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AUTHORS	Ing-Marie Gren Chuan-Zhong Li
ARTICLE INFO	Ing-Marie Gren and Chuan-Zhong Li (2011). Enforcement of environmental regulations: inspection costs in Sweden. *Environmental Economics*, *2*(2)
RELEASED ON	Friday, 22 July 2011
JOURNAL	"Environmental Economics"
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

Ing-Marie Gren (Sweden), Chuan-Zhong Li (Sweden)

Enforcement of environmental regulations: inspection costs in Sweden

Abstract

The purpose of this paper is to estimate inspection costs of environmental regulations in Sweden and to carry out econometric test of the allocation of inspections among heterogeneous firms at two different jurisdictional levels – county and municipality. The inspection task of environmental regulations is delegated from central to regional and local jurisdictional levels, and the authors test if and how the allocation of inspections among firms coincide with the intentions set by the Swedish Environmental Protection Agency (SEPA). A two-step approach is applied where, firstly, inspection cost functions are estimated, and, secondly, marginal costs are derived and tested against marginal environmental weights given by the SEPA. The test results indicate that the allocation of inspection costs among firms deviates from their relative environmental impacts as determined by SEPA at both the county and the municipality jurisdictional level. At both levels, relatively too much expenses are used for inspecting firms with relatively large marginal environmental impacts.

Keywords: inspection costs, heterogeneous firms, environmental regulation, Sweden, delegation, econometric test.
JEL Classification: D78, K42, Q58, R50.

Introduction

This paper raises questions on the determination of inspections for monitoring compliance of heterogeneous firms. The issue emerges from the increasing role of monitoring and enforcement in environmental policy for, among others, combating emissions of green house gases and diffuse source pollution of waters, and for introducing carbon sequestration measures aimed at reducing carbon content in the atmosphere (e.g., NRC, 2000; Babiker et al., 2002; Kooten and Sohngren, 2007). A specific feature with enforcement of environmental regulations and other public regulations is that choices of the two common enforcement parameters – supervision of compliance and penalties for violation – are most often made by different authorities (see Polinsky and Shavell (2000) for a review of public enforcement). One type of agency, often a local authority, is responsible for supervising firms and reports suspected non-compliance to another agency mostly at a higher jurisdictional level, such as county or state bodies (e.g., Cohen, 1999). The eventual penalty of a violating firm is determined in a settlement or by a judge. However, although the inspection activities are delegated to local authorities, their monitoring discretion is usually regulated by a central authority which also delegates responsibility of a given number of heterogeneous firms. In spite of this widespread system internationally there is little empirical research on if and how the local inspector behavior coincides with the central environmental protection agency's intentions. The main purpose of this paper is to test whether inspection behavior at the local level complies with the intentions set by the Swedish Environmental Protection Agency (SEPA). This is made by estimating inspection cost functions from which marginal costs are derived and tested against marginal environmental weights given by the SEPA. Cost functions are estimated and tests are carried out for two different inspection levels – county and municipality.

Inspired by Becker (1968) the environmental economics literature on enforcement of regulations has focused on optimal enforcement including monitoring and sanctioning (e.g., Harrington, 1988; Segerson and Tietenberg, 1992; Gren and Kaitala, 1997; Cohen, 1999; Heyes, 2000; Earnhart, 2004; Shimsak and Ward, 2005). However, the empirical literature is more scant and deals mainly with two types of questions. One is focused on enforcement agencies' targeting of inspections among firms and the other on regulated firms' responses to changes in enforcement parameters such as the detection rate (see Cohen (1999) and Heyes (2000) for excellent reviews of the theoretical and empirical literature). This paper belongs to the empirical literature elucidating the first type of question. It is also related to the small empirical literature on delegation and devolution policies in enforcement of environmental regulations.

