UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Project in Economics

An Empirical Analysis of the Determinants of NOx Emission Standard Stringency for Boilers at Swedish Combustion Plants

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Master Degree Project No. 2015:61
Graduate School

Abstract

Operators at Swedish combustion plants have raised a concern that the stringency of boiler specific NO_x emission standards varies between counties, potentially causing competitive advantages for plants in counties with relatively less stringent regulations. By utilizing a unique dataset we are provided with an opportunity to analyse the determinants of emission standard stringency in order to explain these potential variations. Relying on pooled OLS estimations we find that more stringent standards are imposed in counties where the NO_x associated environmental damages are more severe. We also find that less stringent standards are imposed in counties where concerns about the employment levels are higher or where the environmental awareness among the inhabitants is lower. Furthermore we find that plants with a higher bargaining power obtain less stringent standards. The last three findings indicate that structural differences in the regulation is present, potentially leading to unjustified competitive advantages for some plants. This suggests that a more uniform enforcement of the emission standards between Swedish counties may be necessary.

Key words: Emission standards, NO_x, decentralized decision making, combustion plants

Acknowledgements

We would like to take the opportunity to thank those that have helped us in the process of writing this thesis. First of all, we owe the biggest thanks to our supervisor Jessica Coria for your guidance, comments and ideas, for support and understanding. Thank you for constantly being available for questions and also for providing us with a unique opportunity to work on a very interesting topic. Thank you, Magnus Hennlock, our supervisor from IVL, Swedish Environmental Resource Institute, for your time and valuable input on the thesis. We are also very thankful to IVL for providing us with office space and for the encouragement and cheering from the nice people working there. We thank Ida Muz, PhD student, for helping us with the data. Lastly we send our special thanks to our opponents Sofia Nyström and Andrea Berggren for the valuable comments about the content and structure of the thesis.

Gothenburg, June 2015

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1. Introduction

Emissions of nitrogen oxides (NO_x) contribute to environmental problems such as acidification, eutrophication and the creation of ground-level ozone, causing negative impacts on plants, animals and human health (e.g., Pleijel, 2007). NO_x emissions are created at any type of combustion and in Sweden about 30 percent of the emissions originate from boilers located at combustion plants, making them the second largest pollutant after the transport industry (SEPA, 2015). Since the late 1980s, boilers at combustion plants have been subject to various NO_x regulations. Beside a national system of NO_x emission charges, many boilers are also subject to individual emission standards. These emission standards are specified in the operating licences of the combustion plants and are determined case-by-case mainly at a decentralized level by the County Administrative Boards (CABs) (SEPA, 2012).

In a recent report by the Swedish Environmental Protection Agency (SEPA) (2012), it was indicated that the stringency of these emission standards may vary between counties. According to representatives from the regulated plants, this could cause competitive advantages for plants located in counties where the decision makers set relatively less stringent standards (ibid.). Such an indication raises the question of why this variation in the emission standard stringency may be observed. According to environmental economics theory, variations in regulatory stringency can be justified from an efficiency point of view if the NO_x related environmental problems are of different severity between counties (e.g., Sterner & Coria, 2013). However, the literature on decentralized environmental policy-making has implied that variations in regulatory stringency may be caused by other factors, such as considerations of the regional economic activity and employment (e.g., Oates, 2001).

The objective of this thesis is to identify the determinants of NO_x emission standard stringency for boilers at Swedish combustion plants in order to explain differences in emission standard stringency both between and within counties. To our knowledge, a similar analysis has not yet been performed since it has not been possible due to lack of data. Using a recently developed dataset from the Optimal Regulation of Multiple Pollutants (ORMP) project at the University of Gothenburg, we are provided with a unique opportunity to fill this gap.

