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COMPETITIVE TENDERING, OWNERSHIP AND COST EFFICIENCY IN ROAD MAINTENANCE SERVICES IN SWEDEN: A PANEL DATA ANALYSIS

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Abstract

This paper uses econometric methods to study the cost efficiency of road maintenance provision in Sweden for the first time. The novelty lies in the application of econometric techniques to a new and rich panel dataset (73 contracts; 11 years, 2004-2014) with a wide range of variables and approaches to controlling for heterogeneity (including weather variation). The analysis is applied in the context of a sector where all road maintenance contracts are subject to competitive tendering, but with a state-run provider competing against private firms. The key focus is whether, even after competitive tendering, efficiency differences remain between the state provider and private entrants. We find that the state-run provider has significantly higher costs (between 8 and 20%) than private firms despite holding 60% of the market. The results suggest that substantial savings are possible through opening up road maintenance to the private sector through competition for the market; but that in Sweden, the tendering process is still not working optimally. Further research is needed to understand why the current cost gap persists between public and private providers, despite competitive tendering having been present across the whole market for several years.

Keywords: road maintenance; cost efficiency; competitive tendering; unbalanced bidding; ownership; unobserved heterogeneity; tendering.

JEL Classification: C23, D24, O18, R42

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1. INTRODUCTION

Roads are one of the essential public assets that contribute to socio-economic development and growth by providing its users access to, inter alia, hospitals, schools and jobs. Road construction requires substantial resources, typically funded by government[1]. Like other infrastructure assets, roads are subject to deterioration. The intensity of the deterioration process is associated with the passing traffic volume, weather conditions and maintenance activities. Geographical areas with higher traffic volumes and severe weather conditions require a more concentrated maintenance activity. Therefore, an advanced road asset management system is essential to plan the type and the frequency of maintenance activities.

Road maintenance activities are generally classified as routine, periodic and urgent (Burningham and Stankevich, 2005; Smith, 2012). Routine maintenance includes small-scale cyclic works such as grass cutting, surface patching, cleaning of the roads and drainage systems. Periodic maintenance comprises large-scale works that includes resurfacing and strengthening or reconstruction of the road. Urgent maintenance consists of the unforeseen works which require a reactive response such as collapsed culvert, road damage due to the traffic accident, as well as responding to inspections or complaints regarding the road condition. Winter services - such as keeping the roads clear of ice and snow – is a further important category of road maintenance activity.

In an attempt to increase the efficiency of the road maintenance, governments around the world have initiated competitive tendering for the right to provide road maintenance services. While road authorities are still responsible for a diligent execution of road maintenance, its performance might be in-house or contracted out (Goncalves and Gomes, 2012). In-house road maintenance is performed by a work unit under the responsible authority. In contracting out road maintenance, works are tendered under competitive conditions, where both public and private companies may participate. The international evidence suggests that competitive tendering reduced road maintenance costs by around 20-30% in Australia (Lyon and Dwyer, 2011), 10-35% in Canada (ISTED, 2002) and 22-27% in Sweden (Arnek, 2002).

Given international trends towards opening-up road maintenance to competitive tendering, with the aim of reducing cost and improving efficiency, the purpose of this paper is to assess the relative efficiency performance of different road maintenance contractors in Sweden over the period 2004-

[1] There are also different types of public and private collaboration in building roads, Public-Private Partnership (PPP), where financial aspects of a road construction may depend on the agreement between parties. For instance, a private actor engages into a road construction by covering a certain share of the costs with their own funds in exchange for charging a fee/toll from road users during a certain period specified in the contract. See Ahlstrand (2001), Bovaird (2004), Levinson (2005), Hammar et al. (2008), Perkins (2013) and Rizzi (2014) for alternative financing mechanisms for roads.

2014. Though a competitive tendering was first introduced in 1992 in Sweden, this subject has not been analyzed previously due to lack of data. Our new and unique dataset comprises Sweden's national road network with 73 maintenance contract areas (operated predominantly by three private contractors, and one state provider) over the period.

A key challenge in comparing the efficiency of road maintenance contracts across different areas of the country is the need to deal with unobserved heterogeneity that is not related to efficiency performance. This issue is addressed by modelling a rich cost function specification that includes multiple control variables (including for example weather-related factors), as well as regional dummies to control for remaining heterogeneity at the regional level; in our dataset, Sweden is divided into four regions. Whilst we prefer a random effects specification, we also additionally control for omitted factors that may be correlated with the regressors by testing a fixed effects alternative and the results are unaffected (indicating that we can safely use the random effects model).

We find statistically significant cost differences between firms operating in the sector, which suggest that the state-run maintenance provider performs maintenance activities at a significantly higher cost (between 8 and 20%) than private firms. Indeed there appears to be one contractor, Skanska, that is lower cost than all of the other private operators as well (this being a statistically significant finding). This finding is important because the state-run firm still retains the majority of contracts (60% of the market), thus suggesting that the tendering procedure is not yet functioning optimally. There are a range of possible explanations derived from the literature - discussed further in the paper - that could explain this cost differential; that are not directly related to relative efficiency performance. First private firms may have an incentive to shade non-contractible quality and thus have lower costs than the state-run provider as a result (e.g. Hart et. al., 1997). Second there are a number of arguments relating to gaming within the bidding process such as unbalanced bidding (e.g. Stark, 1974), or the use of low-ball offers to win contracts (in the anticipation of securing additional payments later). Since our data is based on data that includes the final payment to the procurer (including additional payments), these latter arguments centre around the question of whether the state-run provider, or private firms, are better able to play these games to their advantage, which in turn depends on, inter alia, informational advantages. Further research is needed to verify these hypotheses.

Whilst there has been a long history of efficiency benchmarking in the roads sector, econometric techniques have been little applied (see Nash, 2018); though there has been recent developments in the literature focusing on the application of econometric methods to assess the relative efficiency performance in local authority roads in Great Britain (see Wheat, 2017), and also interest from the Office of Rail and Road in Great Britain in applying such approaches to strategic roads (see KPMG, 2016). Our paper therefore contributes new empirical evidence to a relatively limited but emerging international literature focused on comparing the efficiency of road maintenance and renewal activities. The novelty lies in the application of econometric techniques to a new and rich dataset with a wide range of variables and approaches to controlling for heterogeneity, prior to the estimation of efficiency. We also benefit from a large cross section and a long panel compared to previous studies – with the analysis applied in the context of a sector where all road maintenance contracts are subject to competitive tendering. The particular interest here is whether, even after tendering, efficiency differences remain between the state provider and new private firms entering the market.