The empirical literature on inspection targeting includes econometric estimates of the explanatory power of different firm characteristics for the allocation of inspections among regulated firms (Deily and Gray, 1991; Laplante and Rilstone, 1996; Dion et al., 1998; Helland, 1998; Lear-Nordby, 1999; Firestone, 2002; Kang and Myunghun, 2004; Eckert and Eckert, 2010). Several studies show that firm size affects the inspection probability, but the results are mixed. Most studies find that inspection probability is higher for large firms and for firms with relatively high environmental impacts (Laplante and Rilstone, 1996; Dion et al., 1998; Lear-Norby, 1999). There are also evidence on the opposite inspection pattern where small firms face higher level of inspection probability (Deily and Gray, 1996; Firestone, 2002). This phenomenon is explained by the regulatory agencies' sensitivity to political power (Deily and Gray, 1996), and by the large firms' resources to combat penalty actions (Firestone, 2002). Another finding is the role of state dependent inspection; firms in compliance in prior periods have a lower inspection and enforcement rate in subsequent periods (Deily and Gray, 1996; Kang and Myunghun, 2004). Results also point at the implications of business conditions; inspection rates decrease for firms in industries with relative high closing probability (Deily and Gray, 1991). More recently Eckert and Eckert (2010) show the influence of location of firms where inspection probability increases for firms within clusters of regulated firms as compared with more isolated firms.

There is a considerable theoretical literature on delegation and devolution of enforcement of environmental regulations (e.g., Baron, 1985; Oates and Schwab, 1988; Hutchinson and Keenedy, 2008; Heyes and Kapur, 2009). This literature is focused mainly on environmental federalism, such as the role of competition among local governments for environmental policy implementation (see Dijkstra and Fredriksson (2010) for a review). However, the empirical literature on enforcement of environmental regulations at different jurisdictional levels is scant (Burby and Paterson, 1993; Helland, 1998b; Cutter and DeShazo, 2007). Helland (1998b) observes the influence of local interests on enforcement of environmental regulations. Results from Burby and Paterson (1993) indicate that local enforcement generates higher compliance rate than state enforcement in the US. Similar observations are made in Cutter and DeShazo (2007) who found that inspection rates of hazardous waste are higher for municipalities that were granted authority than for counties in California.

We perceive three types of contributions to the empirical literature of enforcement of environmental regulation in this paper. The main contribution is the estimation of regional and local agencies' inspection costs. We also add to the empirical literature by the test of regional and local agencies' compliance with SEPA's monitoring recommendations. The empirical application to a European country, Sweden, constitutes a contribution in itself since most other studies are applied to US or Canada. We find, similar to other studies, that marginal inspection costs are higher for firms with perceived larger environmental impacts. This occurs at both inspection levels. The third contribution is the test of inspection agency behavior with respect to allocation of cost among heterogeneous firms. The test results obtained in this paper indicate that an inspection rule following Swedish EPA's recommendations can be rejected at the five percent confidence level for large firms but not for firms with relatively small environmental weights at both the county and municipality enforcement levels. Firms with highest environmental impact are thus inspected 'too' much at both enforcement levels as compared to the recommendations made by Swedish EPA.

The paper is organized as follows. Section 1 gives a brief presentation of inspection of environmental regulations in Sweden. In Section 2 the data underlying the econometric test are presented, and the econometric tests are made in Section 3. The paper ends with a discussion of the results.

1. Brief description of inspections in Sweden

Supervision of environmental regulations in Sweden is made for command and control policies and is divided among three authorities: SEPA, counties and municipalities. The SEPA has the overall responsibility for supervising environmental regulations, and the operative responsibility is delegated to counties and municipalities, where each jurisdictional unit obtains a given number of firms to supervise. Their responsibilities are regulated by the classification of firms into four different categories – *A*, *B*, *C* and *U* – according to the Environmental Protection Act. Firms classified into the *A* and *B* classes require licences issued by counties for operation, where an *A* classified firm is more environmental hazardous than a *B* classified firm. Examples of *A* classified firms are nuclear power plants and firms operating in the steel, paper or pulp industries. Large farms and food producers provide examples of *B* classified firms. The *C* classified firms have to report their activities to the municipalities, and the *U* classified firms, such as petrol stations and laundries, need neither license nor reporting about their activities but are under observation by the municipalities for classification into any other class.

