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Public Versus Private Production and Economies of Scale

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Abstract:

The cost of producing the same good often differs substantially for public and private producers. We investigate the effect of organization in a case where the production technology is simple: The cleaning of Danish schools. Three forms of organization are used: Decentral municipal, central municipal or private. For small schools the organizational form has little impact on cost. For larger schools decentral municipal production is the most expensive. On average centralization reduces costs by 5%, while privatization reduces costs by 30%. Similar cost differences are reported in the literature for other cases, but it is a new result that the cost differences are due to economies of scale. Public choice theories predict that cost differences are due to ownership or competition. We find evidence that both theories help explain the cost differences.

Keywords: Cost function, non-parametric regression, private vs public production, scale effects

JEL classification: C14, D78, H72, L33

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I. Introduction

This paper compares public and private production in the case of cleaning, where the production technology is simple. Our data set covers 1081 Danish primary schools. They are owned by the municipalities, which have full freedom to decide how they are cleaned. Three forms of organization are used: Most are cleaned by the municipality itself, either decentrally at the level of the individual school or by a central organization. The rest are cleaned by private companies. It is analyzed how the three forms influence cleaning costs for a given cleaning quality, and furthermore we test two public choice theories about public and private production: The *ownership* and the *competition* theory.

School cleaning is produced by a simple technology with a low capital-labor ratio. The cleaning business has a fast circulation of personnel, and new technologies are rapidly disseminated. Therefore our data are treated as a set of observations of one cost function with a fixed capital-labor ratio. It is estimated conditional on form of organization, cleaning quality, scale and municipal characteristics.

For larger schools we find systematic cost differences due to organization: Private cleaning is cheapest, while decentral municipal cleaning is the most expensive. A key predict-tion is that if cleaning at all schools was privatized, it could lead to savings of roughly 25% of the present costs, corresponding to the salary of about 1000 new schoolteachers.

The cost difference between publicly and privately produced cleaning arises from differences in the ability to exploit economies of scale. This finding extends and refines the standard result found in the literature of an average cost difference of almost 30% in favor of private production. For surveys on empirical studies of private versus public production see, for example, Borcherding, Pommarehne and Schneider (1982), Domberger and Jensen (1997) and Vickers and Yarow (1988). Only few studies have been made for Denmark, see Kristensen (1982), Jensen and Rasmussen (1997), PLS Consult (1997) and Blom-Hansen (2003).

Why public producers do not exploit the economies of scale may be explained by two basic public choice theories, namely that it is due to differences in either *competition* or *ownership*. They are not mutually exclusive, and they are empirically difficult to distinguish. The two theories are expressed in a form that can be tested empirically, and the evidence shows that both explanations are valid.

Section II presents the two theories and develops testable implications. The data and institutional factors are described in section III. The results the cost function estimation are reported in section IV. Section V contains the test of the public choice theories and section VI has a policy analysis. Finally, section VII discusses of the historical reasons for the results. The Appendix contains details of the nonparametric estimation, bootstrapping and derivation of specific confidence bands.

II. The ownership and competition theories

The ownership or property rights explanation focuses on the owner's incentives to minimize costs. Private production has owners who are residual claimants, while the residual claimants in public production are much more vaguely defined. Private producers thus have a much larger interest in knowing and controlling costs. The modern theory of ownership goes back to Alchian (1969), see Pejovich (1997) for a survey.

To test the ownership explanation, a measure of the incentives of the owners to minimize cost is needed. Our measure is the fraction of the population (of voting age) in the relevant region that depends upon the public sector, either as employee or recipients of a social payment meant to replace income. This measure is termed the *welfare coalition* (w), though it is, of course, only a potential coalition. The higher the welfare coalition, the harder it is for politicians to pursue cost saving policies in the public sector and, thus, a higher cost of production is to be expected. Therefore the ownership explanation is consistent with the following hypothesis:

$$H^1 : \frac{\partial cost_{public}}{\partial w} > 0, \frac{\partial cost_{private}}{\partial w} = 0,$$

where $cost_{public}$ and $cost_{private}$ are the the cost per unit (here, size of school) for publicly and privately organized production, respectively.

The competition theory is developed from the observation that monopolists often have higher production costs than the cost minimizing solution. This was first described by Leibenstein (1966) and named X-efficiency. As reasons for X-efficiency, Leibenstein mentioned incomplete contracts for labor, unknown production functions and non-marketed inputs. Later developments starting with Tullock 1967, see Tullock (1993), changed the wording to X-inefficiency, which is explained by rent sharing used to build coalitions of stakeholders to uphold the monopoly. The monopoly rents are thus partly converted to and hidden as extra costs. According to Niskanen 1971, see Niskanen (1994), public monopolies tend to hide information on cost and rents. The process of rent sharing is seen also for private monopolies, but they are rarer since they have to fear entry.

A test of the competition explanation consists of comparing the cost of public and private production after correcting for the effect from the ownership explanation. This leads to the following hypothesis:

$$H^2 : cost^*_{public} > cost^*_{private}$$

where $cost^*$ is the cost corrected for the effect due to ownership. In our context, the source to the possible validity of the comptition explanation can be an unknown cost function. It is not possible to identify whether an unknown cost function is the reason for X-inefficiency. An indication would be that the shapes of the cost functions are different. In section V the above tests are implemented.

III. Data and institutional facts

Table 1 shows the variables analyzed in this paper. The first four variables in the table are obtained from our questionnaire sent to all 275 Danish municipalities in the spring of 1998. This resulted in a sample of 1081 primary schools from 189 municipalities. The data covers half of the Danish primary schools. The representativity of the data is analyzed in section IV in terms of selection bias. The municipal characteristics mentioned in the last line of the table are obtained from a database at AKF, see Christoffersen & Paldam (2003) for details.

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Table 1

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The dependent variable is the cost of cleaning the school measured per m^2 (c/s). The rest of the section describes the explanatory variables listed in the table.

Quality: It is crucial to control for the quality[1] of the cleaning to make a fair comparison between the different forms of organization. About 70% of the schools use a well-defined cleaning standard called »511«. It is specified in the *Cleaning Manual* (1977), by the relevant trade unions and the National Union of Local Authorities. Subsequent technological developments have caused minor revisions only. The reference standard describes how often various types of facilities should be cleaned, and the intensity by which this should be done. In addition, the manual specifies the area a cleaner should cover in an hour, as will be discussed below.

Two additional cleaning qualities are defined relative to the reference standard »511«. One is a high quality. Schools using standards above »511« are all coded »high« since there are too few observations on each of these higher standards. The third cleaning quality is named »assessed«. This is not a well-defined standard, but it is usually a lower standard than »511«.

The quality variable in the data set is based on specifications in directives to schools or in contracts with employees, unions or firms. The quality actually delivered is unobserved. The monitoring of the cleaning quality is left to the schools. Private companies may have a larger incentive to cut corners, but a private company may loose the contract if it does not deliver the required quality of cleaning. Hence, we assume that the difference between the specified and the actual quality does not vary systematically with the organizational form.