The remainder of the paper is organized as follows. Section 2 describes the road maintenance system in Sweden. Section 3 reviews the relevant literature. Section 4 sets out our methodology and estimation procedure. The data description and the results are presented in Section 5 and 6, respectively. Section 7 draws conclusions.

2. ROAD MAINTENANCE IN SWEDEN

The Swedish road network is about 580 000 km in length, of which state roads (motorways and major highways) comprise 98 000 km (17%), communal roads (local roads) comprise 42 000 km (7%) and private, primarily forest roads 436 000 km (76%) (SKL, 2015). The responsibility for road maintenance of the state roads is on the Swedish Transport Administration, while the respective communes are in charge of roads within their respective territory. Private roads are the obligation of the different individual road associations. Government subsidizes the maintenance of all state roads and nearly 17% of the private roads (if these roads are considered to be a complement to the state roads).

The Swedish government enacted a law prescribing the commencement of a gradual procurement of road maintenance activities under competition from 1992. At present, about ten companies participate in road maintenance activities. In order to join the tendering process, each potential bidder has to go through a prequalification process (requirements include sufficient technical competence, possession of machinery etc.). Contracts are then awarded based on the lowest price bid. The number of bidders for each contract is typically above three. More than 90% of maintenance areas are contracted out to four companies, i.e. NCC, Peab, Skanska and Svevia. The regional shares2 of these companies indicate that Svevia is the dominant provider of the road maintenance activities across all the regions. Svevia is the commercialized version of the previous in-house maintenance unit (previously part of the Swedish Transport Administration), which is now an autonomous state owned company. Smaller operators, for which data exists only sporadically in the

[2] There are six regions, North, Central, South, Stockholm, West and East. Due to lack of data for Stockholm and the West region, our dataset covers four regions: North, Central, South and East.

sample (they enter one year and disappear the next) are excluded from our model, which therefore only includes four companies: the state provider plus NCC, Peab and Skanska.

The whole state road network is divided into 111 maintenance areas[3]. Each area is awarded to a single company, so that the responsibility for the base road maintenance activities is on one company during the contract period. Contract periods range between 3-5 years, with the option for extension from one to three years after that.

A base road maintenance contract with the specification of the expected output, i.e. an output-based contract, is a common type of contract used in road maintenance internationally[4], though with some elements of detailed requirements as in the input-based contracts (Lingegård et al., 2011). The Swedish base road maintenance contract includes services covering paved and gravel roads, bridges, side areas and establishments, road equipment as well as winter services. Winter services include such activities as keeping the roads clear of ice and snow, with a predefined urgency of performing these services depending on the class of the road. The roads are classified by the level of traffic volumes, where the roads with higher traffic volumes have the highest priority to be served.

Total expenditure on maintenance of the state roads in Sweden was SEK 3.3 billion in 2014, where on average a 60% is spent on winter services (the size of the winter expenditures may vary depending on the maintenance area and the weather conditions in particular season). Within-country weather variation – also common in other countries – means that controlling for weather variables is important prior to making a relative efficiency assessment.

3. LITERATURE REVIEW

There is an extensive literature studying the marginal cost of road infrastructure – that is, the incremental road operation, maintenance and renewal costs induced by a marginal increase in traffic volume. An efficient and sustainable use of transport infrastructure presumes pricing its usage based on the marginal cost of road use (Nash and Sansom, 2001; Nash and Mathews, 2005; Link, 2014). In the marginal cost principle, a cost model is specified as a function of traffic and other road network characteristic and can be estimated using econometric methods. If a traffic variable turns out to be statistically significant in explaining cost variations, then it serves as evidence that increased traffic impacts on road wear and tear and in turn cost.

An alternative approach is to use average variable cost per traffic volume. Data from national road accounts provide information on total road expenditures (capital and running cost) and traffic volume, which allows producing an approximation to marginal cost by computing average variable

[3] This number refers to 2015.Historically there were some mergers of certain areas; therefore we have an unbalanced panel.
[4] In Sweden, periodic maintenance activities, i.e. larger resurfacing or reconstruction works, are tendered separately, so that these works are not included in the base road maintenance contracts.

cost per traffic volume (Ricardo-AEA, 2014). This approach fails to control for differences in geographic location, weather and other road specific characteristics (bridges, tunnels, resting places, median barriers etc.). Therefore we focus on econometric studies where traffic cost elasticity estimates are obtained for road maintenance and operation costs.

Two collaborative EU funded projects have formed the basis for developing the econometric literature on road marginal wear and tear costs (GRACE; Link et al., 2008) and CATRIN (Lindberg, 2009). The former project provides evidence that the cost elasticity for road operation is close to zero, and for road maintenance is in the range 0.12-0.69. The latter project, which largely is built on the GRACE project framework, provides cost elasticity estimates within the same range (0.3-0.5). The relatively wide range of estimates might be explained by different model specifications, road surface type, and cost structure (for example, operation and maintenance costs are sometimes modelled separately or together; and sometimes renewals are included within maintenance costs). A better understanding of the cost structure can have implications beyond toll pricing policies, and lead to policy recommendations on the tender. For instance, Link (2006) highlights that road authorities in Germany should tender larger lot sizes due to the existence of economies of scale in highway renewal.

Along with the marginal cost literature, there is a new and emerging research area within efficiency literature that studies efficiency in construction and maintenance of road infrastructure. Though, the efficiency benchmarking has a long history in academic literature, the use of econometric methods gives renewed impetus to more advanced research (Nash, 2018). Welde and Odeck (2011) study the efficiency of 20 Norwegian toll companies that have been in operation 2003-2008 using data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Findings suggest a potential for efficiency improvement, but the variation in the efficiency scores is dependent on the method used. Further, using electronic tolling systems for collecting tolls enhances the efficiency of companies compared to the use of manual collection systems. Massiani and Ragazzi (2008) examine the efficiency of 18 highway operators in Italy and show that there are large differences in cost efficiency among operators implying the potential for yardstick competition.