The Swedish EPA also makes recommendations on the priority setting of inspections among the four categories. These categories are given different weights according to their 'environmental seriousness' according to: 40 for *A* classified firms, 8 for *B* classified firms, 2 for *C* classified firms and 0.5 for *U* classified firms. The largest weight is thus 80 times larger than the smallest. These weights are the same for all regions. Given these weights, first-order condition for an inspection following the recommendations would require that the quotient of marginal inspection cost equals the ratio of weights between firms. This implies, for example, that the quotient between *A* and *U* firm would be 80, and that between *B* and – 16, and so forth. According to the results from an interview study by Bengtsson (2004), Swedish enforcement agencies apply these weights when making priorities for inspection among firms.

Counties have the responsibility for supervision of firms classified in the *A* and *B* categories and municipalities for firms in the other categories. However, upon voluntary request from municipalities, counties are allowed to delegate responsibility for supervising the *A* and *B* classified firms to the municipalities. Neither counties nor municipalities allocate budget resources particularly devoted to inspections of environmental regulations. Instead, soft budgets are given for environment and health protection more generally (RRV, 1997). It is, therefore, difficult to treat inspection cost as limited by budget resources, as made in other studies (e.g., Gray and Deily, 1991; Helland, 1998a). A difference in decision-making between counties and municipalities is that the municipality boards are composed by local elections while the members in county boards are chosen by the government. The county boards can then be regarded as the government's extended hands. There might thus be more room for local influence on inspections at the municipality than at the county level.

2. Description of data

The test of counties' and municipalities' decisions with respect to allocation of inspections among the four different categories of firms is made in two steps. First, cost functions are estimated, and then it is tested whether marginal costs of different categories are allocated according to the relative weights given by the Swedish EPA. When estimating the cost function for inspection it is assumed that inspection agencies minimize total costs under restrictions of regulated number of firms in different categories and given labor wages and time needed for an inspection in each category, supervision cost can, from duality theory, be derived as a restricted function of input prices, outputs, and allocated firms (see, e.g., Gasmi et al. (2002) for theoretical derivations and empirical approximations of cost functions). Since labor is the input for inspections, wages in different regions would constitute an independent variable. However, salaries in Sweden are regulated by the law and are the same for each profession irrespective of where it is located. There are thus no or minor differences in salaries between regions, and this input variable is therefore excluded. The cost function thus constitutes a multi-output function, with detection rates for the four different categories as outputs. However, detection rates as output variables cannot be obtained from the data, and instead number of firms in different categories is used as independent variables. The regression result thus estimates how inspection costs change as a result of larger number of firms in each category. These marginal costs are then compared with the weights given by the Swedish EPA.

In years 1992 and 1995 Swedish Statistics and Swedish Environmental Protection Agency made a joint survey of inspection costs for counties and municipalities in Sweden (SCB, 1993; SCB, 1996). Unfortunately, these surveys were not followed up during later years, so existing data may seem outdated. However, there have been any significant changes in the organization of inspections during the years (SEPA, 2011). There are 24 counties and 287 municipalities in Sweden. This gives 48 observations at the county inspection level. However, not all municipalities report inspections and associated, and the number observations for the two years at the municipality level is 471. Descriptive statistics for the number of firms in different categories and for inspection costs are presented in Table 1.

Table 1. Descriptive statistics, regulated firms and inspection costs at the county and municipality jurisdictional levels

	Firm allocations in categories				Cost, thousand SEK[1] per year in 2010 prices
	A	*B*	*C*	*U*	
Counties (N = 48)					
Mean	19.8	209			3 756
St. dev.	12.7	109			1 677
Min	2	22			1 380
Max	63	438			9 208
Municipalities (N = 471)					
Mean	0.5	11.5	71.0	181	720
St. dev.	1.6	19.8	82.8	213	1 096
Min	0	0	0	30	35
Max	13	157	753	988	11 966

Notes: 1 – 10.20 SEK = 1 Euro (average for 2010).
Sources: SCB (1993; 1996).

Total inspection cost at both jurisdictional levels amounts to approximately 261 millions per year, which corresponds to 3 per cent of the average industrial cost for environmental protection during the ten year period of 1997-2007 for which these costs are reported (SCB, 2008a). The inspection cost constitutes only a small fraction, 0.06 per cent, of total county and municipality expenses (SCB, 2008b).