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Table 2

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Form of organization: The cleaning of primary schools is organized in three different ways as shown in table 2. A majority of 66.5% of the schools is cleaned by decentral municipal labor. The municipality decides on a budget for the school,[2] and the school then employs and monitors the cleaning personnel. A smaller fraction of 19% of the schools is cleaned by personnel employed and monitored by a central municipal cleaning bureau. Finally, 14.5% of the schools are cleaned by a private company. Private companies are typically chosen after competitive bidding.

The number of private cleaning companies is large, and the school contracts are a small fraction only of their activities. The size structure of the companies is skew: One is a very large multinational company, a second is large,[3] and the rest is many small companies. However, entry costs to the cleaning market are low. In addition, many consultants organize tenders and advise municipalities about current market prices. Hence, the market for cleaning is rather competitive.[4]

Our data includes 30 central municipal production units. Each unit controls all cleaning in the municipality. Therefore, a production unit has some degree of monopoly, but the production units are aware that the municipality can decide to tender the contract. Consequently, the municipal production units of school cleaning should not be treated as true monopolies. Similarly, the decentral organized cleaning units at the individual schools have a certain degree of monopoly.

Size: The schools differ more than fifteen times in size. Figure 1 shows the distribution of size. Of the total school area, 10% is in schools of less than 3000 m^2, 20% in schools 3000 m^2 to 6000 m^2, 40% in schools 6000 m^2 to 9000 m^2, and 30% in schools above 9000 m^2. The measure of school size is the area, s, which is used in the *Cleaning Manual* (1977) and apparently in all cleaning contracts.[5]

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Figure 1

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One clearly relevant cost factor is the layout of the school, which is partly a result of the age of the school. Most of the schools have been renovated, reconstructed and expanded – often several times – so no meaningful measure was obtained. The school layout is thus an omitted variable, and we assume that it is independent of the choice of organizational form.

Municipal characteristics: The municipalities are characterized by 23 variables covering 6 areas: (i) Modern/traditional economic structure, (ii) diffusion patterns for modernization such as distance from major town, (iii) economic pressure such as immigration to municipality and prior increases in taxes, (iv) size of public sector, (v) political orientation,

(vi) stability of present rule.

The welfare coalition measuring incentives on politicians to pursue cost reductions is a municipal characteristic. It is the fraction of the population (of voting age) that depends upon the public sector, either as employees or as recipients of an income-replacing social payment (including the old age pension).[6] This variable is included to investigate the ownership explanation[7] described in section II.

To get a first impression of the relationship between cost and the size of a school, a set of non-parametric regressions of the log to unit cost on the log to the size of the school is performed using local polynomial regression. Under mild conditions this procedure provides a consistent estimate of any continuous regression function. The details of the non-parametric regression are reported in the Appendix.

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Figure 2

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Figure 2 shows the estimated pointwise 0.90-confidence intervals of these regressions in the case of cleaning quality »511«, which is the only cleaning quality with enough observations to allow the non-parametric regressions for the three organizational forms to be compared. The confidence intervals are estimated using the bootstrap, which is typically a better estimator than the commonly used estimators based on the asymptotic distribution. Details on the bootstrap are also provided in the Appendix.

The figure reveals two important characteristics. First, there is a clear downward trend in the unit cost of privately produced cleaning. Secondly, for schools larger than app 3000 m^2 ($Ln(3000) \approx 8.0$), the unit cost of privately produced cleaning is below the unit cost of both central municipal and decentral municipal organized cleaning. Schools larger than 3000 m^2 represent more than 90% of the total school area in the sample.

Figure 2 suggests that a linear regression function of the logs to cost and size may be a good functional specification, that is, a Cobb-Douglas cost function. Since we want to include all cleaning qualities and control for many other explanatory variables, it is necessary to use a parametric specification to obtain a good precision. This is done in the next section.

IV. Estimation of the cost function corrected for selection bias

The non-parametric estimates in section III suggested a Cobb-Douglas functional relationship between unit cost (*c/s*) and size of school (*s*). This is used as a building block though tested later. Since the aim is to test differences over organizational forms (***z***), different slopes are allowed. Differences in cleaning quality are captured by dummy variables for the different qualities (***q***). To test the ownership hypothesis, the welfare coalition (*w*) is included allowing for different effects over the three different organizational forms. Finally, the vector of municipal characteristics (***m***) is included. The estimation strategy is to keep variables on organizational form (***z***), quality (***q***), and school size (*s*) in the regressions and use a general-to-specific approach to eliminate insignificant municipal characteristics.

A potentially serious problem is selection bias. The sample covers 189 of the 275 municipalities. Given that the questionnaire was sent to and returned from the municipalities, the choice to return the questionnaire is mainly made in the administration of the municipality, not at the individual schools. Therefore, we check for selection bias using an estimator similar in spirit to the Heckman selection estimator, see Heckman (1979) or Vella (1998) for a survey. Our estimator is different because the selection unit (the municipality) is not the same as the measurement unit (the school). First, the choice to return the questionnaire is estimated by a probit model, where the municipalities are the observational units.[8] Secondly, based on the estimates of the probit model, a selection correction (r) – the inverse Mills ratio – is included in the estimating equation of the cost function.[9] Consequently, schools in the same municipalities have the same selection correction.

Another potential problem is simultaneity bias. Maybe the choice to privatize is not random, but depends on costs. We have heard stories indicating that municipalities may be more inclined to privatize when costs are particularly high, but we have found no data allowing us to control for such a reverse causality. However, if the stories are correct it would cause the estimates to underestimate the cost savings from privatization.

The estimating equation has the following form:

$$(1) \qquad \ln(c_i/s_i) = \boldsymbol{\alpha}'\boldsymbol{z}_i + \boldsymbol{\beta}'\boldsymbol{z}_i\ln(s_i) + \boldsymbol{\gamma}'\boldsymbol{q}_i + \boldsymbol{\delta}'\boldsymbol{z}_i\ln(\boldsymbol{w}_i) + \boldsymbol{\phi}'\ln(\boldsymbol{m}_i) + \lambda r_i + \epsilon_i ,$$

where ϵ_i is the unobserved component assuming $E(\epsilon_i \mid \boldsymbol{z}, s, \boldsymbol{w}, \boldsymbol{q}, r, \boldsymbol{m}) = 0$. Using OLS, this estimating equation provides consistent estimates of the coefficients $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, γ, $\boldsymbol{\delta}$ and $\boldsymbol{\phi}$ of the cost function.[10]

The result of the probit model of selection is shown in table 3. The only remaining significant explanatory variable in the choice to return the questionnaire is the degree of urbanization. This is in accordance with the fact that relatively many among the non-participating municipalities are small. None of the economic or political characteristics of the municipallities turned out to be statistical significant.

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Table 3

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Table 4 shows the estimation results for the cost function (1) in column [1]. The general to specific approach using a 5% significance level for choice of municipal characteristics left only one, namely, the logarithm to the average tax base. There is no statistical significant selection bias. This means that the effect of an underrepresentation of the smaller municipalities has no significant impact on the cost function.

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Table 4

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The cost function can be further simplified. The selection correction is highly insignificant (p-value = 0.71) and is eliminated. The welfare coalition for the private organizational form is also eliminated for the same reason. The effect of the welfare coalition on the two public organizational forms is statistically the same. Thus, they are restricted to be the same. The result is shown in column [2] in table 4. Note that the coefficient estimates on the remaining variables did not change much, but their standard errors are lower. Valid restrictions will improve the efficiency of the estimators in addition to making the model easier to apply in practice. Therefore, this model is used from hereon.