Two recent studies performed by Perino and Talavera (2014) and Ghosal et al. (2014) relate to our thesis in terms of that they also identify determinants of regulatory stringency decided at a decentralized level. Perino and Talavera (2014) identify the determinants of sulphur dioxide (SO_2) emission standard stringency at US coal-fired power plants. NO_x and SO_2 emissions both origin from combustion processes and contribute to similar environmental damages (e.g., Pleijel, 2007). The authors utilize a panel of 510 boilers between the years 1985 and 1994. They specify a dynamic model with the lagged SO_2 emission standard and various state and plant level variables as explanatory variables and estimate it with Generalized Method of Moments (GMM). Their results suggest that more stringent standards are imposed in states where the SO_2 related environmental damages (approximated by a weighted mean of the pH level in rainwater) are more severe. They also find that less stringent standards are imposed in states where the bargaining influence from the industry (measured by the manufacturing and coal mining industries' share of the state GDP) is higher. Furthermore they find indications that more stringent standards are imposed in states where the demand for environmental quality is higher (defined as better-off states in terms of higher median income). However, their results may not be directly transferrable to the purpose of this thesis due to for example differences in regulatory structure between the US and Sweden. A major difference is that US states have the power to legislate in some matters, which the Swedish County Administrative Boards do not. Furthermore, the US states have a larger possibility to affect the environmental regulatory stringency whereas the CABs only have been delegated the responsibility to interpret and enforce the national environmental law regionally (SFS 2013:251).

In a working paper, Ghosal et al. (2014) construct plant specific productivity indexes using annual input-output data of large pulp and paper plants in Sweden between the years 1996 and 2011. They hypothesize that an increase in environmental regulatory stringency causes an increase in a plant's green total factor productivity (TFP) growth and that this regulatory stringency (and thus green TFP growth) is affected by various municipality, and plant level variables. The authors find indications that plants located in environmentally less sensitive areas (which they define as more densely populated municipalities, areas by the coast and agglomerations) obtain less stringent regulations. Furthermore, they find that plants with a higher bargaining power (in terms of the plant's share of the total number of employees in a municipality) probably obtain less stringent regulations. The authors also find indications that large plants (in terms of total output per year) obtain more stringent regulations. The results are interesting for the purpose of our thesis, however by using data that directly measure regulation stringency and by applying the analysis to a larger share of the regulated Swedish combustion plants, we have the possibility to identify the determinants of regulation stringency more directly.

From findings in the above-mentioned studies, further literature on decentralized regulations, the Swedish environmental legislation and from interviews with decision makers at the County Administrative Boards, we develop our hypotheses. We hypothesize that various county, plant, and boiler level variables are important determinants of NO_x emission standard stringency. Using pooled OLS, we regress the emission standards on several variables. The sample consists of 471 boilers that operate in the power and heat, pulp and paper, wood, food, metal, and chemical sectors. The data stretches between the years 1992 and 2012.

Firstly our empirical results suggest some county level determinants that could explain the variations in emission standard stringency between counties. We find that more stringent standards are imposed on boilers in counties where the NO_x associated environmental problems (approximated by the NO_x concentration in the air) are more severe. We also find that less stringent standards are imposed in counties where concerns about the economic activity and employment are higher (measured by the unemployment level) or where the environmental awareness among the inhabitants (measured by the share of votes for the Green Party in the general election) is lower.

Secondly, we find that the previous results may only apply to boilers in the power and heat sector. For boilers in the other sectors, the decision makers do not seem to consider the environmental status in the county or the economic activity and employment when determining the emission standard stringency. In contrast, we find that the bargaining power of the plant (measured as the share of employees per sector of the total working force in the county) is a determinant of the stringency.

Finally our results imply that the most significant determinants of NO_x emission standard stringency are various boiler characteristics, which explains variations in emission standard stringency within the counties. The size of the boiler and the type of fuel used are found to have the largest effect, where larger boilers and boilers that use less NO_x intensive fuels are more strictly regulated.

The rest of the thesis is structured as follows. In the next section we present the conceptual framework of the thesis. Section 3 provides a description of the data and section 4 presents the empirical model and the results. In section 5, we summarize and draw our conclusions.