The average number of total allocated firms varies considerably between county and municipalities, being approximately 15 times as many for the municipalities at the same regional aggregation. However, the number of firms in categories *A* and *B* is larger at the counties than at the municipalities. Since counties inspect only these two categories, the average cost per firm is almost 10 times larger than for the municipalities. At both enforcement levels the number of firms to inspect is the highest for the largest urban areas Stockholm, Gothenburg and Malmöhus counties, and also for northern counties where much of the Swedish natural resource-based industries – paper and pulp, and iron and steel – are located.

3. Econometric specification

Let $C_{j,t}$ denote the total inspection cost in region *j*, *j* = 1,2,…,*n*, where *n* is the number of regions, at time *t* where *t* corresponds to 1992, 1995. Assume that the cost is related to the number of different objects (firms), $X^A_{j,t}$, $X^B_{j,t}$, $X^C_{j,t}$, and $X^U_{j,t}$, of types *A*, *B*, *C*, and *U*, respectively, as described above. Our objective here is to estimate some form of the cost function $C_{j,t} = F(X^A_{j,t}, X^B_{j,t}, X^C_{j,t}, X^U_{j,t})$ and then test whether marginal costs equal Swedish EPA's unit environmental weights. In addition, a model is assumed where dummies are introduced for the two years (1992 and 1995) and for the three most densely populated large regions in Sweden. If inspection costs are determined by transport distances, and if they are longer in rural regions we would expect the regional dummy to be negative.

The simple linear model of the inspection cost is written as (for simplicity, we omit the region and time subscripts in the sequel):

$$C = \alpha + \beta_A X^A + \beta_B X^B + \beta_C X^C + \beta_U X^U + \\ + \beta_Y Y + \beta_D D + \varepsilon, \quad (1)$$

where α and β_i, i = *A*, *B*, *C*, *U*, *Y*, *D* are parameters, *Y* = 0 for year of 1992, *Y* = 1 for year of 1995, *D* = 1 for three most densely populated regions, *D* = 0 for all other regions, and ε is a stochastic variable. As usual, we assume that this stochastic variable is normally distributed with zero mean and constant variance, and uncorrelated across regions. A Breush-Pagan test revealed no heteroskedasticity at the 1 per cent confidence level. Since only a fraction of the firms in each type of the objects is inspected, the model parameters should be interpreted as the expected inspection cost per object. For example, the parameter β_A corresponds to the product of the marginal cost per inspection of an *A*-object and the probability for an *A*-object to be visited. Anyhow, we refer to the β parameters for firm categories simply as marginal costs for notational ease.

Using the OLS (Ordinary Least Square) estimator, results from the estimation of the linear model (1) are shown in Table 2. The results indicate that the model as a whole has a better goodness-of-fit for the municipality cost function than the county function with adj. R^2 = 0.81 and R^2 = 0.48, respectively. Almost all estimated firm parameters are statistically significant at the conventional confidence level of five or ten per cent for the municipality cost function. Both firm parameters are significant at the five per cent level for the county cost function.

Table 2. The estimated linear cost function

Parameter	Estimate	Standard error	T-value	P-value
Counties:				
α	1363	495.2	2.75	0.009
β_Y	-89.8	312.2	-0.29	0.775
β_D	1039	587	1.77	0.084
β_A	63.91	19.81	3.23	0.002
β_B	4.11	1.87	2.20	0.033
$\bar{R}^2$ = 0.49, SSE_U = 46879000, N = 48				
Municipalities:				
α	710.4	1026	0.69	0.493
β_Y	-9.72	740	-0.013	0.990
β_D	5893	1530	3.85	0.000
β_A	239.9	85.59	2.80	0.008
β_B	12.67	6.41	1.98	0.055
β_C	1.52	0.93	1.63	0.111
β_U	0.43	0.24	1.76	0.087
$\bar{R}^2$ = 0.81, SSE_U = 177160000, N = 471				

Common to both cost functions is that the time dummy is negative but statistically insignificant, and that the dummy for densely populated regions is positive and statistically significant at the 10% level. The latter result is in contrast to our expectation of a negative impact due to the presumed lower transport costs in densely populated regions.