The Cobb-Douglas specification fits well. To test the correctness of the functional form, two heteroskedastic robust RESET LM tests are calculated, see Wooldridge (2002). The result shown in table 4 does not indicate any misspecification. However, the tests for heteroskedasticity are significant using a 0.05 significance level, but it has implication only for the efficiency of the estimator. Also, it causes us to use the Huber-White robust heteroskedasticity consistency estimator to obtain the standard errors. This implies that the t-tests (conditionally) are asymptotically standard normal distributed given no selection bias. Hence, the reported standard errors are consistently estimated, and the functional form of the cost function is not misspecified.

V. Interpretation of cost function and test of public choice hypotheses

The estimated Cobb-Douglas cost function has a straightforward economic interpretation. It has a constant elasticity of scale given by $(1+\beta)$, see (1). School cleaning produced by form of organization z^j has economies to scale if $\beta_j < 0$, constant return to scale if $\beta_j = 0$, and diseconomy to scale if $\beta_j > 0$. In table 4 it is seen that the estimates of the β's are different and negative for all three organizational forms. School cleaning has significant economies of scale, but the scale effect depends significantly upon the organizational form. For decentral organized cleaning the effect of scale is small. For centrally organized cleaning the effect is a little larger, but for privately organized cleaning the effect is large. It should be noted that the difference between the scale effect in public and private cleaning is significant.

The γ's are coefficients to quality of cleaning. In the estimation, γ_2 is normalized to 0. The two other qualities are defined relatively to quality »511«. The coefficients are scaled to give a straightforward interpretation: When $\gamma_1 = 0.118$, and $\gamma_3 = -0.048$, it means that it costs on average 12% more to use a higher quality than »511«, while 5% are saved by using a lower quality. The structure of the model implies that these relations are the same for all three forms of organization.

Danish municipalities have almost the same average income, the standard deviation being about 10% of the average. However, five rich municipalities north of Copenhagen have average incomes that are 1.5 to 2.2 times higher than in the rest of the country. In those five municipalities cleaning wages, and hence cleaning costs, are significantly above the rest.

Differences in cost between organizational forms depend on the explanatory variables. In the following, values of the explanatory variables are found for which one form of production is cheaper than another. The cost differences are calculated by the expected cost differences to log unit cost. The differences in costs depend on the school size and the welfare coalition, see Appendix A2. The black graph in figure 3 is the breakeven between decentrally and privately organized production. All the points above the graph are combinations of *s* and *w* for which private organization is cheaper than decentral organization, and opposite below the line. Statistically significant combinations can also be derived. They are non-trivial to find as the cost of the three forms of organization are calculated from the same sample. The derivations can be seen in the Appendix. The upper gray graph in figure 3 is the combinations of *s* and *w* for which private organization is significantly (on a 5% significance level) cheaper than decentral organization.[11] Similarly, the lower gray graph in figure 3 is the combinations of *s* and *w* for which private organization is significantly (on a 5% significance level) more expensive than decentral. Figure 4 shows the same for central versus privately organized production.

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Figure 3

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Figure 4

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The occurrence of schools in the different regions of figure 3 and 4 are calculated in table 5. It is seen that 86.5% of schools using decentralized organization will get a signify-cantly lower cost by using private organization. The number is 95.5% if measured by school size. Less than 1% of the schools using decentral or central organization (measured either way) will get significantly higher cost by changing to private organization. For schools using private organization, the opposite pattern is seen. Many of them will incur significantly higher cost by changing from private organization. Thus, most schools in the survey are in the region of significantly lower cleaning costs by using private organization.

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Table 5

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The first public choice theory to be tested is the ownership explanation, H^1. This is a test of a significant positive effect of the welfare coalition variable (w) on public production costs. For model [2] in table 4, the welfare coalition on public production has a t-stat = 10.2 with a p-value = 0.00, whereas it is insignificant for private production. Recall model [2] is the result of eliminating insignificant variables from model [1].[12] Thus, with a 5% significance level, the ownership cannot be rejected for either of the two public organizational forms. This indicates that municipalities dominated by voters who depend on the public sector have substantially higher costs when cleaning is publicly organized. This is in accordance with the hypothesis that such voters form an implicit welfare coalition that defends public spending.

The second public choice theory tested is hypothesis H^2 concerning the X-inefficiency explanation. It can be tested by correcting the cost function for the effect of the ownership explanation and then comparing cost. One practical way of correcting the cost is to subtract the effect of the welfare coalition $(\phi \cdot \ln(w))$ and adjust the level of cost by $(\phi \cdot \ln(\overline{w}))$, where $\overline{w}$ is the average of the welfare coalition variable.[13] The average of the welfare coalition is $\overline{w}$

= 67.3. Table 6 reports the breakeven school sizes. For example, for schools larger than 765 m^2, costs corrected for the ownership explanation of decentral organized production are more expensive than privately organized production. A significantly (with a 5% significance level) lower cost corrected for ownership effects is obtained for schools larger than 1526m^2 and 1561m^2 compared to decentral and central organized production, respectively. Thus, the X-inefficiency explanation cannot be rejected for those school sizes. In our sample, more than 90% of the schools or 98% of the school areas are larger. Hence, there is strong evidence that the X-inefficiency explanation is also a significant explanation for the cost differences between public and private production.

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Table 6

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The lower cost of private production occurs in schools above a certain (small) size. The reason is that private production exploits economies of scale. From table 4 it is seen that the economies of scale between private and any of the public productions is significant with a 5% significance level. Bringing this together with the evidence on the X-inefficiency found above suggests that a reason for X-inefficiency can be that the cost function was unknown when the public production was organized.

VI. Policy Analysis

This section compares different policy scenarios. In particular, the potential gain of using the cheapest form of organization is predicted.

In figure 5, the estimated regression lines are transformed to area (m^2) and cost in

DKK for the most commonly used quality of cleaning, »511«. The values chosen for the municipal characteristics are their averages of each of them.[14] The cost functions on figure 3 should not be interpreted as the average cost functions since the model is estimated logarithmmically.[15] When doing relative comparisons, however, a difference can be interpreted as an average cost difference.

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Figure 5

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Part of the same information shown in figure 5 is also given in table 7 for selected school sizes, but for all three types of qualities of cleaning.

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Table 7

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It is seen that for all schools larger than 2000 m^2, privately organized cleaning is on average cheaper than both of the two public forms of organizations for all cleaning qualities.

In table 8, the effect of changing the quality of cleaning is calculated. Given the structure of the estimated Cobb-Douglas cost function, the relative differences in unit cost due to changing cleaning quality do not depend on form of organization or size of school. Not surprisingly, the better quality, the higher cost.

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Table 8

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The main policy decision is the choice of organizational form. Table 9 shows the cost savings for different school sizes depending on organizational form. Municipalities may on average save by centralizing the cleaning function for schools larger than app 3000 m^2. A much larger gain results from using the market. The breakeven point is app 1000 m^2. For small schools (with 2000 m^2) the savings are 16.5%, and over 50% for the largest schools.