A question remains whether competitive tendering and resorting to the private sector improves the efficiency of road maintenance. As pointed out by Levin and Tadelis (2010) in the general case of procurement, the improvement of productive efficiency depends on the ability of the public authority to specify and implement performance requirements. In theory, road maintenance has great potential for involving the private sector (Blom-Hansen, 2003). Indeed, *ex ante* quantities of maintenance works required are known to the public buyer and specified in the call for tender, while unit costs are fairly standard (Bajari et al., 2014). Furthermore, quality can be measured with relative ease, which limits the scope of quality shading according to Lindholst et al. (2018).

In practice, there are some limits to introducing competition. Firstly, the literature has identified that road maintenance is subject to economies of scale. For instance, Wheat (2017) analyzes the efficiency in road maintenance for 51 local authorities in England and finds that sharing maintenance services (or mergers) across small local authorities would lead to potential cost savings. Moreover, there is, on average, scope for 17% cost savings without compromising maintenance quality and level of traffic flow.

A second point related to economies of scale is the fact that the cost of road maintenance depends on the location of the works and the distance to asphalt plants (Bajari et al., 2014). Therefore, a firm's bid depends on the location of their depots and the size of the company (Krasnokutskaya, 2004). Due to these spatial specificities, the market may be less competitive in some areas. In Norway for instance, Leiren et al. (2016) suggest that lack of competition limits the scope for cost savings in parts of the country.

Thirdly, Bajari et al. (2014) point out that actual quantities produced are different from estimated quantities, meaning that contracts are incomplete and subject to renegotiations. Since the seminal work by Klein, Crawford and Alchian (1978), such a setting leads to the possibility of post contractual opportunistic behaviors. Therefore, cost savings depend on the ability of the public authority to limit the cost of renegotiations. This suggests first that, to measure efficiency, it is important to focus on final payments (Bajari et al., 2014) and secondly, that contractual arrangements play a key role in dealing with the uncertainty on quantities. Previous work has emphasized, for instance, that the type of contract is an important determinant of the efficiency of road maintenance (Fallah-Fini et al., 2012 and Bajari et al., 2014), as well as the duration of the contract (Anastasopoulos et al., 2010).

The gradual introduction of competitive tendering of road maintenance in Scandinavian countries has led to new insights on the shift from in-house production. The results by Blom-Hansen (2003) suggest that involving the private sector in road maintenance led to a cost reduction in Denmark, despite the fact that "*the asphalt industry in Denmark is notorious for its cartel-like conditions*" (p. 422). Yet in the case of Norway, Odeck (2014) finds that full privatization is necessary in order to significantly reduce cost overruns in roads projects, while maintaining a semi-monopolistic public firm does not deliver such improvements.

Our study therefore provides new evidence on road maintenance procurement and efficiency, fitting within this new and emerging literature; and applies econometric methods similar to those used for estimating marginal wear and tear costs. Whilst our focus here is on efficiency, in section 6 we comment on the traffic elasticities reported in our results.

4. MODEL

We estimate the following random effects cost model (testing also for the presence of correlation between the regressors and the effects; see section 6):

$$C_{it} = \alpha_0 + X_{it}'\beta + D_P'\gamma + D_R'\varphi + \omega t + \mu_i + v_{it} \quad (1)$$

where C_{it} is road maintenance cost for maintenance area *i=1,…,I* at time *t;* X_{it} represents the characteristics of the maintenance area, including road length, vehicle kilometers, road length with low buoyancy[5], road length with a median barrier; winter period specific cost driving factors (number of days with icy road conditions[6] and snowfall[7]); D_P is a dummy variable representing the four contractors (three private and one state provider); $\beta, \gamma, \varphi, \omega$ are the vectors of respective parameters to be estimated; μ_i is unobserved maintenance area heterogeneity; D_R is a dummy variable representing the region of operation; t is a time trend, and v_{it} is a random noise term. We consider that a standard econometric framework (as compared to other approaches, such as data envelopment analysis (DEA) or stochastic frontier analysis) is best suited to the problem at hand, given the need to test the statistical significance of the factors of interest, and adequately control for heterogeneity through the cost function; without the need to impose arbitrary distributional assumptions for the error term.

Equation (1) adopts the Cobb-Douglas functional form, after appropriate testing suggested that this model was preferred to the translog approach; see section 6[8].

4.1 Model estimation

The dependent and time-varying explanatory variables are log transformed in the model presented above. However, two variables in the model include zeroes, namely road length with low buoyancy and roads with a median barrier. Therefore, we need to decompose these two variables. Denoting these variables as Z variables the decomposition is as follows: first, a dummy which

[5] Defined as the road length with reduced load-bearing capacity.
[6] Defined as wet precipitation at times of low temperature (air temperature between -5 and -2).

[7] Snowfall is defined as a combination of two parameters in the Swedish Transport Administration's system: precipitation=snow and amount of precipitation (mm)>0 (in permanent form).

[8] Link (2014) estimates a multi-output cost function with translog specification, as well as and hybrid cost specifications with Box-Cox transformed output variables.

indicates zero values of Z is created, i.e. *DZ=1* if *Z=0*, 0 otherwise; second, we log transform *Z*, i.e. *Ln(Z)*, replacing missing values (due to zeros) with the minimum value of *Ln(Z)*. Finally, we include *DZ* and *Ln(Z)* variables into the model, instead of the *Z* variable.

It should be noted that our focus here is on the relative efficiency performance of the four main contractors (three private and one state provider) in Sweden. Given that these same companies carry out maintenance across a number of different contracts, we assume that there are no efficiency differences across contracts within the same company (which is standard in the literature where inefficiency is generally assumed to reside at firm level). We do however include contract-specific effects (μ_i), which capture unobserved heterogeneity. Studying inefficiency differences both between and within contractors would be an interesting further study[9]. We further address unobserved heterogeneity through the inclusion of regional dummies (D_R). The relative efficiency of the different contractors is inferred from the coefficients on the contractor dummy variables (D_P).