The difference in the estimated marginal inspection cost between the counties and municipalities can be explained by the municipalities' higher interest in supervision (RRV, 1997). The delegation of supervision of A and B firms from the counties to the municipalities is made on a voluntary basis upon request from the municipalities. Similar observations are made in Cutter and DeShazo (2007) who found that inspection rates of hazardous waste are higher for municipalities that were granted authority than for counties in California. Results from Burby and Paterson (1993) indicate that local enforcement generates higher compliance rate than state enforcement in the US.

Based on the results in Table 2, it is investigated whether the cost structure is consistent with the conditions of relative environmental weights and costs when following the Swedish EPA's recommendations. Recall that the relative environmental weights assigned to the A, B, C, and U-objects are $w_A = 40$, $w_B = 8$, $w_C = 2$, and $w_U = 0.5$, respectively, according to their 'environmental seriousness'. Using the regression results in Table 3 and these weights, it is tested whether the marginal cost ratio equals the ratio between the respective weights, or, equivalently, whether the weighted marginal costs are equalized across the different objects, i.e.,

$$\partial E(C)/\partial X^i = \frac{w_i}{w_k}\partial E(C)/\partial X^k \,, \qquad (2)$$

where $E(C)$ denotes the expected total cost, i.e., the systematic part of the model (1). For the linear model (1), the marginal costs are simply the parameters themselves such that $\partial E(C)/\partial X^i = \beta_i$.

To test whether the condition in (2) is satisfied simultaneously for all the objects, we perform a F-test for the joint hypothesis

$$H_0 : \beta_B = \frac{w_B}{w_A}\beta_A, \beta_C = \frac{w_C}{w_A}\beta_A, \text{and } \beta_U = \frac{w_U}{w_A}\beta_A \qquad (3)$$

against an alternative hypothesis that at least one of the equalities is violated. The restricted model thus becomes:

$$C = \alpha + \beta_A \tilde{X} + \varepsilon \,, \qquad (4)$$

where $\tilde{X} = X^A + \frac{w_B}{w_A}X^B + \frac{w_C}{w_A}X^C + \frac{w_U}{w_A}X^U$. The results from the F-test are presented in Table 3.

Table 3. The restricted linear model estimates

Parameter	Estimate	Standard error	T-value	P-value
Counties:				
α	236	432.9	5.40	0.000
β_Y	-228.5	340.6	-0.67	0.51
β_D	2132	527.5	4.04	0.000
β_A	0.95	0.41	2.29	0.027
$\overline{R}^2 = 0.38$, $SSE_R = 58225000$, $N = 48$				
Municipalities:				
α	3128	1006	3.11	0.003
β_Y	760.1	809.2	0.94	0.35
β_D	9481	1464	6.72	0.000
β_A	0.007	0.004	1.89	0.065
$\overline{R}^2 = 0.65$, $SSE_R = 344230000$, $N = 471$				

The results in Table 3 show that the $\overline{R}^2$ measure becomes considerably lower than that of the unrestricted model. For the counties, the critical F-value at a significance level of 1% given the degrees of freedom (1.43) is about 4.31, which is far below the actual F-value being 8.88. Therefore, we can reject the null hypothesis (3) at the 1% significance level for the county choice of allocating inspection resources. Similar F-test of municipalities' estimated cost function shows that the F-statistic also exceeds the critical value. In other words, the weighted marginal costs are not all equal to each other across the different objects for either of the counties or the municipalities.

To see exactly what pairs of the weighted marginal costs violate the efficiency conditions, we perform a number of T-tests, as shown in Table 4.

Table 4. The pair-wise t-tests based on the linear model

H_0	Estimate	Standard error	T-value	P-value
Counties:				
$\beta_A - (w_A / w_B)\, \beta_B = 0$	43.36	21.09	2.07	0.038
Municipalities:				
$\beta_A - (w_A / w_B)\, \beta_B = 0$	176.5	68.75	2.56	0.010
$\beta_A - (w_A / w_C)\, \beta_C = 0$	206.9	89.01	2.32	0.020
$\beta_A - (w_A / w_U)\, \beta_U = 0$	205.5	92.10	2.23	0.026
$\beta_B - (w_B / w_C)\, \beta_C = 0$	6.59	7.27	0.91	0.363
$\beta_B - (w_B / w_U)\, \beta_U = 0$	5.79	6.43	0.90	0.368
$\beta_C - (w_C / w_U)\, \beta_U = 0$	-0.20	1.72	-0.12	0.904

