The efficiency of Norwegian road toll companies

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Abstract

This paper deals with the efficiency of Norwegian toll companies. Efficiency and productivity are compared using different efficiency measurement approaches. The focus of the paper is to demonstrate differences in efficiency and productivity among Norwegian toll companies employing methodologies such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). DEA and SFA both represent alternative methods of estimating frontier functions and measuring efficiency of production, but whereas DEA involves the use of linear programming, SFA is based on econometric methods. Despite the differences in the assumptions underlying the assumptions of the two methodologies we find them to produce similar results. The main conclusions in the paper are: 1) there is a great variation in efficiency among the toll companies where the larger ones are the best performers, 2) there is clear evidence of unexploited economies of scale in the sector and 3) toll companies have over the period studied improved their productivities, mainly due to newer toll collection technologies. This suggests that toll companies could make significant savings by employing industry best practice. From the authorities point of view an important policy implication is that the organisational framework, with a large number of small and medium sized companies, should be reconsidered. By merging some of the toll companies, inherent benefits of scale economies could be exploited.

Keywords: Tolled roads; Toll Collection Technology; DEA; SFA; Non-profit organisations

JEL-code: D24

1. Introduction

Tolls are used as an instrument to finance new road infrastructure throughout the world and the increasing share of toll financing compared to public finance and the increasing number of companies involved illustrates that toll financing and -collection has become an industry of its own. Norway provides an example of a country which relies heavily on tolls and currently over 40 percent of its total annual budget for road construction is made up of tolls. According to the newly released National Transport Plan for the years 2010 to 2019, this percentage is expected to increase in the future.

Toll financing is organised differently between countries. From pure commercial enterprises responsible for construction, maintenance and finance, through public private partnerships with varying degrees of risk sharing to not for profit companies established solely with the purpose of providing finance in order to get roads constructed faster – toll roads are organised in many different ways. What all toll roads have in common though, is a need to collect tolls from the motorists as efficiently as possible, i.e. to run the charging points or toll stations at a minimum of costs and to minimise disturbance of traffic while tolls are collected. From a commercial point of view, the costs of collecting tolls - the operating costs, reduce profit margins and increases the payment period of loans. Operating costs are real costs and are also important from a socio economic point of view – the higher the operating costs, the lower will the net present value of a toll financed road be. As stated by Amdal et al. (2007), all toll roads should provide a net benefit in social cost-benefit analysis terms, generate substantial net revenues and be acceptable to a major proportion of the public. Minimising the operating costs is critical for meeting all these three basic criteria.

Data on operating costs in toll companies are rare and often regarded as competition-sensitive information which is not readily available to researchers. In this context, Norwegian toll financing provides an interesting case. Here detailed cost data from over 40 toll companies operating in different geographical regions and employing different tolling technology are available to the authorities annually. This allows us to answer several interesting questions: These are: (1) Do companies operate as efficient as their peers? (2) Do they progress in their operations? (3) Which factors outside the toll companies control determine their

inefficiency? And finally, but not least: (4) What could be done to improve the efficiency of toll companies? These questions should be of interest to toll companies, authorities and motorists alike. As tolls are removed as soon as possible once the costs of constructing the road are covered, this means that if toll companies operate efficiently then tolls can be removed even earlier. Because tolls are a cost to road users, their removal will incur benefits to roads user and to society. Studies of elasticities in 20 Norwegian toll projects suggests an average elasticity of -0.56, meaning that an increase in generalised costs due to tolls by 10 % will reduce traffic by 5.6 % (Odeck and Bråthen, 2008). Further, gauging the impact of factors that may influence efficiency such as the technology for toll collection may give additional information relevant for improving performance in the toll road industry.

The literature on efficiency and productivity measurement of toll operations are rare even if tolling is practised widely throughout the world. However, a related issue that has been debated recently in the transportation literature is the operating costs of tolls; see for instance Prud'Homme and Bocajero (2005), Mackie (2005) and Raux (2005). In the Norwegian context that we relate to in this paper, Welde and Amdal (2006) and Amdal et al. (2007) have investigated the levels of operating cost per vehicle in the Norwegian toll road industry. They applied regression analysis using panel data and found that operating costs varied tremendously between 6 and 20% of gross revenues with the larger toll companies serving larger traffic levels having lower operating costs per vehicle served. Their results indicated that there may be inefficiencies in the sector and that economies of scale were most likely to be present. Odeck (2008) extended these studies, but in the context of efficiency and productivity measurement using Data Envelopment Analysis (DEA). He verified the claims by Welde and Amdal (2006) and Amdal et al. (2007) to the extent that there are scale economies in the sector, there are potentials for efficiency improvements and added that toll companies have in fact improved their productivities over the years studied, possibly as a result of using new technologies for toll collection. The objective of this paper is to contribute further to the debate surrounding the performance of toll companies in Norway.

The rest of this paper is organized as follows. Section 2 gives a short overview of the tolling industry in Norway. Section 3 assesses the potential for efficiency improvements in light of principal agent theories.

Section 4 gives a brief a count of the theoretical model to be applied. Section 5 describes the data to be used in the analysis and Section 6 presents the results. Concluding remarks are given in section 7.

