1	0.4637	9.816
β_2	0.0001	3.134
σ_v	10974	
σ_u	15674	
loglikelihood	-167.3500	

The constant intercept term in the model is not significantly different from 0. Having a constant term in a subsidy allocation system would not be desirable. The new parameter β_2 is significant; β_1 becomes less significant than in Table 5, but the t-ratio still indicates a highly significant effect. The 'fit' of the model is represented by the loglikelihood value (in the bottom line of the table). A higher value (closer to 0) indicates a better 'fitting' model (in fact it says that it is more likely that the observed data have produced the model at these parameter values). The loglikelihood of the model with one geographical attribute (Table 6) is 8 points higher than the model without this variable (Table 5). This is a significant increase in the loglikelihood: the model with OAD is a (statistically) superior model. We expect that introducing a geographical attribute like OAD will especially reduce the two-sided error term, because such attributes can not be influenced by the regions and can have either negative or positive consequences for the cost of providing public transport. This is confirmed by the simulation results. When compared to Table 5 (the same model without OAD) the standard error of v (σ_v) is almost reduced by 50%, whereas the standard error of u decreases much less. The average inefficiency is 8% (without OAD 10%).

The same model was successfully estimated with revenues instead of kilometres (see Table 7).

Table 7 - Estimates for linear model on revenues with OAD for 15 regions

Coefficient	Estimated value	t-ratio
β_0	-9385	-0.568
β_1	2.7973	7.561
β_2	0.0001	0.773
σ_v	12274	
σ_u	9872	
loglikelihood	-164.9479	

As in the model on kilometres (Table 6), the constant term is not significantly different from 0. The OAD parameter here is not significant. Nevertheless, the 'fit' of the model, as given by the loglikelihood value, is slightly better than that of the model on kilometres. The standard error of v (σ_v) is slightly higher than in the model on kilometres, but the standard error of u is clearly lower. The average inefficiency is 5%; it was 8% in the model with kilometres and OAD.

The estimation results for 15 regions have been used to calculate for each of the 15 regions the residual v and the inefficiency u. The residual is computed as the observed cost minus the minimum cost (according to the model) minus the efficiency: k-f-u. In 11 out of 15 cases the multiplicative model with kilometres and OAD gives a smaller inefficiency than the model with kilometres only. The residual (in absolute values) is smaller in 12 out of 15 cases. Both models with OAD (using kilometres or revenues) produce relatively small residuals; only 4 (kilometres) or 3 (revenues) residuals are in absolute values larger than 10%. The model with revenues and OAD gives a smaller inefficiency than the model with kilometres and OAD in 8 cases; for 5 cases the opposite situation occurs, and in 2 cases the inefficiencies are equal. The absolute value of the residual term is for 8 cases highest in the model on kilometres and in 6 cases highest in the model on revenues (in 1 case they are equal).

Based on the individual outcomes reported above, we calculated the following unweighted residual (using absolute values) and inefficiency (see Table 8).

Table 8 - Calculated residual and inefficiency in 3 models

	Average residual percentage	Unweighted average inefficiency percentage
Model with kilometres	15%	17%
Model with kilometres and OAD	8%	12%
Model with revenues and OAD	6%	9%

The unweighted average inefficiency is higher than the average inefficiency for these models reported earlier in this section, because the relative inefficiency in large regions generally is great and in small regions small. Here too, we see that adding a geographical attribute decreases especially the residual (from 15 to 8%), but also causes a decline in the estimated inefficiency (from 17 to 12%). We also calculated the amount of subsidy for each of the 15 beneficiaries, which is predicted by the models with OAD, after subtracting the inefficiencies. Most regions are predicted to receive less than what they actually received in 1996. This is not surprising, since we subtract the calculated inefficiency in all cases. For some of the regions, especially the smallest, the predicted subsidy is substantially (30-50%) lower than the actually received subsidy.

CONCLUSIONS

On the basis of the research study undertaken, the following conclusions can be drawn.

- Introduction of a new public transport subsidy system in the Netherlands, based only on performance, as measured by passenger kilometres carried or amount of fare revenues received, will mean that many beneficiaries will experience substantial changes (in the order of 30% up or down) in the amount of subsidy received. To minimise any dramatic change, the inclusion of correction factors using objectively derived structural characteristic may be required. To avoid possible hardship, transitional agreements may become necessary to ease any excessive stress or strain on the local or regional network.
- Structural characteristics can soften the blows (by between 30% to 60%) that are likely to be associated with a purely performance based payment system. Characteristics such as address density in the administrative area or the age structure are legitimate contenders for inclusion as correction factors because they are objectively determined by (impartial) third parties and can not be fixed or influenced directly by the beneficiaries in question.
- In the estimation process, different specifications of production and cost models give some evidence to the existence of inefficiencies in urban and regional transport. However, the issue is not totally independent of allowing (or not) the inclusion of structural characteristics. Adding address density to the cost function (by way of a variable factor on performance) will reduce the size of inefficiency measured. The remaining size of the inefficiency is on average some 10% of the cost per beneficiary. If subsidy per recipient is calculated for 15 regions, and allowing for the removal of inefficiency according to the model, then this will result in a situation that a few of the beneficiaries (namely the smaller regions) will subsequently experience substantial reductions (30-50%) in subsidy receipt when compared with the existing allocation system.
- Applying different analytical techniques gives an optimum size for the organisation of the public transport network either in terms of scale of operation or size of the responsible municipality. Results using stochastic frontier models indicate the presence of scale economies (or diseconomies). If the number of operators or networks is reduced to 19, scale economies could be achieved, even when there are 55 regions. This suggests merging of operating companies will yield financial and economic benefits. However, if there are only 19 operators or simply with 15 regions, then there are signs of scale diseconomies; and, therefore, splitting is an interesting possibility. The optimal number of beneficiaries on the basis of linear interpolation suggest about 30 is the optimum size.
- The stochastic frontier models used here are rather well known in econometrics. There are only few applications in transport, and the studies that have been carried out mainly deal with companies in the United States. Yet, stochastic frontier models offer a potentially very useful tool to measure efficiency in transport operations, which is becoming a major topic in many countries.

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