Estimating the model using random effects (generalised least squares (GLS) assumes that any unobserved maintenance area heterogeneity. For example, it assumes that omitted variables, such as the quality of the road network and/or the quality of the construction are uncorrelated with the other explanatory variables in the model. Since this assumption might be restrictive, we also test the random effects model against fixed effects (this is done by including group mean variables for the time varying variables, and testing their joint significance; see LIMDEP (2016)[10] and Mundlak (1978)):

$$C_{it} = \bar{X}_i\rho + X'_{it}\beta + D'_P\gamma + D'_R\varphi + \omega t + \mu_i + v_{it} \tag{2}$$

Let's denote equation (1) and (2) as Model I and Model II respectively. The choice between these two models is based on the testing the restriction of the Model I, namely that unobserved heterogeneity is uncorrelated with the regressors. To test this restriction, Model II is estimated, then a null hypothesis of no correlation between the regressors and unobserved maintenance area heterogeneity is tested, which is equivalent to testing that the coefficients on the group means of time-varying explanatory variables are jointly zero. We use a Wald test on the joint hypothesis: $H_0: \hat{\rho} = 0 \ \forall \ \hat{X}_i$. If the null hypothesis is rejected, this would indicate correlation between the regressors and the contract area effects, indicating a possible preference for Model II over Model I.

[9] We do note that Smith and Wheat (2012) argue that there could be inefficiency within the same company.
[10] LIMDEP Version 11 Econometric Modelling Guide, page E-366.

5. DATA

Our study uses an unbalanced panel comprising a 73 Swedish state maintenance areas over the period 2004-2014. Maintenance areas are an aggregation of a number of road sections within a certain administratively defined maintenance area, hence all data on a road section level is aggregated to the maintenance area level. For each maintenance area there is a contract between the Swedish Transport Administration and one of four contractors: NCC, Peab, Skanska (all private contractors) and Svevia (state-owned provider).

The dependent variable is road maintenance cost which is the sum of the costs of routine, maintenance and winter services. The costs include both the initial work elements included in the base contract, plus additional work that is determined at a later point (though it is not possible to separate these with the current dataset). Our discussions with the industry reveal that such payments for additional work within contracts is common in Swedish road maintenance (and re-investment) contracts[11]. It is possible that the additional work may include some costs relating to periodic maintenance, which are not part of routine maintenance work (though it is not possible to identify such costs in the data, though we expect them to be small).

The explanatory variables are road length, vehicle-km, road characteristics (length of road with low buoyancy and length of road with a median barrier), weather (number of days of snowfall and icy road conditions). This climate information has a direct impact on the frequency and extent of performing maintenance activities, and in turn on the costs of these activities[12]. Regional dummies are also included, capturing unobserved heterogeneity at the regional variable. We also include dummy variables to capture any efficiency differences between the four different contractors. Our dataset comprises the four largest companies, which are responsible for 90% of road maintenance activity in Sweden. The traffic data consists of vehicle-kilometers for all vehicles and heavy vehicles, which is a multiplication of the road length travelled with the number of passages[13] of a respective vehicle type (i.e. all vehicles vs. heavy vehicles). However, due to the high correlation between these

[11] See also (in Swedish): Nilsson, J-E., Johansson, O., Nyström, J., Ridderstedt, I. och Wikström, D. (2018). Kostnadsanalyser av upphandlade kontrakt: Två studier av investerings- ochreinvesteringsprojekt. VTI rapport 976; Nilsson, J-E., Nyström, J. och Salomonsson, J. (2019). Kostnadsöverskridande i Trafikverkets entreprenadkontrakt. VTI rapport 1011; Trafikverket (2016). Kontraktsanalys basunderhåll väg – slutrapport. TRV2016:128.

[12] Yarmukhamedov and Swärdh (2016) provide detailed information on climate variables and their potential impact on maintenance costs.

[13] The number of passages is an estimated value i.e. the data is based on measurements of vehicle passages at certain times (not a year-round measurement), which are then used to forecast an annual daily traffic. Moreover, there is a potential risk of overestimating the effect of passage (traffic volume), because it is not currently possible to observe whether the same vehicle has passed the whole road section or just a part of it.

variables, vehicle-kilometers for all vehicles is used to describe a traffic volume in our preferred model[14].

The maintenance cost, weather and geographical data have been provided directly by the Swedish Transport Administration, while the road characteristics and traffic data are from the National Road Data Base (NVDB).

5.1 Descriptive statistics

The descriptive statistics is based on the unbalanced panel on 73 maintenance areas covering state roads (motorways and major highways; see definitions in section 2[15]) over the period 2004-2014, which amounts to 623 observations.

A Table 4.1 suggests that substantial resources are allocated to road maintenance activities in Sweden, with an average cost per area of around SEK 25 million (in 2014 prices). The overall traffic is about 416 billion vehicles kilometers, where the traffic volume of heavy vehicles is one eighths of a total traffic volume.

Table 1 Descriptive statistics, maintenance area average for 2004-2014

	Mean	SD	Min	Max
Maintenance costs, SEK (in thousands)	25,164	9,203	1,340	64,849
All vehicle kilometers (in millions)	416,433	294,581	36,040	1,346,725
Heavy vehicle kilometers (in millions)	50,023	38,916	4,068	221,346
Road length, kilometers	1,022	273	593	2,818
Road length with low road buoyance, kilometers	54.23	71.82	0	323.12
Dummy road buoyancy (takes value 1 if there are no roads with low buoyancy)	0.019	0.138	0	1
Road length with a median barrier, kilometers	20.88	42.88	0	183.33

14 Of course, the wear and tear of heavy vehicles is likely to be higher than that of other vehicles. Therefore, we conduct a sensitivity analysis on the choice of traffic measure (see Section 6).

15 Some connecting / slip roads are included within this definition.

Dummy median barrier (takes the value 1 if there are no roads with a median barrier)		0.457	0.498	0	1
Icy road conditions, number of days		69.24	22.36	24	147
Snowfall, number of days		122.02	35.45	41	206
Contractor dummies:	NCC	0.162	0.369	0	1
	Peab	0.159	0.366	0	1
	Skanska	0.101	0.302	0	1
	Svevia (state-owned)	0.578	0.494	0	1
Regional dummies:	North	0.268	0.443	0	1
	Central	0.331	0.471	0	1
	South	0.229	0.421	0	1
	East	0.172	0.377	0	1
Years (time trend)				2004	2014

As can be seen from the table, the road length variable ranges from 593 to 2800 km, with a mean of 1021 km. The length of the roads with lower buoyance ranges from zero to 323 km, which implies that in certain maintenance areas there are no roads with lower buoyance. The dummy for the road buoyance suggests that nearly two percent of the maintenance areas have no roads with low buoyancy. Similarly, the length of the median road barriers varies between zero and 183 km, implying that not all the roads within a maintenance area are equipped with a median barrier. The dummy variable for median barrier shows that in 46% of the maintenance areas, none of the roads have a median barrier

Due to the northern location of Sweden, the average duration of the winter season is characterized by just over 2 months' icy road conditions and almost four months snowfall.