2. The organizational framework of Norwegian tolling

Norwegian toll financing is often described internationally as a success story given that more than 100 projects have been realized using tolls and given that new ones are constantly being proposed. Currently, toll financing of road projects account for about 40 % of the total road budget and indicates the popularity of this mode of finance. The organizational framework of the Norwegian mode of toll financing has been discussed extensively in the literature - see for instance Odeck and Bråthen (1997, 2002, 2004 and 2007), Amdal et al. (2007), Odeck (2008) and Bråthen and Odeck (2009). Thus, only the main properties of Norwegian toll financing are explained below.

Each toll project is based on an initiative from the local municipality, local authorities or other members of the local community. This initiative is based on a real or perceived need for new roads in the area and will usually result in the founding of a toll company, organised as a limited liability company, non-recourse to the Norwegian Public Roads Administration (NPRA). The toll company acts as an enthusiast and will, often along with local politicians, work to establish political acceptance for the project. Once the road project is realised, the role of the toll company is to operate the toll system, often through the employment of commercial toll road operators, and to administer the toll revenues.

It should be noted that not all construction costs are covered by tolls. Some percentage of the cost, normally 20–50 %, is supplemented with government funds. This percentage is proposed by the toll companies, evaluated by the NPRA and may be accepted and sanctioned by the parliament. Factors determining this percentage would include the level of traffic, total construction costs, and level of toll fees. There are also instances in which local authorities finance a certain percentage of the construction costs. Briefly summarized, the process by which toll companies come into being is as follows; see Odeck (2007):

I. Local authorities represented by the local government, local road authorities and local interest groups (e.g., industrial organizations) foresee that a much-needed road project cannot be realized in the near future within the government budget. Therefore, they propose toll financing.

II. The proposal for toll financing of the particular project is sent to the NPRA for evaluation of its socio-economic and financial worthiness. The considerations are: (1) an application of toll financing should include the formation of a toll company to cater for the collection of funds, i.e., the down payment of the loan taken to fund the project and operation of the toll(s), and (2) the application includes a financial assessment proving that it is possible to repay the loan within 15 years of the start of toll collections. The rates are proposed by the local initiators but must be within an 'acceptable' range suggested by guidelines issued by the NPRA.

III. Once approved by the NPRA, the proposal is forwarded to the Ministry of Transport, which prepares a bill to be tabled in Parliament. Once passed by Parliament, the toll company starts operation by taking up a loan to begin road construction. Typically, the collection of tolls starts after the road has been built. There have, however, been instances where tolls have been collected in parallel with road construction work.

IV. Once in operation, toll companies are monitored by the NPRA according to guidelines issued by the Ministry of Transport and Communication. In other words, it is the NPRA that has the task of controlling the companies' accounts to ensure that operations proceed in accordance with the guidelines.
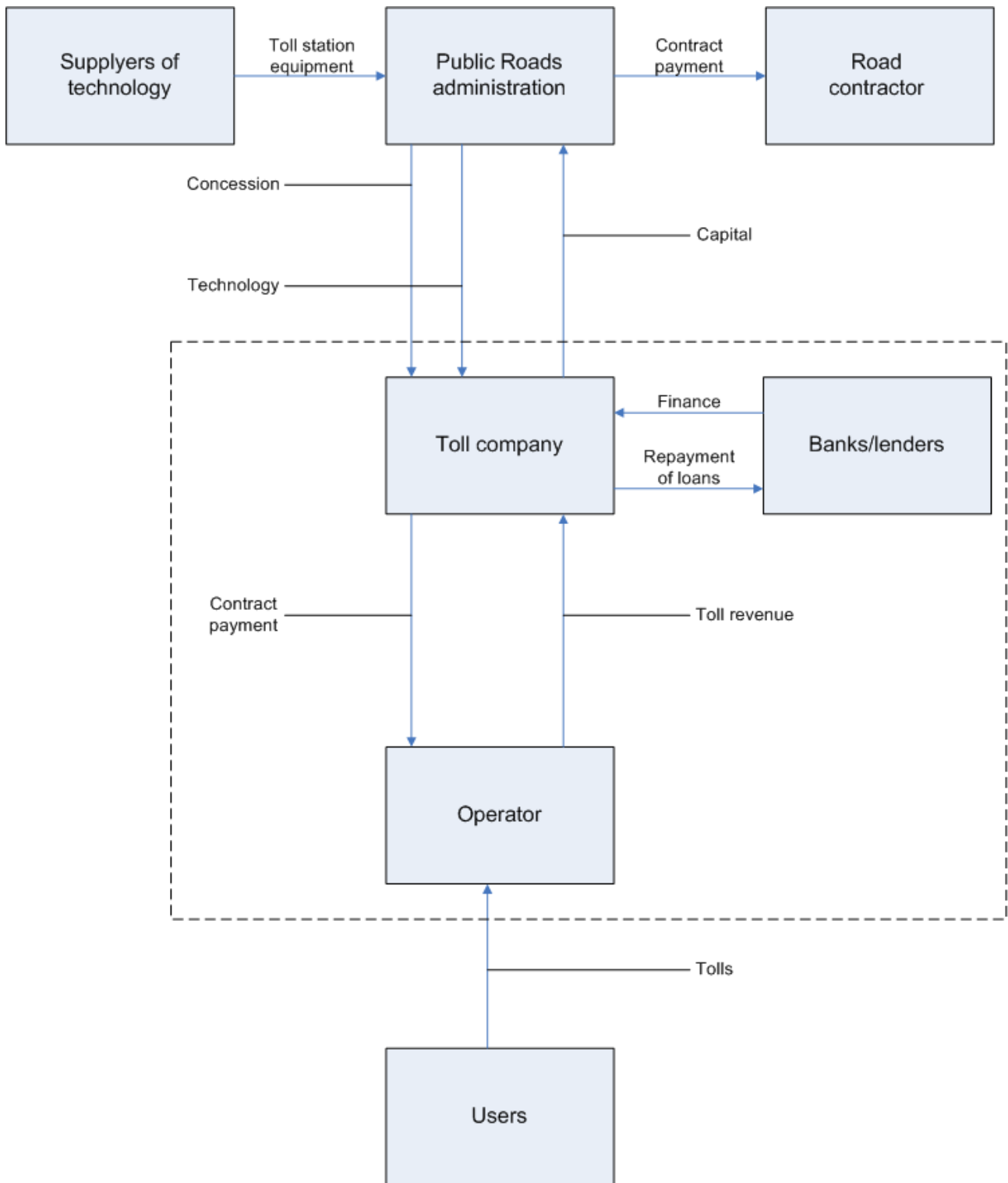
Figure 1: The Norwegian toll industry