2. Conceptual framework

In this section we present the theory of optimal emission levels and review empirical literature on decentralized environmental regulations. Furthermore, we describe the legal framework for determining the NO_x emission standards in Sweden and provide an overview of how decision makers at the County Administrative Boards may reason when they determine emission standards. Finally, we present our hypotheses based on the concepts discussed.

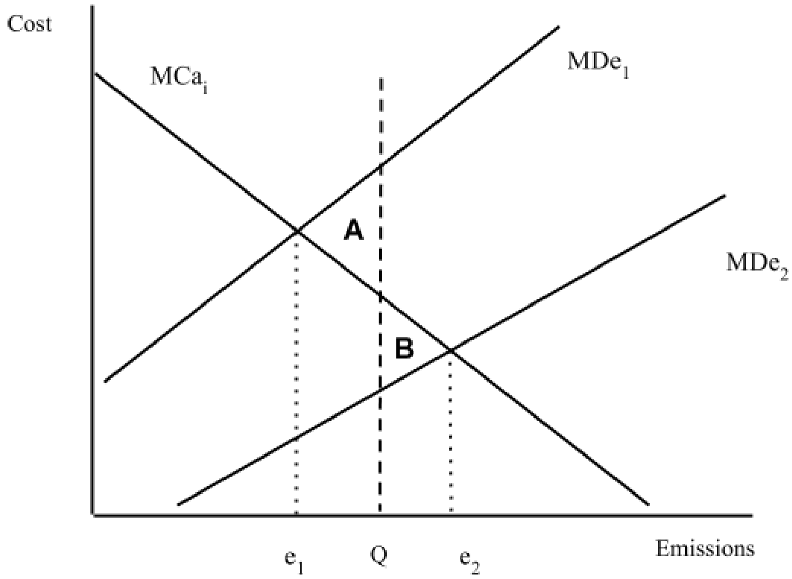
2.1 Economic theory: Optimal emission levels

Environmental economics theory provides a framework for determining when the level of emissions is optimal. It builds on the idea that emissions cause social costs (damage cost of emissions) in terms of for example environmental degradation and health problems. Further, that there is a cost of emission reduction in terms of abatement costs for the polluting plant. The optimal level of emissions is found when the marginal damage of emissions equals the marginal cost of abatement (e.g., Sterner & Coria, 2013).

The level of environmental damage cost depends not only on the amount of emissions but also on the inherent capacity in the environment to resist pressure from the pollutant. This creates heterogeneous damage costs implying that the same level of emissions cause more severe problems in one area compared to another due to variations in resistance between areas (Sterner & Coria, 2013). In our context, we can somewhat simplified say that some counties have more resistance compared to other counties. As an example, we can consider the NO_x related environmental problem of acidification. The south-eastern parts of Sweden is almost unaffected due to high concentration of limestone in the bedrock, providing efficient resistance to acidification. In the other parts of southern Sweden, where the environmental conditions are less beneficial, the problems of acidification are more severe (Miljömål, 2015a). Another example is that the more individuals that are exposed to the emissions, the higher is the marginal damage (Sterner & Coria, 2013).

When a pollutant give rise to damage costs close to the source of pollution (as NO_x emissions partly does), the optimal emission levels should be determined on geographically separated markets where the emission level is adjusted to local optimality conditions (Sterner & Coria, 2013). In Figure 1, we illustrate the gain in economic efficiency from having a regulation that is adjusted to regional differences in environmental damages from emissions compared to a uniform emission standard. The graph builds on figures and reasoning in Sterner and Coria (2013).

Figure 1. Optimal emission levels with heterogeneous damage costs



Notes: MCa_i = Marginal cost of abatement for plant 1 and 2. MDe_i = Marginal damage of emissions from plant 1 and 2 respectively. Q = emission standard. e_i = optimal level of emissions for county 1 and 2 respectively.