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Table 9

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An estimate of the cost for an average municipality can be calculated when all schools have the same form of organization. The average municipality has a size distribution of its schools as shown in figure 1. From these data we have calculated a standardized size distribution and then calculated a relative school cleaning budget (RB) assuming the same quality throughout:

$$RB = \Sigma(c_k s_k f_k),$$

where k is an index over all school sizes and f is their frequency. From the average normalized budget (RB), the changes in cost for the average municipality when changing organizational form can be estimated as shown in table 10.

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Table 10

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The small schools have a small weight in the average municipal schoolcleaning budget. Even if there are no savings here, it matters little for the total budget. Also, the effect of changing from a decentral to a central organization is small. What matters is whether the market is used or not used.

Table 2 showed that approximately 66.5% of municipalities use decentral and 19.1% use central municipal cleaning. If they all privatized their cleaning, while keeping quality constant, the savings could be approximately $29.6 \times 0.665 + 25.7 \times 0.191 = 25\%$ of the present cleaning costs, corresponding to about DKK 300 million.

VII. Discussion

The main finding in this study is that there are significant cost differences in public and private production, and that the difference depends on economies of scale.

The X-inefficiency explanation is significant for most school sizes. A possible explanation why politicians are unaware of the cost function may be the way the cleaning budgets are determined. If politicians believe that there are no economies of scale, then an optimal way of allocating resources is by means of cost norms and standards. For the school cleaning, the norms are given in the *Cleaning Manual* (1977) as linear. The norm is that a cleaner should cover a certain number of square meters per hour. A special section deals with mini-schools, but apart from that everything is linear. Figure 6 depicts a political system managed by general cost norms and standards.

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Figure 6

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Municipalities know that productivity advances occur in many fields. Therefore, they frequently apply pressure to reduce costs. This is shown as a pressure line in figure 6. The typical process of savings is to cut everybody by the same percentage, which is generally perceived as fair. The equal treatment also follows from the use of norms and standards. Given that the municipal authorities do not know the true cost curve, they apply pressures till someone protests. The first to do so are the small schools, which are truly hurt. This stops the pressure. Unfortunately, there are few small schools, so the pressure stops before it really begins to bite into the costs of the larger schools, and the opportunity to find economies of scale is missed. In contrast, when the market is used, costs are determined by competitive bidding. This process is more likely to converge to the true costs.[16]

To explain why such a decision process persists, elements of the ownership explanation can be invoked. The incentives to change the system may not be too strong because the residual claimant – the taxpayer – is not directly involved in the decision process, and in casting a vote many other issues play a role in choosing a representative. The ownership explanation can be used to explain directly why the true cost function has not been found. Finally, there is the interplay with another aspect of X-inefficiency, namely, the coalition of stakeholders. Such a coalition would have an interest in preserving the decision process. Our empirical result on effects of the welfare coalition on cost of municipally produced cleaning demonstrates the importance of stakeholders.

For policy purposes it is important to identify the explanations for the decision process. If the cost difference arises solely from ignorance of the true cost function, only a small fraction of the school contracts may need to be privatized in order to identify the cost function. If, on the other hand, the ownership explanation is the main responsible, then throughout privatization is necessary.

When the working paper version of this paper became available in 1999, our results were widely covered by Danish newspapers. A recent study by KL, the organization of Danish local governments (KL, 2000) shows a rapid increase in the privatization of school cleaning since 1999. This suggests that the municipalities were unaware of the true costs, but once they learned, many took action to reduce costs. In view of the two basic public choice explanations, the ownership explanation has lost validity once the true cost was revealed. In contrast, the competition explanation has gained support in the fact that municipalities seem to choose to privatize, which suggests that they do feel capable of dealing with stakeholder alliances.

Appendix.

A1. Nonparametric regression and bootstrapping

The regression function is estimated using local polynomial regression, see Fan (1992), Härdle (1990) or for surveys Blundell and Duncan (1998) and Yatchew (1998). The estimator of the regression function at *s* is $m(s,\hat{\alpha})$, where $m(s,\alpha)=\alpha_0+\alpha_1 s+\alpha_2 s^2$ and $\hat{\alpha}$ minimizes the criterion function

$$\frac{1}{n}\sum_{i=1}^{n}(\ln(s_i/c_i)-m(\ln(s_i,\alpha))^2 K_h(\ln(s_i)-\ln(s)).$$

where K_h is a normalized kernel function, and h is the bandwidth. The estimate of α_0 is the Nadaraya-Watson estimator, if the terms α_1 and α_2 are excluded. Compared to that estimator, a local polynomial regression is usually less biased. The estimate of α can be obtained by ordinary least squares, for a given kernel K_h and bandwidth h.

For some organizational forms and qualities, the data can be sparse for a range of school sizes. We therefore modify the kernel to an adaptive kernel estimator. In essence, the adaptive kernel estimator uses a bandwidth that varies inversely with the density of the data. The bandwidth used on observation *i* is ($h\lambda_i$), where

$$\lambda_i = [\{f_{h_p} \ln(s_i)\} / \{Exp(\sum_{j=1}^{n} \ln(f_{h_p} \ln(s_j)) / n)\}]^{-\rho}$$

and f_{h_p} is the standard estimator of the density of the data using a pilot bandwidth h_p. We used $\rho = 0.5$ and the standard normal density as kernel function.

The choice of kernel is less important than the choice of bandwidth *h*. In short, a large bandwidth gives a smooth estimate of the regression function, but also a high bias, whereas a small bandwidth gives a wiggly estimate with a high variance. The tradeoff between bias and variance is solved by minimizing the integrated mean square error. The optimal bandwidth was selected in practice by minimizing a cross-validation function that mimics the behavior of the mean squared error.

The confidence intervals for the regression functions are estimated using the bootstrap. The usual asymptotic based symmetric 90%-confidence interval at ln(*s*) is constructed as

$(m(\ln(s),\hat{\alpha}) - a_{0.95}\sqrt{v(\ln(s))}, m(\ln(s),\hat{\alpha}) + a_{0.95}\sqrt{v(\ln(s))})$, where $v(\ln(s))$ is the variance[17] of $(m(\ln(s),\hat{\alpha})$ and $v(s) = \sum_{i=1}^{n}[K\left(\frac{\ln(s)-\ln(s_i)}{h}\right) / \sum_{i=1}^{n} K\left(\frac{\ln(s)-\ln(s_i)}{h}\right)]^2 (\ln(c_i) - m(\ln(s),\hat{\alpha}))^2$

Here $a_{0.95}$ is the 0.95-quantile of the standard normal distribution. The bootstrap confidence interval is constructed by replacing the 0.95-quantile of the standard normal distribution by the 0.95-quantile of the bootstrap distribution found the following way:

1. Make a random sample of pairs (c_i, s_i) from the (original) sample. Denote this a bootstrap sample $((c_1^*, s_1^*), (c_2^*, s_2^*), ..., (c_n^*, s_n^*)$

2. Using the bootstrap sample from 1, calculate the regression function $m^*(\ln(s), \hat{\alpha})$ and the variance $v^*(\ln(s))$. Then calculate the absolute t-ratio

$$|t^*| = \left| \frac{m^*(\ln(s), \hat{\alpha}) - m(\ln(s), \hat{\alpha})}{\sqrt{v^*(\ln(s))}} \right|$$

3. Step 1 and 2 is repeated 1000 times. The 950th largest value of the $1000|t^*|$ values is the 0.95-quantile, $a_{0.95}$, of the bootstrap distribution.