The toll company is organised as a non profit enterprise and the share owners receive no dividends. For those

unfamiliar with Norwegian tolling, the concept of not for profit involvement might be difficult to understand.

There are, however, other parties involved in the Norwegian toll road industry that operate on a pure commercial basis. Figure 1 illustrates all the parties involved in the toll road industry. The NPRA is responsible for all roads construction and –maintenance through the use of private road contractors. Local toll companies provide the finance needed to get the roads constructed faster and national and/or international banks provide loans which normally are guaranteed by local or regional authorities, securing low interest rates. Toll station equipment is regarded as part of the road infrastructure and is contracted by the NPRA. This technology is then put at the disposal of the toll company which is responsible for collecting tolls. Over the last decade, toll companies have increasingly started to contract out the collection of tolls to commercial toll road operators. The dotted square in figure 1 illustrates the responsibility of the toll company. The main objectives of the toll company are thus: (1) secure loans for funding roads, (2) collect road tolls as efficiently as possible, i.e. keep the operating costs as low as possible and (3) see to it that funds collected are used for what they are meant, i.e. repayment of loans and to cover operating costs. In this paper we focus on tasks (2) and (3) and how these could be carried out as efficiently as possible.

The technology used for collecting tolls

The next issue worth addressing is the charging arrangements that definitely influence the performance of toll companies. The collection of tolls in Norway was traditionally done manually where a toll, based on the size of the vehicle and number of passengers, was paid to a toll attendant. This allowed for a detailed prize differentiation but the collection itself was expensive for the toll companies and time consuming for the motorists. This triggered an interest in developing technological solutions that could reduce costs to both operators and users. Thus, in 1987, Norway became the first country in the world to deploy an electronic toll collection (ETC) system. The use of ETC systems was enhanced further by the opening of the toll cordons in Bergen, Oslo and Trondheim in the years 1987-1991. The use of electronic tags mounted on the windscreens of vehicles became widespread in urban areas. Today, Norwegian ETC is based on a national Dedicated Short Range Communications standard named AutoPASS which offers users full interoperability between all ETC systems in all Scandinavian countries. Currently over half of all Norwegian vehicles are equipped with an AutoPASS tag.

It should be borne in mind however, that even if all new toll projects are based on modern ETC system the system for toll collection in Norway differs between toll companies according to when they were opened. The systems in use among the toll companies considered in this paper can be classified as follows:

1. *Manual collection:* Cash payment to toll attendants
2. *ETC/Manual collection:* Majority of tolls collected electronically, but cash payment to toll attendants available to infrequent users without tags.
3. *ETC/Coin machines:* As in (2), but toll attendants replaced by coin machines.
4. *AETC:* All electronic toll collection. No cash collection, toll plazas replaced by gantries and all collection done electronically either through tags or invoicing of non-tag holders in arrears.

As charging equipment is considered part of the road infrastructure, it is the Norwegian Public Roads Administration (NPRA) that determines which charging arrangement is to be used in each toll project. As such the objective of the toll companies is to operate the toll collection as efficiently as possible given the prevailing legal and technological conditions.

3. The potential for inefficiency in the Norwegian toll road industry

From the above, it is clear that Norwegian toll companies are heavily regulated, but given the differences in traffic levels and technology we expect to find huge variations in operating costs, as observed by Welde and Amdal (2006) and Amdal et al. (2007). The question is whether these variations are present because of differences in exogenous factors, or are they due to inefficiencies that could and should be corrected for.

The reasons why inefficiencies arise have been discussed for decades and a relationship where a principal wants an agent (or a group of agents) to maximise the interests of the principal (Rees, 1985a, 1985b) is often used as a starting point. The problem for the principal is that he does not have access to the same amount of information as the agent. Instructing the agent hence becomes difficult, as the principal cannot observe all

the actions of the agent. The relationship between the NPRA and the toll companies is often described as one between a principal and an agent. The toll companies act as agents for the NPRA in that they are established to finance a road project on behalf of the road authorities. With the huge number of toll companies, there will always be an element of asymmetrical information which complicates the NPRA's monitoring of the companies. Vickers and Yarrow (1988) argue that the asymmetry of information inherent in principal agent relationships gives rise to imperfect incentives and therefore inefficiency. As the agent generally is far more knowledgeable about his company's operations than the principal is able to be, he might be able to pursue different goals than those of the principal without the principal finding out. Poor incentive systems, inadequate control systems and a lack of competition could increase the challenges inherent in principal agent relationships.