As noted above, the state-owned service provider, Svevia, dominates in the maintenance market with a market share of almost 60%, with the remainder broadly equally shared between the other three, private contractors.

6. RESULTS

In this section, we present the estimation results as well as the specification and hypotheses tests described in Section 4.1. The results are then discussed in section 6.2.

6.1 The estimation results

The estimation results for our preferred, random effects model, are shown in Table 2. We test for the fixed effects alternative via a Wald test of the joint significance of the group mean terms (Wu test; Wu, 1973). This test confirms that the group mean terms are not jointly significant and we thus prefer the random effects specification (Wald test: Chi-square=10.21, p=0.18). A translog cost function was also considered as an alternative to the Cobb-Douglas specification, where the choice between a Cobb-Douglas and translog specifications hinges on the joint hypothesis test of the significance of the squared and interaction terms. However, the second order terms proved to be jointly insignificant, and we thus retain the Cobb-Douglas functional form.

Table 2. Regression results: Dependent variable: Road maintenance cost

		Model I Random Effects		Model II Fixed Effects[16]	
		Coef.	SE	Coef.	SE
Row \ Col		1	2	3	4
1					
2	Ln (All vehicle km)	0.138**	0.062	0.093	0.098
3	Ln (Road length)	0.671***	0.108	0.445**	0.212
4	Ln (Road buoyance)	-0.011	0.011	-0.023	0.015
5	Dummy road buoyance	-0.303**	0.124	-0.378***	0.135
6	Ln (Median barrier)	0.007	0.016	0.007	0.021
7	Dummy median barrier	0.107	0.090	0.102	0.104
8	Ln (Snowfall)	0.465***	0.084	0.475***	0.091
9	Ln (Icy road conditions)	0.070	0.048	0.075	0.052
10	Entrepreneurs:				
11	Ncc	-0.080*	0.042	-0.066	0.046
12	Peab	-0.047	0.049	-0.043	0.050
13	Skanska	-0.221***	0.055	-0.223***	0.055

[16] Estimated as a random effects model with group means – see section 4.

14	Regions:				
15	Central	0.039	0.081	0.039	0.089
16	South	0.200*	0.104	0.209	0.141
17	East	0.001	0.105	0.001	0.135
18	Year	0.004	0.011	-0.004	0.004
19	Group means of:				
20	All vehicle kilometers			<0.001	<0.001
21	Road length			<0.001	<0.001
22	Road buoyance			0.001*	0.001
23	Median barrier			-0.001	0.001

***, **, * Significant at 1%, 5% and 10%, respectively.

Note: Region North and entrepreneur Svevia (state-owned company) are reference categories.

Table 2. Regression results (cont.)

		Model I		Model II	
		Coef.	SE	Coef.	SE
Col / Row		1	2	3	4
24	Group means of:				
25	Snowfall			<0.001	0.003
26	Icy road conditions			-0.001	0.004
27	Year			0.007*	0.004
28	Constant	14.793**	7.491		
29					
30	Number of observations	623		623	
32	Wald test			10.21	

***, **, * Significant at 1%, 5% and 10%, respectively.

As noted in section 5, it is possible that road condition is affected more by heavy vehicles as compared to the other vehicle types. However, due to the high correlation between traffic volume measures, all vehicles and heavy vehicles, it was not possible to include both measures in the same model. Instead, we tested the substitution of all vehicles with separate variables for heavy vehicles and other vehicles and found the results not to be greatly affected (though the significance on the traffic variables was affected as expected).

The estimation results of Model I in Table 2 show that all the parameter estimates have expected signs. In respect of the traffic variable, the results show an increase in traffic volume by 1% increases maintenance costs by 0.14%. Further, a 1% increase in road length leads to a 0.67% growth in maintenance costs. Note that it is important to separately estimate the effects of traffic and road length in the same model because the traffic (density) and scale effects might differ (Munduch et al., 2002; Yarmukhamedov and Swärdh, 2016). Compared to previous studies, the cost elasticity with respect to traffic for road maintenance and operation in our study is within the range for findings from the previous literature (with ranges from 0.12 to 0.69 from studies covering a range of countries), though is towards the bottom end of the range. Our estimates are lower than studies relating to Sweden (with ranges from 0.39 to 0.80). As noted in the literature review, the wide range of results for this elasticity is driven by factors such as the precise costs included in the study and road type; and previous Swedish results are not directly comparable to our study due to the differences in cost structure and road surface type studied.

We do not get clear and significant results in respect of the impact of road length with low buoyancy, though the indicator variable suggests that those areas that have no roads in this category have costs that are lower by 26%[17]. The median barrier variables are also not statistically significant.

The coefficient estimate for the number of days with snow suggests that, on average, a 1% increase in the occurrence of these days leads to a 0.47% increase in the maintenance costs. Number of days with icy conditions does not appear to be significant, but takes the expected sign as noted above. Compared to the northern regions of Sweden (the excluded dummy variable), the maintenance costs are significantly higher in southern region, i.e. southern regions have maintenance costs that are just over 20% higher than regions in north. There is no evidence of any statistically significant time trend in the data, which could suggest a lack of technical progress in this sector over the sample. This finding is in line with Nyström et al. (2016) which find that Swedish contractors have restricted degrees of freedom in construction contracts that impedes innovation in the sector.

The key findings in respect of the efficiency performance of different contractors indicate that all the private operators have lower costs than the state-owned company, Svevia, though it is only in the case of NCC and Skanska that this finding is statistically significant (at the 10% and 1% levels respectively). Based on these findings, our results show that NCC and Skanska provide maintenance services around 8 and 20% cheaper respectively than Svevia. Given the controls we have made for unobserved heterogeneity in this model, we thus interpret these findings to suggest that private

[17] (exp(-0.303)-1)*100=26.14

contractors are in general more efficient than the state-owned provider, even in a situation where competitive pressure exists in the form of competition for the market for all contracts. Indeed there appears to be one contractor, Skanska, that has lower costs than all of the other private operators as well (this being a statistically significant finding).