From the P-values, it is seen that the hypotheses that the marginal inspection cost for an *A*-object equals the weighted marginal costs for the other objects are rejected at 5% significance level at both the county and the municipality enforcement levels. Since the differences are all positive for these three pairs, it may be concluded that the marginal cost of the *A*-objects set by the inspection authorities are significantly greater than recommended by the Swedish EPA. Alternatively, we may also interpret the results as that the cost ratios for the *A* objects to those of the other objects exceed the ratios of the corresponding weights. The relative relationships among the other objects, i.e., *B*, *C*, and *U*, seem to satisfy the efficiency conditions as set by equation (2). At least, given the data available, we cannot reject the null hypothesis for these firm categories.

Quadratic regression equation estimates give the same results as for the linear equations except for the pair-wise comparison of *A* and *B* firms at the municipality level (see Appendix). The results thus seem robust to model specification at the county enforcement level and for large (*A*) and relatively small firms (*C* and *U*) at the municipality level.

Summary and discussion

The main purpose of this paper has been twofold, to estimate inspection cost functions and to test whether the targeting of inspection of firms subjected to Swedish environmental regulations is consistent with recommendations made by the Swedish EPA. The estimation of inspection cost functions and the econometric test of compliance with the Swedish EPA recommendations were based on a unique panel data for the Swedish counties' and municipalities' enforcement of command and control regulations. The Swedish EPA quantifies its recommendation as weights of different firm categories according to their environmental damage. The test was then designed to compare the marginal cost ratio with the marginal weight ratio. Weighted marginal inspection cost across the different objects turned out to be statistically significantly different, especially the cost ratios of the firms with relatively large environmental impacts. In addition, the results were not sensitive to model specifications – both the simple linear model and a quadratic model provide rather similar results.

Assuming a positive correlation between cost and inspections, the results are in line with the empirical studies where inspection is found to be increasing in plant size or emissions (Laplant and Rilsone, 1996; Gray and Deily, 1996; Dion et al., 1998). However, relatively high inspection costs may not imply higher enforcement rate at the firm level. On the contrary, from optimal penalty theory we would expect inspections, which affect violating firm's probability of being detected, and the size of penalty to be negatively correlated. Lear-Nordby (1999) and Firestone (2002) find that EPA penalty decrease with firm size. Thus, relatively low penalties for detected violation by firms with relatively large environmental impacts is consistent with the results in this paper and seem to have support from expected penalties sanctioned in Sweden. In average, approximately 5 per cent of the registered environmental crimes and offences results are penalized, and the fine payments are perceived as low (SCB, 1996; Bengtsson, 2004).

The relatively high marginal inspection cost for firms with large environmental impacts can also be explained by the dual role of inspection agencies: to give advises and to control compliance with regulations. The perceived need for more advising of large firms may then result in relatively higher inspections costs of these firms. This, in turn, raises another interesting issue with regard to the strategy of the inspection agency, cooperation versus confrontation strategy, which have been investigated and compared since early 1980s (e.g., Lundqvist, 1980; Harrison, 1995; Vogel, 2003).

Unfortunately, available data of Swedish enforcement do not allow for empirical test and comparison of these potential causes of high marginal inspection cost for firms with relatively large environmental impact. All explanations seem plausible and point at the wider context within which inspectors operate than has been tested in this paper. Nevertheless, although the decision contexts differ between the two inspection levels included in this paper, the empirical results seem robust and indicate that inspection agencies at both jurisdictional levels allocate cost towards firm with perceived relatively large environmental impact and that marginal inspections costs are higher than the recommendations set by the Swedish EPA for firms with the largest environmental impacts.