Although toll companies are mainly financial vehicles established to act in public interest, the incentive structure of Norwegian toll financing has been criticised (see OAGN, 1999; Welde et al., 2003; Bråthen and Odeck, 2009). If traffic growth in a toll project is higher than forecast and net revenues exceed expectations, toll collection will end and the toll company will be dissolved earlier than anticipated. It is not unreasonable to expect that the toll company's management and its employees might want to carry on operations as long as possible. As Migué and Bélanger (1974) argue, the highest reward for a bureaucrat is the opportunity to enjoy "the quiet life". What complicates the issue further is that poor performing toll companies will not have any economic consequences for the NPRA as inefficiencies will only result in the motorists paying higher tolls or tolls for a longer period then necessary. As Busch and Gustafsson (2000) argues, services financed by user fees will often have a lower productivity because of less control and follow up by the principal.

The NPRA not doubt has a demanding task in monitoring and controlling the toll companies to ensure that they act in accordance with the objectives set out in the concession and operate as efficiently as possible. However, regardless of the toll companies opportunities to operate in their own self interest and regardless of possible opportunistic actions, with over 40 toll companies in operation it would be more surprising if they

all were equally efficient than if variations existed. In this paper we aim to identify the better performing companies to facilitate learning and cost reductions to the benefit of users, toll companies and to society.

4. Methodology

We use two different approaches: DEA and SFA to examine efficiency of Norwegian toll companies. The rationale for using two competing methods is counter check whether results received by one methodology can be confirmed by the other. We briefly describe each of the methodologies below.

4.1 Data Envelopment Analysis (DEA)

The DEA method is regarded as one of the most successful techniques of efficiency assessment proposed by researchers in Management Science and Operations Research, as is evident by the diversity of its application in the last decade; see for instance Coelli (1995) and Seiford (1996) for recent reviews.

DEA proceeds by defining the best virtual producer (in this case, toll company) corresponding to each real producer, where the virtual producer does not necessarily exist, but is imputed from linear combination of the inputs and outputs of one or more efficient producers. If the corresponding virtual producers perform better than the real producer by producing more output with the same level of inputs or the same level of output with less input, then the real producer is inefficient. It has been shown by Charnes, Cooper and Rhodes (1978, hereafter CCR) that the process of the finding the efficiency index for the real producer can be formulated as a linear programming problem.

The original CCR formulation is non-flexible in the sense that it assumes constant returns to scale (CRS) in its production possibility set. Since we are also interested in exploring the assumption of variable returns to scale (VRS), the VRS formulation of Banker et al. (1984), hereafter (BCC), is also calculated this study. As it will be shown in equation (2) later, BCCs formulation makes it possible to calculate scale efficiencies more easily. The input oriented BCC formulation may be expressed as:

$$\text{Min } E_1 \qquad\qquad (1)$$

$$\text{s.t } \sum_{j=1}^{n} \lambda_j x_j - E_1 x_0 = - s_j^- \qquad\qquad (1a)$$

$$\sum_{j=1}^{n} \lambda_j y_j - y_0 = s_j^+ \qquad\qquad (1b)$$

$$\sum_{j=0}^{n} \lambda_j = 1 \qquad\qquad (1c)$$

$$\lambda_j \geq 0, j = 1,. . ., n \qquad\qquad (1d)$$

Where x_o and y_o respectively, denote the input and output vectors for selected units of the grain production industry. E_1 is the input decreasing efficiency measure of unit *o*. λ_j is the non-negative weight of unit *J*'s output and inputs that defines a comparison point on the frontier. Restriction (1a) states that the efficiency-corrected use of inputs ($E_1 x_o$) must at least equal the amounts employed by the reference unit. Constraint (1b) states that the reference unit must produce as much output as unit j. Constraint (1c) restrict the best practice technology to permit a variable returns to scale (VRS). Note that this where the BCC's formulation is flexible as compared to CCR's formulation. For non-increasing return to scale (NIRS), the appropriate restriction is the inequality in (1c).

By calculating three efficiency measures using these three restrictions, it can be determined whether a given producer is operating at decreasing, increasing or constant return to scale. The following general rule will then apply for determining the scale of a producer (see for instance Färe, Grosskopf and Lovell, 1985):

$$
\left\{
\begin{array}{l}
\text{(i) If } E_{CRS}\big/E_{VRS} = 1; \text{the firm is operating under CRS(} is\ scale\ efficient) \\[2mm]
\text{(ii) If } E_{CRS}\big/E_{VRS} < 1; \quad \text{the firm is operating under VRS } (is\ scale\ inefficient) \\[2mm]
\text{(iii) If } E_{VRS}\big/E_{NIRS} > 1; \text{ the firm is operating under Increasing Returns to Scale} \\[2mm]
\text{(iv) If } E_{VRS}\big/E_{NIRS} = 1; \text{ the firm is performing under Decreasing Returns to Scale}
\end{array}
\right\} \quad (2)
$$

Note that condition (iv) in eq. (2) above is not a sufficient condition for decreasing returns to scale (DRS) unless condition (i) is not satisfied. The linear program (1) above is run sequentially for each of (n) grain producers. Technically efficient units are identified in units that have input and output slack vectors $s_j^- = \mathbf{0}$ and $s_j^+ = \mathbf{0}$ in addition to $E = 1$ at optimality. These best practice units display either an optimal composite of inputs (or outputs) or a single exceptional input-output ratio. Less efficient units will obtain an E_1 score of less than 1 and might have non-zero input or output slacks. In order to compute the output-oriented measure E_2, the reciprocal of model (1) above may be considered. The objective is then to maximize output within the given finite stock of inputs available.