The bootstrap confidence interval is constructed using the t-ratio in step 2, because an asymptotic refinement can be obtained compared to the usual (first-order) asymptotic approximation, see Horowitz (1999) for details.

A2. Confidence bands for cost differences in figures 3 and 4

Consider the two organizational forms decentral and private as an illustration to find the breakeven. Let $\theta = (\alpha', \beta', \delta', \phi')$. Then the cost for each organizational form in table 4 [2] can be expressed as:

Decentral: $E(\ln(c/s)|x_{01}) = \theta' x_{01} = \theta'((1,0,0),(\ln(s),0,0,q',\ln(w),\ln(m'))'$

Private: $E(\ln(c/s)|x_{03}) = \theta' x_{03} = \theta'((0,0,1),(0,0,\ln(s)),q',0,\ln(m'))'$,

where x_{01} and x_{03} symbolizes the explanatory variables associated with the decentral and private organizational form, respectively. The estimated expected cost difference is:

$$\hat{D} = \hat{E}(\ln(c/s)|x_{01}) - \hat{E}(\ln(c/s)|x_{03}) = (\hat{\alpha}_1 - \hat{\alpha}_3) + (\hat{\beta}_1 - \hat{\beta}_3)\ln(s) + \hat{\phi}_1 \ln(w)$$

The difference only depends on school size (s) and the welfare coalition (w). The breakeven $(\hat{D}=0)$ combinations of size of school (s^*) and welfare coalition (w^*) are:

$$(2) \qquad s^* = Exp\left\{-\frac{\hat{\alpha}_1-\hat{\alpha}_3}{\hat{\beta}_1-\hat{\beta}_3}-\frac{\hat{\phi}_1}{\hat{\beta}_1-\hat{\beta}_3}\ln(w^*)\right\}.$$

For a given w^*, if a school size is larger than s^* in (2), then the expected log unit cost of private organization is cheaper than decentral organization.[18]

Some of the estimated coefficients are the same for all organizational forms, so the estimated cost for the different organizational forms are dependent. This dependence must be taken into account whan calculating significant cost differences. To calculate an asymptotic confidence interval for the expected cost $\hat{D}$, the variance of $\hat{D}$ is needed:

$$Var(\hat{D})=(x_{01}-x_{03})'Var(\hat{\theta})(x_{01}-x_{03}),$$

where $Var(\hat{\theta})$ is the variance of the parameter estimator and $(x_{01}-x_{03})'=((1,0,-1),(\ln(s),0,-\ln(s)),0,\ln(w),0)'$. Note that even though some of the coefficients in $(x_{01}-x_{03})$ are 0, the dependence over organizational forms influences the variance of, for instance, the coefficient to ln(s) for decentral organization due to $Var(\hat{\theta})$. An asymptotic (1-α^*)-confidence interval is:

$$\left[\hat{D}-Z_{1-\alpha^*/2}\sqrt{Var(\hat{D})},\hat{D}+Z_{1-\alpha^*/2}\sqrt{Var(\hat{D})}\right],$$

where $Z_{1-\alpha^*/2}$ is the (1-α^*/2)-quantile of the standard normal distribution.

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Tables and figures

Table 1. Variable definitions

Name	Type
c	Annual cost in Danish Crowns (DKK) per school
q = $(q^1,q^2,q^3)'$	Quality: q^1 (»high«), q^2 (»511«), q^3 (»assessed«)
z = $(z^1,z^2,z^3)'$	Form of organization: z^1 (decentral municipal), z^2 (central municipal), z^3 (private)
s	School size in m^2
m	Vector of municipal characteristics

Note: The q's and z's are dummies, being 1 if the property is present and 0 otherwise.

Table 2. Cleaning qualities and forms of organization

	q^1, »high«	q^2, »511«	q^3, »assessed«	Sum
z^1: Decentral municipal	56	479	184	719
z^2: Central municipal	26	170	10	206
z^3: Private	22	107	27	156
Sum	104	756	221	1081

Figure 1. The number of schools of different sizes and cleaning standards

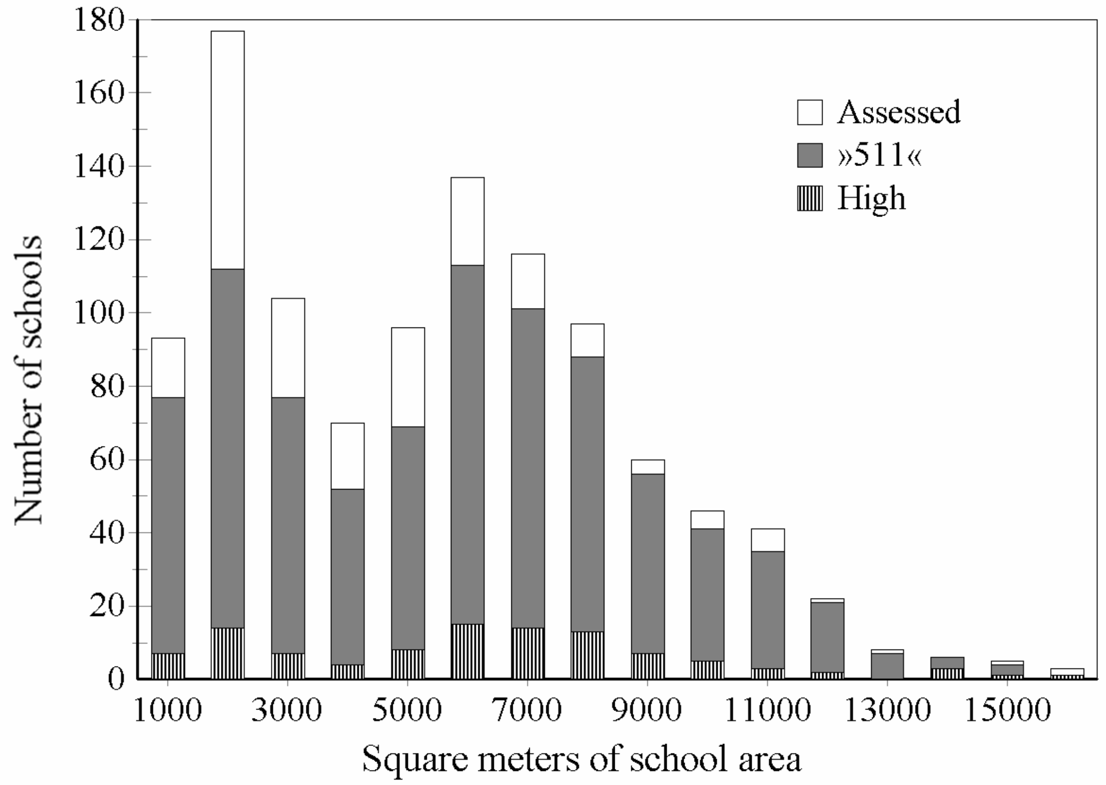


Figure 2. Log to cleaning cost per m^2 as a function of Log to size for quality »511«.