6.2 Discussion

As noted above, our results show statistically significant contractor level cost differences. That is, the state-owned maintenance provider, which has the biggest market share (almost 60%), is considerably more expensive than private contractors. Our results are robust to a range of tests with respect to the functional form, model specification, and estimation procedure.

Of course there is a wide international literature that shows, in general, that private firms are more cost efficient than state-owned providers. However, there are some important qualifications. Most notably, a significant strand is the literature, starting with the seminal paper of Caves and Christensen (1980), suggests that where there is competition, efficiency differences between state-owned and private firms may disappear. The argument is that the competitive process, or even the threat of competition, disciplines even state-owned firms to improve efficiency. This finding has been observed in many industries in many countries around the world (see for example, Domberger et.al., 1986; 1987; and Alexandersson, 2009).

In our case, at one level the findings may not be surprising: private firms are found to be more efficient than state-owned operators. On the other hand, given that all road maintenance contracts in Sweden are awarded through a competitive process (for the whole of the period of our sample), it might have been expected that this competition would have eliminated any efficiency differences. The fact that private firms remain cheaper suggests that the competitive tendering process in road maintenance in Sweden may not yet be fully effective.

We can suggest two sets of explanation as to why a less efficient firm could remain within the market: the public firm is able to game the market in order to appear efficient or there is unobserved heterogeneity that explains the significant cost difference and its acceptance by the public buyer. Lower costs amongst private contractors could be explained by arguments relating to gaming within the bidding process (indeed as mentioned earlier, renegotiations on quantities are common occurrences in road maintenance procurement contracts (Bajari et al., 2014)). First, it may be that firms bid in a strategic manner to set bid prices below cost in order to win a contract, with the expectation of securing contract add-ons later on. Since our data is based on data that includes the final payment to the procurer (including additional payments), this argument would suggest that the state-run provider is better at playing this game than private firms (thus ending up with a higher contract payment), perhaps based on historical informational advantages. In addition, the close links between the state-run provider and the procurer (staff who previously worked together as part of one, state-run organisation prior to tendering) could also potentially lead to the state-run provider obtaining more favourable terms. Further research is needed to verify these hypotheses however.

Second, higher costs for contracts won by the state-run provider could be explained by unbalanced bidding (e.g. Stark, 1974). Again, this argument relates to possible informational advantages that the incumbent contractor may have on the actual need for works within a maintenance area compared to the road authority and other bidders. This information could then be used to the incumbent's advantage in pricing the works in the contract. For instance, a firm knows that work-type A in the contract is going to be at a lower level than specified in the contract, while work-type B is underestimated. Using this informational advantage, a firm sets very low unit price on work-type A but higher unit price on work-type B, and wins the contract because competing firms set the prices on work types A and B based on market prices. The road authority then ultimately pays too much for the final maintenance contract.

It should be noted firstly that the literature in general has struggled to find evidence of unbalanced bidding being applied in practice. Further, it is not clear whether the state-owned contractor would have a different informational advantage to that of rival, private bidders (some of whom have won contracts and then, as incumbents, would also make use of informational advantage in price setting and successfully defend their markets against future competitions). It is also not clear whether a state-owned or private provider would have stronger incentives to implement unbalanced bidding; though there has been some anecdotal evidence within Sweden to suggest that private firms may be more creative in implementing it (with accusations of private firms setting zero or even negative unit prices for some works). The evidence here is rather unclear and anecdotal; but unbalanced bidding remains a possible explanation for the existence of cost differences between private contractors and the state-owned provider. Further research is needed in this area.

The second set of explanations relate to the possibility that the cost differences between operators may partly reflect unobserved heterogeneity in the sample, as in any cost study. Our model guards against this threat in a number of ways, firstly through the inclusion of a rich set of explanatory variables (including weather related variables). We also include random effects at the maintenance contract area level, as well as regional dummies to capture contract and regional level unobserved heterogeneity (and the fixed effects model produced similar results in respect of the comparisons between public and private contractors). Thus our findings in respect of contractors are after having controlled for all these elements.

The efficiency literature in general (across a range of industries) does indicate that in some cases there may be an incentive for private firms to shade (especially) non-contractible quality (see, for example, Hart et. al., 1997 and Alonso and Andrews, 2016), thus suggesting that private firms may be low cost but also low quality. On the other hand there are also numerous studies that indicate that efficient firms are often high quality (see for example, Affuso et. al., 2002). Given that our paper does not directly control for quality, it is possible that quality variations might be included within our findings on contractor efficiency. However, as noted the literature suggests that the effect may go in either direction; and our model controls carefully for heterogeneity in various ways. Further, we are not aware of any evidence suggesting that private firms are delivering lower quality. It remains a possible explanation however.

Finally, another source of unobserved heterogeneity might relate to a cost advantage that an operator has in terms of geography. As pointed out in the literature review, the distance to the job site may have a positive impact on the bid submitted, as well as the urban or rural nature of the location. Therefore, given its history, the public firm could have a cost advantage in remote places where road maintenance is overall more expensive. Levin and Tadelis (2010) suggest that in-house production helps overcome problems in monitoring performance or the need for flexibility. It might therefore be the case that the public firm is expected to bid for the more complex contracts with higher contingencies, which will ultimately entail larger additional payments and overall higher costs (though of course, the public firm, Svevia is an arms-length provider, which signs contracts with the buyer, which is different from the concept of an in-house provider considered in Levin and Tadelis (2010)). Importantly though, our model guards against these possible sources of bias through the use of regional dummies and contract related effects (through either a random or fixed effects model), so these effects should be captured, meaning that our estimates of the difference between public and private should remain unbiased. We also note that both the state-owned firm and private firms have a good share of their contracts in each of the regions, so we do not see a pattern of private firms abandoning certain parts of the country (and regional effects are in any case controlled for). Further, the number of bidders for each contract is typically above three.

In summary our research has therefore shown that private contractors are substantially cheaper than the state-run company in providing road maintenance services in Sweden. This suggests that competitive tendering has delivered substantial savings; however, since the state-run company holds 60% of the market, it is perplexing that a cost gap remains between this provider and private entrants, despite the pressure of competitive tendering across the whole market that has existed for an extended period of time. As noted above, there is a healthy degree of competition. This finding is unexpected based on the literature which tends to show that competition drives out relative inefficiency even between state-owned and private firms. It also means that the full benefits of tendering have yet to be felt. We have offered a number of possible explanations for the persistence of this cost performance difference. It should be noted, however, that the issues involved here, including possible asymmetries of information, gaming of bid strategies, and shading of non-contractible quality are rather subtle and hard to observe; therefore, further research is needed.