There is however, a necessary caution when using DEA techniques. Since DEA yields a relative efficiency measure and defines a unit as inefficient by comparing combinations of input and output with other units, units operating with input-output quantities sufficiently far from the other units at both ends of the size distribution will be identified as efficient simply due to the lack of comparable units. Fortunately, problems of this kind are minimal when examining larger samples of units. This is because larger samples decrease the average level of efficiency, due to the positive probability of including more efficient outliers in the sample.

4.2 The Stochastic Frontier Analysis (SFA)

Following well established conventions as those of Aigner and Chu (1968) and Meeusen and van de Broeck (1977), a stochastic frontier production function for the cross sectional data is specified as:

$$Y_{it} = f(X_{it}; \beta) + \varepsilon_{it} \tag{3}$$

Where Y_{it} denotes output of the ith firm in period t; X_{it} is a vector of functions of actual input quantities used by the ith firm in period t; β is a vector of parameters to be estimated; and ε_{it} is the composite error term. The error is further defined as:

$$\varepsilon_{it} = v_{it} - u_{it} \tag{4}$$

Where the v_{it}s are assumed to be independently and identically distributed random errors, which have normal distributions with mean zero and unknown variance σ_v^2. The random variable, u_{it} is assumed to have half-normal distribution or exponential distribution. In this model the observed output, $Y_{it,}$ is bounded above by the stochastic quantity, $f(X_{it}; \beta) + v_{it}$, where v_{it} accounts for random variation of production outside the control of the individual unit.

Given that the above stochastic model is in original quantities of production, the technical efficiency of the ith unit is defined by the following ratio:

$$TE_{it} = \frac{Y_{it}}{f(X_{it}; \beta) + v_{it}} \tag{5}$$

This measure of technical efficiency for the ith unit is defined for a given level of inputs, specified by the vector X_{it}. If the model is in terms of logarithm of output, then technical efficiency of the ith unit is defined by:

$$TE_{it} = \frac{\exp(Y_{it})}{\exp\left[f(X_{it}; \beta) + v_{it}\right]} \equiv \exp(-u_{it}) \tag{6}$$

Jondrow et al., (1982) have proposed that the technical inefficiency effect, u_{it} be predicted by the conditional expectation of u_{it}, given the composed error, $e_{it} = v_{it+} \, u_{it}$.

There are several different frontier model formulations of this type depending on the specification for the $u_{it}s$, which are termed technical efficiency effects (See Coelli, 1996). The model used in this study is a variant proposed by Coelli et al. (1998), in which the technical efficiency effects are defined as:

$$\mu_{it} = Z_{it}\delta + W_{it} \qquad\qquad (7)$$

where Z_{it} is a vector of explanatory variables associated with technical inefficiency effects; δ is a vector of unknown parameters to be estimated and the $W_{it}s$ are unobservable variables which are assumed to be independently distributed, obtained by truncation of the normal distribution with mean zero and unknown variance σ^2, such that U_{it} is non-negative (i.e. W_{it} is greater/equal to $-Z_{it}\delta$.). The maximum–likelihood estimates of the parameters of the stochastic frontier model are readily obtained using the computer program, FRONTIER, version 4.1. The variance parameters are estimated in terms of parameters, $\sigma_s^2 \equiv \sigma_v^2 + \sigma^2$ and $\gamma = \sigma^2 / \sigma_s^2$. Given this model the hypothesis that technical inefficiency effects are not random are expressed by H_0: $\gamma = 0$, where $\gamma = \sigma^2 / \sigma_s^2$. Further, the null hypothesis that the technical inefficiency effects are not influenced by the level of the explanatory variables in equation (3) is expressed by H_0: $\delta'=0$, where δ' denotes the vector, δ, with the constant term δ_0, omitted, given that it is included in the expression, $Z_{it}\delta$. Note that if: $\gamma=0$, then the model equal to the traditional average response function which is efficiently estimated using ordinary least square regression. The test statistics are calculated as:

$$LR = -2\left\{ ln\left[L\left(\frac{H_0}{H_1} \right) \right] \right\} = -2\left\{ \ln\left[L(H_0) - L(H1) \right] \right\} \qquad\qquad (8)$$

Where L (H0) and L (H1) are values of the likelihood functions under the null and alternative hypothesis, H0 and H1, respectively.

5. The data

When measuring technical efficiency of production units the way we intend to do, important prerequisites include: (i) that the data includes clearly defined production units (companies), (2) that for each company there are outputs and inputs indicating the services produced and the resources used and most critical, (3) that the units (companies) being compared are comparable in the sense that they utilize the same types of inputs to produce the same types of services.