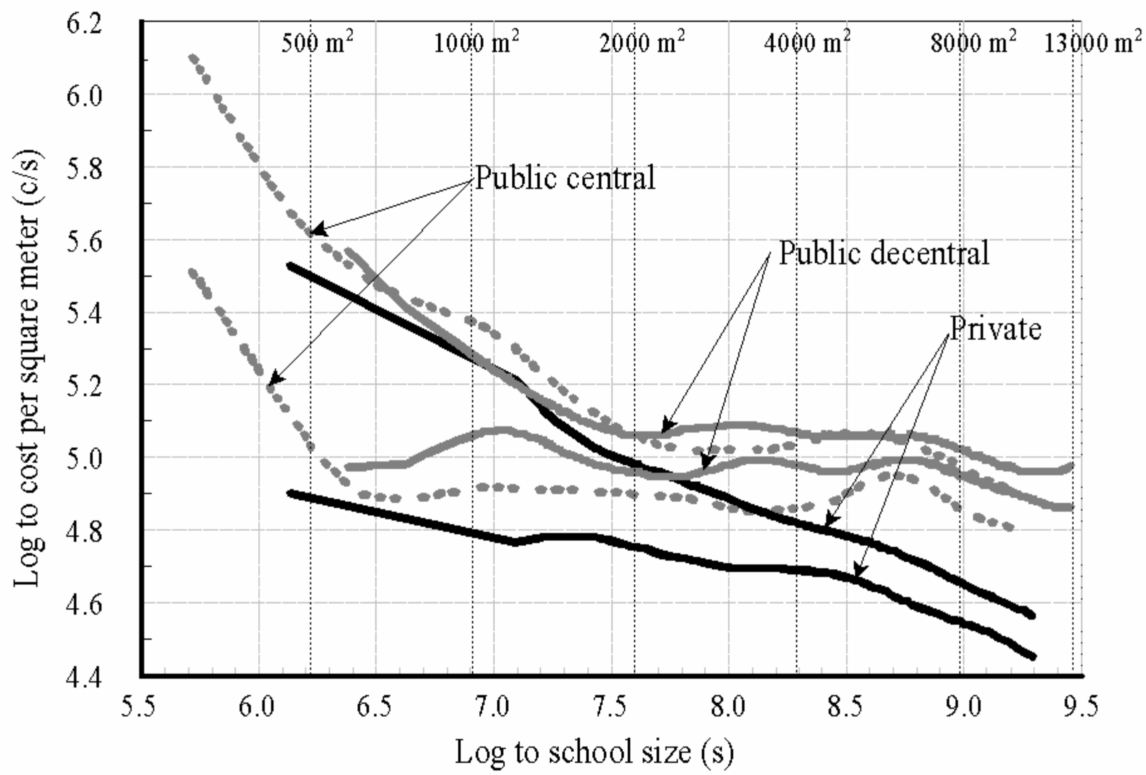


Figure 3. Breakeven combinations of s and w for decentral versus private production

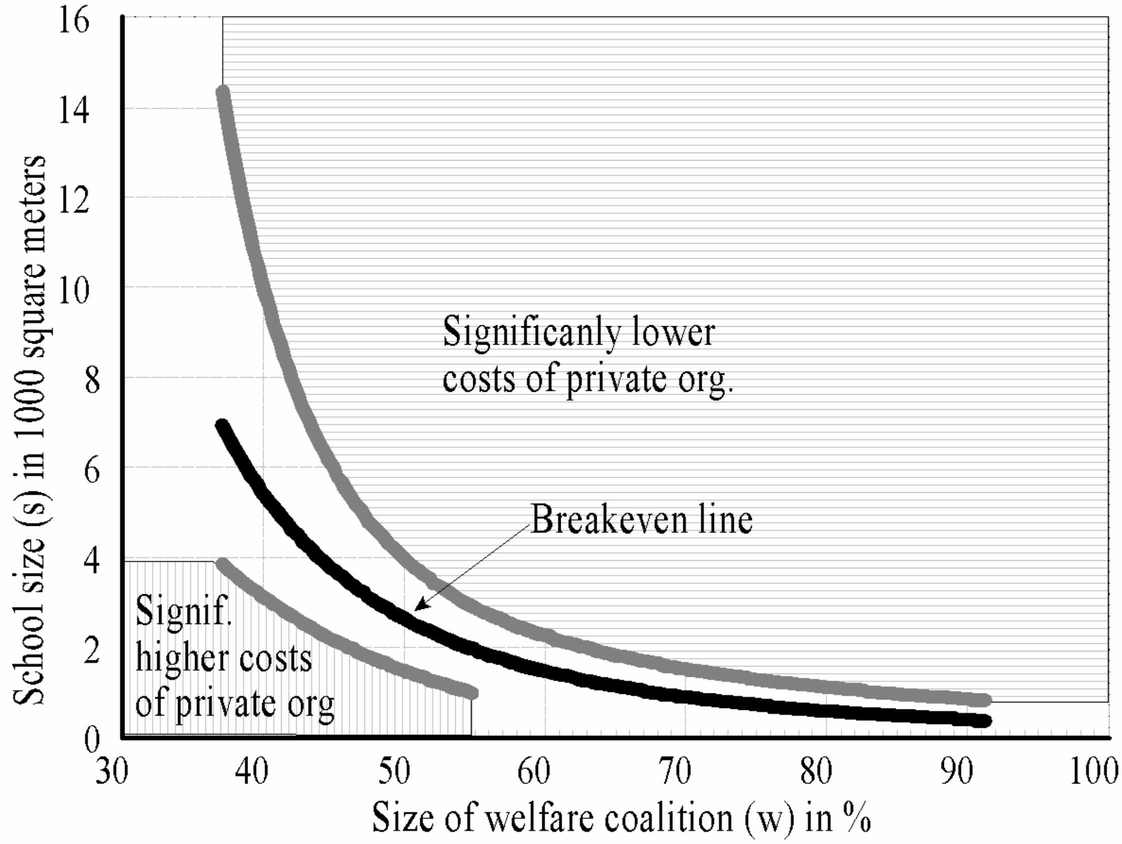


Figure 4. Breakeven combinations of s and w for central versus private production