7. CONCLUSION

This paper provides important new evidence on the relative cost efficiency performance of different road maintenance contractors in Sweden using a new and unique dataset. Although competitive tendering was first introduced in 1992 in Sweden, this subject has not been analyzed previously due to lack of data. This study fits within an emerging literature focusing on the application of econometric methods to assess the relative efficiency of road infrastructure provision (see for example, Massiani and Ragazzi, 2008; Welde and Odeck, 2011; KPMG, 2016; Wheat, 2017).

Our paper therefore contributes new empirical evidence to a relatively limited but emerging international literature focused on comparing the efficiency of road maintenance and renewal activities. The novelty lies in the application of econometric techniques to a new and rich dataset with a wide range of variables and approaches to controlling for heterogeneity, prior to the estimation of efficiency. In particular, our analysis controls for variations in weather conditions across Sweden. We also benefit from a large cross section and a long panel compared to previous studies (73 maintenance contracts over the period 2004-2014; 623 observations) – with the analysis applied in the context of a sector where all road maintenance contracts are subject to competitive tendering. The particular interest here is whether, even after tendering, efficiency differences remain between the state provider and new private firms entering the market. This question has important implications for public procurement policy reforms in other sectors and countries where there may be a decision as to whether public and private firms can co-exist in competition with each other in a way that delivers value for users and funders.

We find statistically significant cost differences between firms operating in the sector; specifically, that private contractors are substantially cheaper than the state-run company in providing road maintenance services in Sweden (the state-owned company's costs are found to be between 8 and 20% higher than those of private contractors). Indeed there is one private contractor, Skanska, that is lower cost than all of the other private operators as well (this being a statistically significant finding). These results suggests that competitive tendering of road maintenance has delivered substantial savings, has occurred in other countries as well as noted in the introduction. However, the persistence of a significant cost gap between the state-provider and private firms is problematic, since the state-run firm still retains the majority of contracts (60% of the market). This finding thus suggests that the tendering procedure is not yet functioning optimally and is therefore not fully delivering services at efficient cost to users; with implications also for taxpayers. This finding mirrors findings from other Scandinavian countries (for road projects) which stresses the importance of privatization, alongside competition, in order to drive out inefficiency.

A number of possible explanations for the cost gap between the state-run provider and private firms have been offered. These relate to possible gaming of the bidding process that favours the state-run provider (based, for example, on potential historical informational advantages and links with the procurer). Further, it may be that private firms have an incentive to offer lower costs by shading non-contractible quality. However, there is currently insufficient evidence on these points, which thus points to future research. Our paper has pointed to a problem – namely that competitive tendering on its own, in a mixed model of state-run and private maintenance contractors, may not fully drive out inefficiency in the provision of road maintenance services – even though competitive tendering has persisted across the whole market for a long time period. This finding has important implications for public procurement strategy not only in road maintenance in Sweden, but in a much wider range of contexts and geographies. Further research is required in order to further understand the reasons for this; and the possible solutions. Our findings contribute to better understanding of the conditions needed to achieve success in tendering road maintenance services, alongside other factors such as size, type and length of contract as highlighted in the previous literature.

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REFERENCES

Affuso, L., Alvaro, A. and Pollitt, M., (2002). Measuring the Efficiency of Britian's Privatised Train Operating Companies. No. 48: Regulation Initiative Discussion Paper Series

Ahlstrand, I. (2001). The politics and economics of transport investment and pricing in Stockholm. *Journal of Transport Economics and Policy*, 35(3), pp.473-489

Alexandersson, G. (2009). Rail Privatisation and Competitive Tendering in Europe. *Built Environment*, vol 35, no 1, p. 37-52

Alonso, J.M. and Andrews, R. (2016). How privatization affects public service quality: An empirical analysis of prisons in England and Wales, 1998-2012, *International Public Management Journal*, 19(2), pp.235-263

Arnek, M. (2002). Empirical essays on procurement and regulation. Uppsala University, *Doctoral Thesis.*

Anastasopoulos, P. C., Florax, R. J., Labi, S., & Karlaftis, M. G. (2010). Contracting in highway maintenance and rehabilitation: Are spatial effects important? *Transportation Research Part A: Policy and Practice*, *44*(3), 136-146.

Bajari, P., Houghton, S., & Tadelis, S. (2014). Bidding for incomplete contracts: An empirical analysis of adaptation costs. *American Economic Review*, *104*(4), 1288-1319.

Blom-Hansen, J. (2003). Is private delivery of public services really cheaper? Evidence from public road maintenance in Denmark. *Public Choice*, *115*(3-4), 419-438.

Bovaird, T. (2004). Public–private partnerships: from contested concepts to prevalent practice. *International Review of Administrative Sciences, 70 (2)*

Burningham, S. and Stankevich, N. (2005). Why road maintenance is important and how to get it done, *Transport Note No. TRN-4*, pp.1-10.

Caves, D.W. and Christensen, L.R. (1980). The Relative Efficiency of Public and Private Firms in a Competitive Environment: The Case of Canadian Railroads, *Journal of Political Economy*, 88(5), pp.958-76.

Demarre, M. (2002). Contracting road maintenance: Example of the province of Alberta in Canada, *La Lettre de I'STED*, No.26

Domberger, S., Meadowcroft, S. and Thompson, D. (1986). Competitive Tendering and Efficiency: The Case of Refuse Collection, *Fiscal Studies*, vol. 7 (4), pp. 69-87.

Domberger, S., Meadowcroft, S. and Thompson, D. (1987). The Impact of Competitive Tendering on the Costs of Hospital Domestic Services, *Fiscal Studies*, vol. 8 (4), pp. 39-54.

Fallah-Fini, S., Triantis, K., Jesus, M., & Seaver, W. L. (2012). Measuring the efficiency of highway maintenance contracting strategies: A bootstrapped non-parametric meta-frontier approach. *European Journal of Operational Research*, *219*(1), 134-145.

Goncalves, R. and Gomes, A. (2012). Maintenance incentives in highway concession contracts. *Journal of Transport Economics and Policy*, 46(1), pp.99-122.