The data we use in this paper were gathered from the annual data on toll operations reported by the individual toll companies to the Norwegian Public Roads Administration (NPRA) who is responsible for monitoring of the toll companies. The data have thus, undergone the scrutiny of the Auditors and are therefore highly reliable. All the data are from the accounting periods from 2003 to 2008; note that this data is not identical to those used by Odeck (2008) who covered the period 2001 -2004 hence, the data used here is newer. It must be added as we shall see that this data set includes also the technology in use for collecting tolls which was not considered by the above mentioned author.

While the average number of toll companies in operation across the period we study was about 45, our data set contain only 20 of the toll companies representing about 45 % of toll companies at every point in time considered. There are reasons for doing this; we wanted a set of companies that have been in operation for a number of years so that productivity improvements or regress could be examined. Further, 45% is such a large percent warranting the deduction of useful information.

Table 1 shows a summary of variables used in the analysis classified into inputs, outputs and exogenous variables. The output for toll companies are the annual traffic handled through tolls divided by the number of lanes served. The inputs are the operating costs and the administrative costs. The exogenous factors are variables, mostly dummy variables in nature that may be thought to impact efficiency but are not under the direct control of the companies. These include the age of the toll company, i.e. how long it has been in

operation, percentage of vehicles using on board units and the collection system determined by the NPRA.

Table 1 show that there is a great variation in the magnitudes of variables among toll companies.

Table 1: Summary of variables

	Mean	S.D	Min	Max
Trafikk lanes(output)	582216	547136	49354	3087922
Operational cost-Input(NOK)	18205167	30055397	115085	182938289
Administrative costs -Input(NOK)	580154	384380	48988	2048030
Exogenous variables				
Age	8.51	5.53	0	23
Toll ring	0.25	0.43	0	1
Passenger payment	0.18	0.39	0	1
Competition	0.42	0.50	0	1
Full ETC	0.06	0.24	0	1
ETC/coin Machine	0.26	0.44	0	1
ETC/manned	0.46	0.50	0	1

6. Empirical results

6.1 Estimating the DEA and SFA models

Because DEA discussed in the methodology section does not account for exogenous variables, which otherwise are included in the SFA model, the standard DEA model was modified. Thus, another way of revealing their impact is to regress them on inefficiency scores defined as 1 minus the efficiency scores. There are many approaches to regression of this type in the literature, see for instance Ruggiero and Vitaliano (1999) and Simar and Wilson (2007). In this paper, we use the approach proposed by Simar and Wilson (2007) which is the use of truncated regression.

In estimating the SFA model we assumed a translog stochastic frontier production function with the following initial form:

$$\ln y_{it} = \alpha_0 + \sum_{j=}^{4} \alpha_j \ln x_{jit} + \sum_{j=1}^{4} \sum_{h=1}^{4} \alpha_{jh} x_{jit} x_{hit} + \alpha_t t + \alpha_{tt} t^2 + \sum_{j=1}^{4} \alpha_{jt} x_{jit} t + v_{it} - u_{it} \qquad (9)$$

Where *ln* denotes the natural logarithms, y_{it} represents produced output for the *i*-th year, x_i the inputs (i=-1,..,4), *t* the linear time trend (2003=1,…,2008=6), *v* and *u* are as before defined. The model for technical inefficiency effect was defined by:

$$\mu_{it} = \delta_0 + \delta_1 (Age)_{it} + \delta_2 D_{1it} + \delta_3 D_{2it}$$
$$+ \delta_4 D_{3it} + \delta_5 D_{4it} + \delta_6 D_{5it} + \delta_7 D_{6it} + W_{it} \qquad (10)$$

Where D_i's are the dummy variables and W_{it} is the disturbance term. The rest of variables included are as in the equation. Note that this equation is similar to that of the DEA truncated model with the difference that the independent variable in the DEA case is the efficiency score from the base model.

In Table 2, the parameter estimates of the DEA-truncated model and the maximum likelihood estimation of SFA are reported. The first order and the second order coefficient for operating costs in the SFA model is found to be strongly significant. For the administrative costs, neither the first nor the second order coefficients are significant. These results indicate that operating costs are the major explanatory variable for the production of toll companies. The results also show that both γ and σ are significant.

Turning now to the inefficiency model results reported at the lower part of the table, we find that the included variables impacts efficiency in the two models more or less alike with respect to the tolling technology whereby all the tolling technologies are significantly efficiency enhancing as

compared to pure manual tolling. Further, both methods concur that passenger payment is inefficient as a means of collecting tolls. The methods do not however, conform to each fully. For instance, age of the toll company is significant according to SFA but not according to DEA, and the reverse is the case with toll rings.

Table 2: Parameter estimates of the DEA-truncated and SFA translog technical efficiency model

Variables	parameter	coefficient	standard-error	t-ratio
Determinants of frontier				
constant	β_0	0.44	0.12	3.79
ln(Operational cost)	β_1	0.45	0.07	6.59
ln(Administrative costs)	β_2	0.10	0.11	0.94
ln(Operational cost)^2	β_{11}	0.12	0.06	1.86
ln(Administrative costs)^2	β_{22}	0.07	0.24	0.28
ln(Operational cost)ln(Administrative costs)	β_{12}	-0.17	0.10	-1.79
t	β_3	0.00	0.05	0.04
ln(Operational cost) x t	β_{13}	-0.03	0.03	-0.94
ln(Administrative costs) x t	β_{23}	0.04	0.05	0.80
t^2	β_{33}	0.00	0.04	0.00