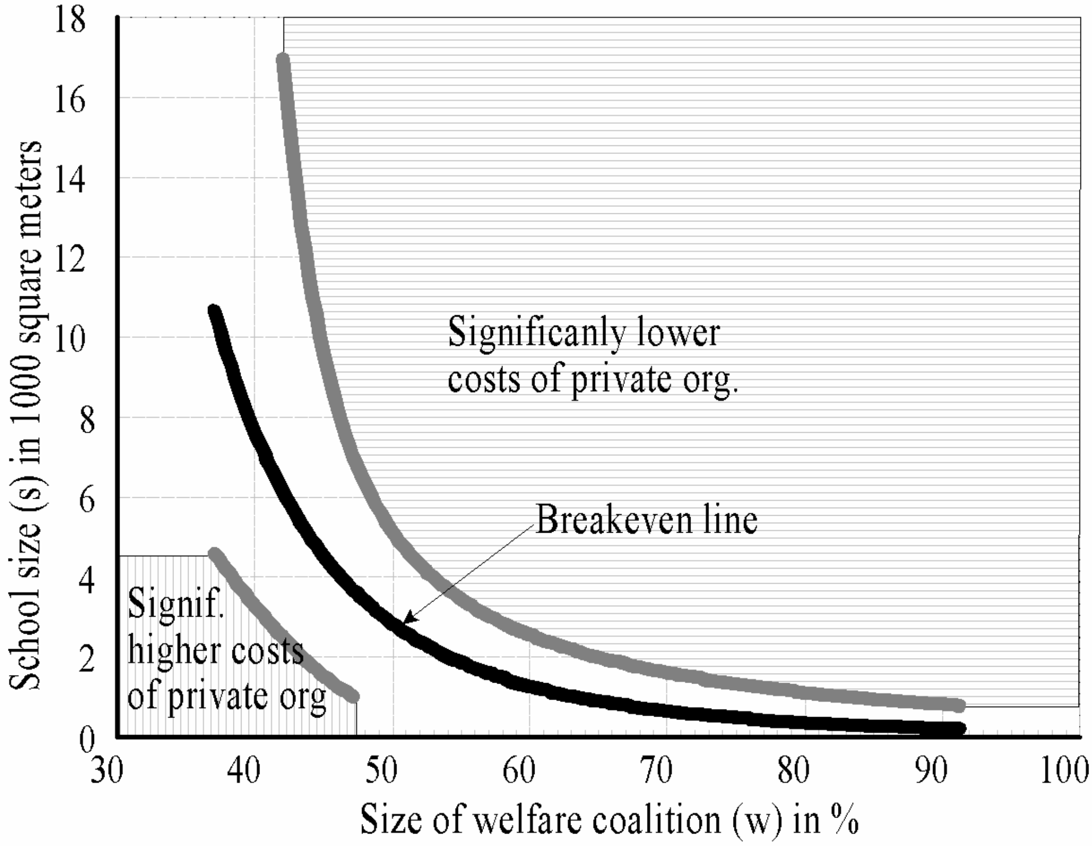


Table 3. Probit model for choice to answer questionnaire (sample selection)

Observations = 275		
Coefficient, variable	Estimate	S.e.
Constant	-0.849	0.361
Degree of urbanization	0.0187	0.00498

Table 4. Estimate of the cost function

	[1] (selection)		[2] (parsimonous)	
Coefficient, variable	Estimate	Robust s.e.	Estimate	Robust s.e.
α_1 to z^1, decentral	1.52	0.635	1.20	0.394
α_2 to z^2, central	1.97	0.764	1.64	0.489
α_3 to z^3, private	5.87	0.748	5.45	0.359
β_1 to $\ln(s_i)z^1$, slope decentral	-0.082	0.016	-0.080	0.015
β_2 to $\ln(s_i)z^2$, slope central	-0.139	0.029	-0.137	0.029
β_3 to $\ln(s_i)z^3$, slope private	-0.288	0.026	-0.288	0.026
γ_1 to q^1 "high"	0.117	0.027	0.118	0.027
γ_2 to q^2 "511" normalized to 0	-	-	-	-
γ_3 to q^3 "assessed"	-0.043	0.027	-0.048	0.025
Ln welfare coalition decentral	0.652	0.086	-	-
Ln welfare coalition central	0.648	0.103	0.667	0.066
Ln welfare coalition private	-0.044	0.122	-	-
Log average tax base	0.325	0.091	0.373	0.063
Selection correction	-0.067	0.097	-	-
Standard error, σ	0.26		0.26	
Number of observations	1064		1064	
Misspecification tests for model [2]			Test statistic	p-value
RESET, $\ln(c/x)^2$, $\ln(c/x)^3$			2.27	0.32
RESET, $\ln(c/x)^2$, $\ln(c/x)^3$, $\ln(c/x)^4$			6.91	0.08
Heteroskedasticity, squared			46.28	0.00
Heteroskedasticity, squared, cross products			48.84	0.00

Table 5. Distribution of actual schools in figures 3 and 4

	significantly lower cost		Significantly higher cost	
Change from / to	% of schools	% of school size	% of schools	% of school size
decentral to private	86.5	95.8	0.422	0.0287
central to private	87.5	94.4	0.500	0.0500
private to decentral	3.92	0.519	87.6	95.2
private to central	1.96	0.172	83.0	89.9

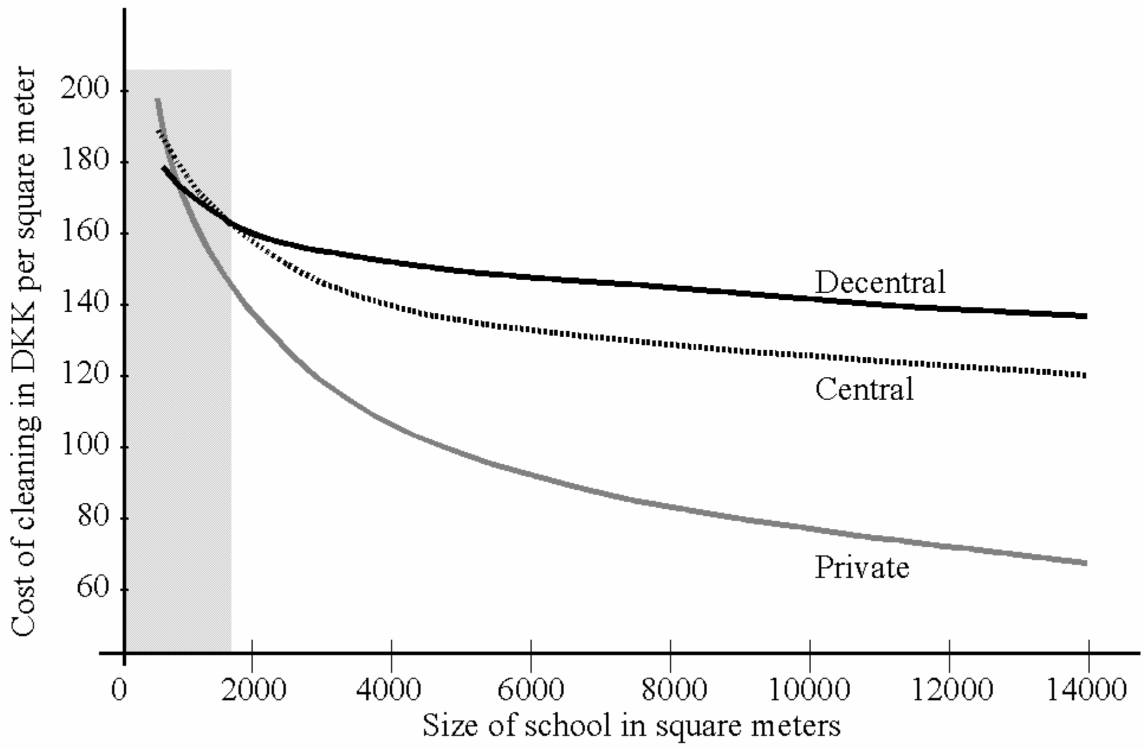
Note: Based on 95% confidence intervals.

Table 6. Distribution of schools corrected for ownership explanation

	significantly higher cost				Significantly lower cost		
Change from / to	Critical	% of	% of school	Breakeven	Critical	% of	% of
decentral to private	527	0.940	0.0556	765	1526	91.2	99.7
central to private	-	0	0	1024	1561	90.3	98.0

Note: Based on 95% confidence intervals.