In Figure 1, we consider two plants located in two different counties (1 and 2). We assume that in county 1, the marginal damage of emission (MDe_1) is higher than in county 2 (MDe_2). For simplicity we assume that both plants have identical marginal abatement cost curves (MCa_i). The optimal emission levels are found at the intersection of the marginal damage and the marginal abatement cost curves. We can see that the optimal emission level for the plant in county 1 is e_1 and e_2 for the plant in county 2. The emission standards should be set equal to these levels of emissions in order to achieve the optimal levels, hence the plant located in county 1 should be more stringently regulated than the plant located in county 2.

If the emission standards are not adjusted to differences in marginal damage, there is a loss in efficiency. To illustrate this, we assume instead that both plants are regulated to emit the same amount of emissions, e.g., through a common emission standard at the level Q. This implies that the plant in county 1 would emit more than optimal ($Q - e_1$), and that the plant in county 2 would have to reduce their emissions more than optimal ($e_2 - Q$). Such a regulation would lead to a loss in economic efficiency the size of triangle A and B in the Figure 1. As expressed in Oates (2012), the assignment of the responsibility of determining regulation stringency should be assigned to the smallest decision making body whose geographical scope includes the relevant costs and benefits of the regulation. In other words, when a pollutant is associated with regional differences in damage costs the determination of regulatory stringency should be decentralized to regional decision makers.

2.2 Empirical literature: Decentralized emission regulations

A concern raised in the literature about decentralized regulations is that decentralized decision makers may not only take environmental damages into account when determining regional regulation stringency. Wishing to promote economic growth and employment opportunities they may be unwilling to impose more stringent regulations that causes increased costs for existing and potential firms in the region. This could cause a so-called race to the bottom, where decision makers in one region implement relatively less stringent regulations compared to another region. Such a strategic choice of regulatory stringency could potentially undermine the efficiency gains from decentralized regulations. (Oates, 2012)

Several studies have aimed to identify whether decentralized regulations lead to a race to the bottom. A first set of studies examines a US environmental regulation reform in the 1980s, when the regulation of air pollutants went from a centralized to a decentralized level. List & Gerking (2000) use data on state emission levels of NO_x and sulphur dioxide (SO_2) and on emission reduction expenditures by state manufacturing industries over the period 1929–1994 and 1973–1990 respectively. The authors estimate panel data models with state and year fixed effects using either emission levels or emission reduction expenditures as the dependent variable. Finding that emission levels increased and that abatement expenditure decreased after the reform indicates that states imposed less stringent regulations, which in turn implies a race to the bottom. By examining the signs of the year fixed effects after the reform their results indicate that no race to the bottom occurred. Millimet (2003) use the same data but applies another method that allows for a comparison of predicted and observed emission levels and emission reduction expenditures after the reform. The results do not show any indications of increased emission levels, however indicate that emission reduction expenditures increased after the reform. The results therefore imply that, in contrast to their expectations, the decentralized regulation lead to a so-called race to the top.

Another strand of literature examines more directly the existence of so-called strategic interaction, i.e. whether decision makers in one region incorporate the stringency of regulations in other regions into their own decision. Fredriksson and Millimet (2002) use panel data over the period 1977-1994 on two measures of regulatory stringency (an industry adjusted index of relative state environmental emission reduction costs and unadjusted emission reduction expenditures per dollar of manufacturing output by state). By applying a fixed effects model they estimate the effect of the environmental regulatory stringency in nearby states on the regulatory stringency in the own state. Their results indicate that states react to regulation stringency in other states, i.e. they set their regulations strategically. The response is however asymmetric. States tend to increase their environmental regulation stringency if the neighbouring states have comparatively more strict environmental regulations. On the contrary, states seem to be much less responsive to changes when the regulatory stringency in neighbouring states is comparatively more lenient. These findings also suggest a race to the top rather than a race to the bottom (Oates, 2012).

A final set of studies explores the possibility of strategic interaction by performing survey-based studies on decision makers at US state environmental agencies. Engel (1997) and Konisky (2008) use a sample of 80 and 500 decision makers respectively and both studies find that decision makers are concerned about the impact of regulatory stringency on the industry in the state. One concern is that stringent regulations will cause firms to relocate or make new firms establish elsewhere. The latter study also identifies that a large share of the decision makers implement regulations in response to the regulations in other states. Thus these findings imply that decision makers may determine regulations strategically and that it could depend on a concern for the industry in the state.