Inefficiency model					*DEA Truncated model*		
	parameter	coefficient	standard-error	t-ratio	coefficient	standard-error	t-ratio
Const.	δ_0	2.25	0.60	3.77	0.52	0.06	9.10
Age	δ_1	-0.10	0.04	-2.35	0.00	0.00	1.00
Tollring(1=yes, 0=otherwise)	δ_2	0.17	0.69	0.24	-0.28	0.06	-4.93
Passenger Payment(1=yes, 0=otherwise)	δ_3	0.78	0.28	2.76	0.05	0.01	3.44
COMP(1=yes if competetive tendering, 0=otherwise)	δ_4	1.02	0.38	2.66	0.03	0.05	0.76
Full ETC based (1=yes, 0=otherwise)	δ_5	-4.08	0.75	-5.48	-0.33	0.11	-2.86
ETC based with coin machines(1=yes, 0=otherwise)	δ_6	-3.02	0.76	-3.99	-0.18	0.07	-2.49
ETC based and manned (1=yes, 0=otherwise)	δ_7	-1.96	0.32	-6.19	-0.10	0.05	-2.11
sigma-squared	σ^2	0.29	0.06	5.00	0.16	0.01	12.84
gamma	γ	0.48	0.09	5.64			
log likelihood function		-71.89			47.84		
LR test o fthe one-sided error		77.41			46.98		

6.2 Efficiency scores -comparing DEA and SFA

Given these findings, the data described is used to investigate inefficiency among Norwegian toll companies. The average efficiency scores by each method are reported in Table 3. The Top panel of the table presents the scores by SFA while the lower panel the DEA results.

Table 3: Average efficiency scores for DEA versus SFA

	2003	2004	2005	2006	2007	2008	Average(all years)
			SFA				
Mean	0.561	0.618	0.617	0.686	0.663	0.646	0.632
S.D	0.218	0.208	0.213	0.240	0.209	0.210	0.174
Min	0.271	0.216	0.220	0.308	0.334	0.271	0.377
Max	0.993	0.970	0.991	0.983	0.987	1.000	0.905
No. of observations	20	20	20	20	20	20	20
			DEA				
Mean	0.574	0.620	0.487	0.546	0.498	0.449	0.529
S.D	0.261	0.274	0.237	0.247	0.233	0.267	0.228
Min	0.086	0.151	0.140	0.158	0.144	0.129	0.167
Max	1.000	1.000	1.000	1.000	1.000	1.000	1.000
No. of observations	20	20	20	20	20	20	20

The mean efficiency scores by the two methods are low at about 0.5 to 0.6 across all the years studied indicating a large potential for efficiency improvement in the sector. The score of 0.5 imply that an average toll company could have reduced its inputs (operating and administrative costs) by about 50 % and still be able to produce the same level of service as they do today. This result may seem far fetched however, the problem with many Norwegian toll companies is that they have relatively low traffic volumes and operate 24 hours a day. Thus operating costs e.g., in terms of labour costs, are incurred even when there is no traffic being served. Obviously, a potential way of improving efficiency would be to reconsider operating hours. The standard deviation of the efficiency scores is large at about 17-30 % and reveals that there is a great variation in efficiency scores between toll companies and by the method applied; while some companies are a 100 % efficient others obtain very low scores.

If we consider the average efficiency scores all the periods, it is observed that the two methods maps each other very well; mean efficiencies increase from 2003 – 2004, falls in the period 2004-2005, increases in period 2005 -2006 and the falls again in 2006-2007 and in 2007 -2008.

So far the two methods confirm that there are large inefficiencies in the performances of the Norwegian toll companies. The next question to address is whether the two methods give the same results; it may be that they give averages that are close to each other, but the scores for the individual companies may be different.

This issue is examined closely in Figure 2 where we have plotted the efficiency scores by DEA versus SFA. The figure indicates that there is some positive correlation between the two approaches but that correlation is not clear-cut. A Pearson correlation measure gave a significant correlation coefficient of 0.30. This correlation coefficient is low and a question may be asked as to why this is so. The answer is simple. These are two different approaches to the construction of frontiers from which efficiency scores are derived. What is of importance is that they both concur that approximately the same average inefficiency is present in the sector.