Figure 5. Cost functions for the three types of organization and quality »511«



Note: The shaded area represents the mini-schools where the variance is very large. The vertical axis is the estimated costs in 1998 Danish Crowns (DKK). The exchange rate is fixed to the Euro at app 7.46 DKK/Euro. For the US $ the exchange rate fluctuates around 8 DKK/$.

Table 7. Costs in DKK per year

	q^1: »high« quality			q^2: quality »511«			q^3: »assessed« quality		
School size, m^2	2000	6000	12000	2000	6000	12000	2000	6000	12000
z^1: Mnp decen	181	166	157	161	148	140	154	141	133
z^2: Mnp centr	183	157	143	163	140	127	155	133	121
z^3: Private	157	115	94	140	102	83	133	97	79

Note: The exchange rate is fixed to the Euro at app 7.46 DKK/Euro.

Table 8. The effect of quality changes

	To »high«	To »511«	To »assessed«
From »high«		-11.1%	-15.3%
From »511«	12.5%		-4.7%
From »assessed«	18.0%	4.9%	

Note: Organizational form and municipal characteristics are kept constant.

Table 9. The effect of changing organizational form for the individual school

		To decentral	To central	To Private
From	2000 m^2	0.9%	-	13.4%
	6000 m^2	-5.5%	-	31.0%
	12000 m^2	-9.7%	-	40.3%
From	2000 m^2	-	-0.9%	16.5%
	6000 m^2	-	5.2%	37.5%
	12000 m^2	-	8.8%	52.7%

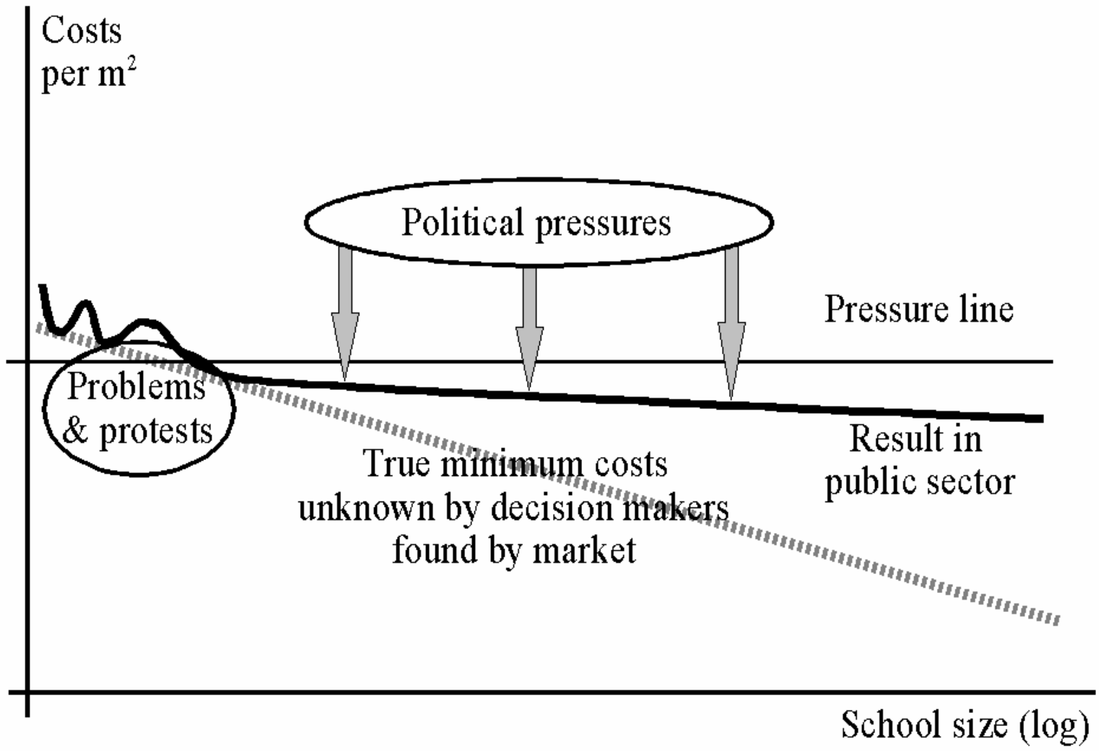
Note: Cleaning quality and municipal characteristics are kept constant.

Table 10. The effect of changing organizational form for the average municipality

Change for all schools	To decentral	To central	To private
From decentral		-5.3%	-29.6%
From central	5.6%		-25.7%
From private	42.0%	34.5%	

Note: Calculated or the average municipality as regards the sizes of its schools.

Figure 6. A model of the decision process of public savings



Notes:

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1. Quality refers to the product supplied to the consumers (schools). The quality of the workplace – though important – is not considered.

2. The cleaning budget might be integrated in some broader budget, allowing the school some substitution between various budget accounts. In such cases, it is possible that not all the administrative costs are included in the cleaning budget.

3. The second largest company has been purchased by the largest after the data was collected. Already after a few weeks the managing director started to speak about higher prices and that cutthroat competition was socially undesirable.

4. The market is not perfect though. Christoffersen, Larsen & Paldam (2001) reports a DEA analysis of the data for private cleaning showing a potential for a further savings of 33% even disregarding extreme points.

5. The number of classes taught at the school was also tried as an alternative measure of size. We found much the same results.

6. This variable has considerable variation, with a range from 40% to 90%. It has a low correlation to the other variables included.

7. Presented and discussed in Christoffersen & Paldam (1998), which shows that the market orientation – the use of private companies after competitive bidding – is smaller in municipalities with a large welfare coalition.

8. The Heckman's two-step estimator often does not produce a good result due to 'weak' identification since the same variables need to be used in both steps, that is, the identification hinges on functional form. Here, we avoid this problem since many variables are available on the municipalities.

9. The use of an estimated regressor (the first step estimation of the inverse Mills ratio) implies that the OLS standard errors of the second step need correction if sample selection is a problem. A standard t-test, however, can be used to test if the selection bias is significant.

10. We also tried to include an interaction-term $\boldsymbol{\eta}'\boldsymbol{q}_i\ln(s_i)$, but it was not statistically significant.

11. A simple numerical search can be used to find those values of s and w for which, for instance, the upper confidence bound intersect 0.

12. If the test is performed as a joint test, then the Bonferroni bound can be used. This is a conservative test procedure. An advantage is the cause of rejection can be recognized. Using the Bonferroni bound, each p-value is compared with a 5/2% = 2.5% significance level. Rejection is for the public production only.

13. Amounts to restricting the corrected cost function to have the same slope parameters but with different intercept.

14. For the log welfare coalition the average is 4.22 for the two types of public cleaning. The average to the log tax base is 4.5.

15. This follows from Jensen's inequality: $\text{Exp}(E(\text{Ln}(C)) \leq E(C)$. If normality is assumed, Exp(E(Ln(C)) can be corrected by the factor $\text{Exp}(0.5\sigma^2)$ to give an estimate of the average cost function, where σ is the standard error of the regression. We do not make such distributional assumptions and, hence, we report Exp(E(Ln(C)).

16. See the survey on competitive bidding by McAfee & McMillan (1987).

17. Assuming the regression function is undersmoothed.

18. A similar expression is valid for breakeven between central and private organizational form (replace subscript 1 with 2).