In sum, the literature just discussed provides contradictory results regarding the existence of a race to the bottom. While the empirical studies find no existence of a race to the bottom, but rather a race to the top, the survey studies seem to provide support for the former.

2.3 Legal framework: NO_x emission standards in Sweden

In Sweden, the boiler specific emission standards for NO_x are specified in the operating licence of the plant where the boiler operates. Depending on the size of the plant, these are determined case-by-case either by one of the 21 regional County Administrative Boards or by one of the five Environmental Courts that cover a geographical area of several counties (SFS 2013:251).[1]

The literature on decentralized environmental regulation described previously was applied on a US context. In comparison to the US federal states, the Swedish County Administrative Boards do not have any power to legislate on any matter. Therefore it can be assumed that considerations of the economic activity and employment may be more of a concern in the US federal states than in the Swedish counties. Furthermore, as summarized in Fredriksson and Millimet (2002), the US pollution control is essentially a combination of standard setting on a centralized level and implementation and enforcement on a decentralized level by the states. Therefore US states retain significant flexibility in the determination of environmental policies, despite the existing federal legislation. In Sweden, however, the environmental law is determined on a centralized level and the County Administrative Boards are only delegated the responsibility to interpret and enforce the law regionally (SFS 2007:825). In that sense, there may be more room for strategic policymaking in consideration of economic activity and employment in the US states compared to the Swedish counties. On the other hand, the fact that Swedish CABs still have some flexibility in the interpretation and enforcement of the law makes the previously described literature on decentralized regulations relevant for the purpose of this thesis.

Important legislative frameworks that the County Administrative Boards must relate to in the determination of NO_x emission standards are some EU directives and the Swedish Environmental Code. Waste incineration plants and large combustion plants are subject to minimum requirements of NO_x emission standards specified in EU directives (e.g., Directive 2000/76/EC and Directive 2001/80/EC). In these EU directives, larger and newer plants as well as plants that use fuels associated with less NO_x emissions are more stringently regulated. Gas fuels are more stringently regulated followed by solid fuels and liquid fuels where the ordering is made, somewhat simplified, after an increasing level of NO_x emissions where gas fuels are associated with the smallest amount of emissions (e.g. SEPA, 2005). If motivated, the regional decision maker can impose more stringent standards than the minimum requirements specified in these directives. These should be determined in line with

[1] After the first of June 2012, only 12 County Administrative Boards instead of 21, are responsible for issuing the operating licences (SFS 2011:1237).

the Environmental Code, which for example states that regulations should be determined after what is environmentally motivated, technically possible and economically reasonable (Miljöbalk, 1998:808).

Operators at combustion plants are required to apply for a new operating licence at the construction of a new plant or when major changes are made to the production (SFS 2013:251). In the application they are required to submit information about the operations at the plant and can propose emission standards that they find are motivated. Furthermore, the application process involves consultation with stakeholders that could potentially be affected by the operations at the combustion plant. The objective of the consultation is for the stakeholders to communicate their opinions about the planned operations and potentially provide ideas on alternative solutions (Miljöbalk, 1998:808).

2.4 Legislation in practice: NO_x emission standards in Sweden

In order to get some insight on how decision makers may interpret the law when determining NO_x emission standards we conducted telephone interviews with in total six decision makers at different County Administrative Boards (the set of questions are found in Appendix A). Though the answers may not be representative for all decision makers at all County Administrative Boards in Sweden, the information still gives some indication on how emission standards for NO_x are determined.

First of all the interviewed decision makers stated that the environmental status in a county affects the way they determine the standards. More specifically, they take the national so-called Environmental Quality Standards (EQS) and the regional and national Environmental Quality Objectives (EQO) into account.[2] To some extent they also consider health effects, however less so in terms of NO_x emissions compared to other types of emissions.