Hammar, H., Lundgren, T., Sjöström, M. (2008). The significance of road transport costs in the Swedish forest industry. *Journal of Transport Economics and Policy*, 42(1), pp.83-104

Hart, O., Shleifer, A. and Vishny, R.W. (1997). The Proper Scope of Governance, *Quarterly Journal of Economics*, vol. 112 (4), pages 1127-1162.

ISTED (2002). La Lettre de I'STED, N26, October 2002

Klein, B., Crawford, R. G., & Alchian, A. A. (1978). Vertical integration, appropriable rents, and the competitive contracting process. *The journal of Law and Economics*, *21*(2), 297-326.

KPMG (2016), Benchmarking Highways England: A report to the office of rail and road. KPMG, London.

Krasnokutskaya E., 2004. Identification and Estimation in Highway Procurement Auctions under Unobserved Auction Heterogeneity, *PIER Working Paper Archive* 05-006.

Leiren, M. D., Lindholst, A. C., Solfjeld, I., & Randrup, T. B. (2016). Capability versus efficiency: contracting out park and road services in Norway. *International Journal of Public Sector Management*, *29*(5), 474-487.

Levin, J., & Tadelis, S. (2010). Contracting for government services: Theory and evidence from US cities. *The Journal of Industrial Economics*, *58*(3), 507-541.

Levinson, D. (2005). Paying for the fixed costs of roads. *Journal of Transport Economics and Policy*, 39 (3), pp.279-294

LIMDEP (2016). LIMDEP Version 11 Econometric Modelling Guide, Econometric software, Inc.

Lindberg, Gunnar (VTI), CATRIN (Cost Allocation of TRansport INfrastructure cost), Deliverable D 12, Conclusions and recommendations. Funded by Sixth Framework Programme. VTI, Stockholm, June 2009

Lindholst, A. C., Helby Petersen, O., & Houlberg, K. (2018). Contracting out local road and park services: economic effects and their strategic, contractual and competitive conditions. *Local Government Studies*, *44*(1), 64-85.

Lingegård, S., Lindahl, M. and Svensson, N. (2011). PSS contracts for rail and road infrastructure. *Functional thinking for value creation:* Proceedings of the 3rd CIRP international conference on industrial product service systems, Technische Universität Braunschweig, Braunschweig, Germany

Link, H., Stuhlemmer, A. (DIW Berlin), Haraldsson, M. (VTI), Abrantes, P., Wheat, P., Iwnicki, S., Nash, C., Smith, A., CATRIN (Cost Allocation of TRansport INfrastructure cost), Deliverable D 1, Cost allocation Practices in the European Transport Sector. Funded by Sixth Framework Programme. VTI, Stockholm, March 2008

Link, H. (2006). An econometric analysis of motorway renewal costs in Germany. *Transportation Research Part A: Policy and Practice*, *40*(1), 19-34.

Link, H. (2014). A cost function approach for measuring the marginal cost of road maintenance. *Journal of Transport Economics and Policy*, 48 (1), pp.15-33

Lyon, B. and Dwyer, A. (2011). Road maintenance: Options for reform. Infrastructure Partnerships Australia, *Report.*

Massiani, J. and Ragazzi, G. (2008). Costs and efficiency of highway concessionaires: A survey of Italian operators. European Transport / Trasporti Europei, 38, pp.85-106.

Mundlak, Y. (1978). On the pooling of time series and cross sectional data. *Econometrica, 46(1)*

Munduch, G., Pfister, A., Sögner, L. and Stiassny, A. (2002). Estimating marginal costs for the Austrian railway system. *Working paper No.78*

Nash, C.A. (2018), Benchmarking Highways Working Paper, mimeo.

Nash, C. and B. Matthews (2005). Measuring the marginal social cost of transport. Research in Transportation Economics, 14.

Nash, C. and T. Sansom (2001). Pricing European transport systems: Recent developments and evidence from case studies. Journal of Transport Economics and Policy, 35, pp.363-380.

Nyström, J., Nilsson, J-E., and Lind, H. (2016). Degrees of freedom and innovations in construction contracts. *Transport Policy*, 47, pp.119-126

Odeck, J. (2014). Do reforms reduce the magnitudes of cost overruns in road projects? Statistical evidence from Norway. *Transportation Research Part A: Policy and Practice*, *65*, pp.68-79.

Perkins, S. (2013). Better regulation of public-private partnerships for transport infrastructure. International transport forum, *Discussion paper 2013-6*

Ricardo-AEA (2014). Update of the handbook on external costs of transport. Final report. Ricardo-AEA/R/ED57769. Issue Number 1.

Rizzi, L.I., (2014). Simple model of road infrastructure financing: The impact of different funding schemes. *Journal of Transport Economics and Policy*, 48(1), pp.35-51

Stark, R. (1974). Unbalanced highway contract tendering. *Operational Research Quarterly*, 25, pp.373–388.

SKL (Sveriges Kommuner och Landsting) (2015). Drift, Underhåll. Retrieved from: http://skl.se/samhallsplaneringinfrastruktur/trafikinfrastruktur/driftunderhall.291.html. Accessed: July 7, 2015.

Smith, A. S. J. and Wheat, P., 2012. Evaluating Alternative Policy Responses to Franchise Failure. *Journal of Transport Economics and Policy*, 46(1), pp. 25-49.

Smith, M. (2012). Sixty years of highway maintenance. The chartered institution of highways and transportation. *Report*

Smith, A.S.J, Buckell, J., Wheat, P.E., and Longo, R. (2015). Hierarchical performance and unobservable heterogeneity in health: A dual-level efficiency approach applied to NHS pathology in England, in Greene, W.H., Sickles. R., Khalaf, L., Veall, M., and Voia, M.C.. eds., *Productivity and Efficiency Analysis*, Springer Proceedings in Business and Economics.

Welde, M. and Odeck, J. (2011). The efficiency of Norwegian road toll companies. Utilities Policy, 19, pp.162-171.

Wheat, P.E. (2017). Scale, quality and efficiency in road maintenance: Evidence for English local authorities, *Transport Policy*, 59, pp.46–53.

Wu, D. (1973). Alternative Tests of Independence between Stochastic Regressors and Disturbances, *Econometrica*, 41, pp.733-750.

Yarmukhamedov, S. and Swärdh, J-E. (2016). Marginal cost of road maintenance and operation. Swedish estimates based on data from 2004 to 2014. *VTI notat 15A-2016.*