Figure 2: DEA versus SFA efficiency scores.
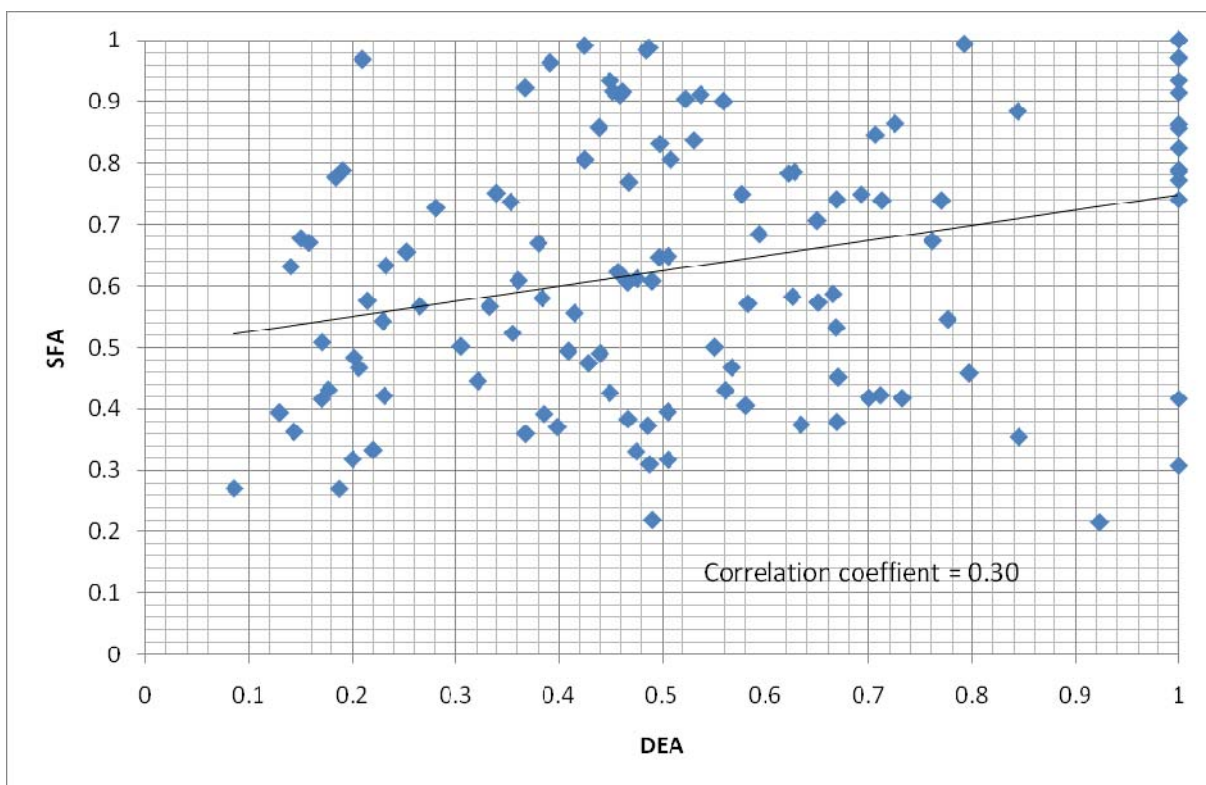
Now, another issue to consider is whether larger companies serving a larger amount of traffic and operating many toll stations are more efficient than others. Figure 2 show a plot of how the efficiency scores by the two approaches relates to the size of companies.

Figure 3: relationship between efficiency scores and size of companies
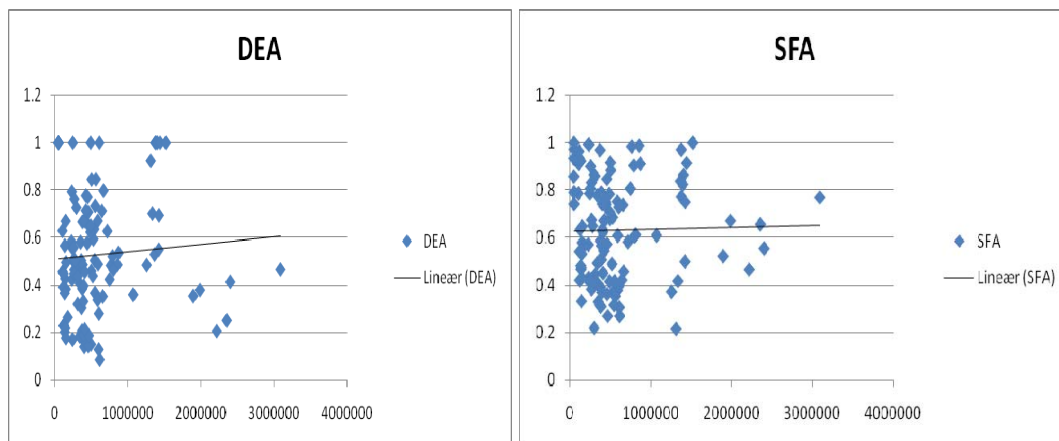
From Figure 3, there is no doubt that efficiency increases with attesting that larger companies are more efficient than smaller ones.

7. Concluding remarks

The objective of this paper has been to analyze the efficiency and productivity of Norwegian non-profit toll companies established with the purpose of collecting funds for road investments. We have used two approaches: DEA and SFA to infer the level of inefficiency in the sector.

Our results reveal the following:

1) A formidable potential for efficiency improvement exists in the Norwegian toll road industry and this potential varies to a great extent among toll the companies.

2) The technology used for collecting tolls matter for the efficiency of companies to the effect that companies who use electronic tolling system in combination with manual/coin machines are more efficient as compared to those who only use manual collection systems. Further, charging passengers rather than only vehicles leads to more inefficiency.

3) Finally, toll companies strive collectively to improve their productivities from one year to the other. A probable explanation for this is the pressure that has been exerted on companies to improve their performance.

The findings of this paper have some implications for decision makers. The authorities concerned with roads (the NPRA and the Ministry of Transport and Communication, in particular) have reason to reconsider the organizational framework of Norwegian toll companies. The major reason for this assertion is that there is strong evidence that economies of scale exist in the Norwegian toll road industry. A second recommendation is that the NPRA should provide guidelines on how toll companies can be run efficiently. Such guidelines should provide examples of best practice companies that more inefficient companies can learn from. The DEA framework used in this study readily reveals such best performances for the individual inefficient companies to compare with. Finally, the use of ETC system in combination with manual should be encouraged by the NPRA and, the passenger payment is inefficient and should be discouraged.

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