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Appendix. Estimate and efficiency test of quadratic cost functions

In order to examine whether the conclusions here are sensitive to model specifications, we have also estimated a quadratic model of the cost function:

$$C = \alpha + \beta_A X_A^2 + \beta_B X_B^2 + \beta_C X_C^2 + \beta_U X_U^2 + \varepsilon . \qquad \text{(A1)}$$

The estimation results are presented in Table A1

Table A1. The estimated quadratic cost function

Parameter	Estimate	Standard error	T-value	P-value
Counties:				
α	2257	317.8	7.10	0.000
β_Y	-125.0	310.1	-0.403	0.689
β_D	762.1	644	1.18	0.243
β_A	1.61	0.494	3.26	0.002
β_B	0.009	0.005	1.86	0.070
$\bar{R}^2 = 0.49$, $SSE_U = 47083000$, $N = 48$				
Municipalities:				
α	3112	559	5.56	0.000
β_Y	45.57	613.4	0.08	0.941
β_D	6042	1201	5.03	0.000
β_A	9.97	2.55	3.91	0.000
β_B	0.060489	0.019390	3.12	0.003
B_C	0.000506	0.000369	1.37	0.178
B_U	0.000033	0.000032	1.04	0.304
$\bar{R}^2 = 0.85$, $SSE_U = 136530000$, $N = 471$				

The restricted version with the equal welfare-weighted marginal costs is

$$C = \alpha + \beta_A \tilde{X} + \varepsilon , \qquad \text{(A2)}$$

where

$$\tilde{X} = X_A^2 + (w_B / w_A) \cdot (\bar{X}_B / \bar{X}_A) \cdot X_B^2 + (w_C / w_A) \cdot (\bar{X}_C / \bar{X}_A) X_C^2 +$$
$$+ (w_U / w_A) \cdot (\bar{X}_U / \bar{X}_A) \cdot X_U^2$$

with $\bar{X}_i$, for $i = A, B, C, U$, denotes the average number of firms of type A, B, C, and U, respectively, per county. The regression results are presented in Table A2.

Table A2. The restricted quadratic model estimates

Parameter	Estimate	Standard error	T-value	P-value
Counties:				
α	2706	526.8	8.61	0.000
β_Y	-265.2	338.1	-0.79	0.437
β_D	2148	526.8	4.08	0.000
β_A	0.022	0.098	2.25	0.029
$\overline{R}^2 = 0.38$, $SSE_R = 58400000$, $N = 48$				
Municipalities:				
α	3970	705.4	5.63	0.000
β_Y	721.8	810.1	0.89	0.378
β_D	9680.1	1533	6.32	0.000
β_A	0.00063	0.00034	1.83	0.074
$\overline{R}^2 = 0.65$, $SSE_R = 345920000$, $N = 471$				

The estimated results for these two models are reported in Tables A1 and A2 in Appendix. The F-statistic here is 10.34 for counties and 20.96 for municipalities, which are greater than the corresponding critical value 2.84 with the degrees of freedom as (3.43) at the 5% significance level. Thus, the hypothesis of an overall equality between the welfare-weighted marginal costs is rejected.

The pair-wise T-test results are shown in Table A3, which shows the same trend as in the linear model case, i.e., the ratio of the marginal inspection cost for *A*-objects to the other objects statistically significantly exceeds the corresponding welfare ratios proposed by the Swedish environmental protection act.

Table A3. The pair-wise t-tests based on the quadratic model

H_0	Estimate	Standard error	T-value	P-value
Counties:				
$\partial E(C)/\partial X^A - (w_A/w_C)\partial E(C)/\partial X^C = 0$	61.80	19.50	3.17	0.002
Municipalities:				
$\partial E(C)/\partial X^A - (w_A/w_B)\partial E(C)/\partial X^B = 0$	19.42	21.31	0.91	0.363
$\partial E(C)/\partial X^A - (w_A/w_C)\partial E(C)/\partial X^C = 0$	75.65	25.64	2.92	0.004
$\partial E(C)/\partial X^A - (w_A/w_U)\partial E(C)/\partial X^U = 0$	77.46	25.57	2.81	0.005
$\partial E(C)/\partial X^B - (w_B/w_C)\partial E(C)/\partial X^C = 0$	11.37	5.14	2.21	0.027
$\partial E(C)/\partial X^B - (w_B/w_U)\partial E(C)/\partial X^U = 0$	11.72	5.13	2.28	0.023
$\partial E(C)/\partial X^C - (w_C/w_U)\partial E(C)/\partial X^U = 0$	0.09	0.77	0.11	0.991