Furthermore they stated that they consider what is technically possible and economically feasible for the plant in order to reduce NO_x emissions. They reasoned that in general, more stringent standards are imposed on larger plants since they potentially have more economic resources to use on emission reduction. Also the type of abatement technology installed and

[2] The EQS are nationally determined and legally binding maximum levels for NO_x concentration in the air (SFS 2001:527). The EQO provide national and regional non-binding targets for environmental quality (Miljömål, 2015b).

the type of fuel used by the boiler affects the decision. Another important aspect is the geographical location of the plant. Generally, more stringent standards are imposed on plants located where relatively more individuals are exposed to the emissions.

The interviewees further stated that the application from the plant, including the suggested emission standards, is important. However, each decision maker always considers whether the suggested emission standards are reasonable or not. In order not to distort the competitiveness, they usually compare emission standards of boilers with similar preconditions (in terms of for example size and sector classification) in other counties when determining emission standards for boilers in the own county. One of the decision makers also implied that boilers in the power and heat sector have traditionally been more stringently regulated than boilers in the other sectors.

Finally some interviewees stated that boilers in the NO_x charge system[3] are treated differently. However we received contradictory statements on the effect. One interviewee stated that it is easier to impose more stringent standards on boilers taking part of the NO_x charge system since the plants are more positive to reduce emissions due to the monetary incentive provided by the NO_x charge. Another stated that due to an already high regulatory burden on these plants, the emission standards imposed are less stringent for boilers in the NO_x charge system.

2.5 Hypotheses: Determinants of NO_x emission standard stringency

Following the discussion about the theory of optimal emission levels, empirical literature on decentralized emission regulations and the legal framework and practice, we hypothesize that the stringency of the emission standards is determined by certain characteristics at county, plant, and boiler level.

[3] The NO_x charge is a market based instrument implemented in 1992. It was implemented as a complement to the emission standards in the operating licences in order to accelerate the emissions reductions of NO_x from combustion plants. Boilers that produce more than 25 GWh energy per year are included in the system. It consists of a charge with return to plants with lower emissions than the average plants included in the system. (SEPA, 2012)

2.5.1 County level

In accordance with environmental economics theory and the Swedish legal framework, we hypothesize that decision makers impose more stringent emission standards in counties where the NO_x associated environmental damages are more severe.

However, as suggested by the theoretical and empirical literature on decentralized emission regulations, the decision makers may also consider economic activity and employment. We therefore hypothesize that decision makers impose less stringent standards in counties where there is a higher concern for the economic activity and employment.

As implied by Perino and Talavera (2014), regulatory stringency may increase with the demand for environmental quality. We argue that the demand for environmental quality increases with the environmental awareness and that there are two reasons for why this relationship could be observed in the Swedish counties. First, a higher environmental awareness may lead to that more stakeholders are involved in the consultation part of the operating licence application process and suggest more stringent standards. Second, due to the public opinion, plants located in counties with higher environmental awareness may be more acceptant to more stringent standards. Therefore we hypothesize that decision makers impose more stringent standards in counties where the environmental awareness is higher.

2.5.2 Plant level

As suggested by Ghosal et al. (2014), plants that are more important as a local employer, suggesting a higher bargaining power, may be subject to less stringent regulations. Therefore we hypothesize that plants with a higher bargaining power vis-à-vis the decision maker obtain less stringent standards.

From interviews with decision makers at the CABs it was suggested that larger plants are generally more stringently regulated following what is economically reasonable to impose. We therefore hypothesize that larger plants obtain more stringent standards.

Also in line with statements in the interviews, we hypothesize that plants located in areas where relatively more individuals are exposed to the emissions obtain more stringent emission standards.

2.5.3 Boiler level

As described for example in SEPA (2005), larger boilers (in terms of installed capacity) generally have better combustion conditions and can have more advanced abatement technology installed which enables larger emission reductions. In line with reasonability and feasibility arguments, we therefore hypothesize that larger boilers obtain more stringent emission standards than smaller boilers.

In the EU directives for boilers located at waste incineration, and large combustion plants it is specified that gas fuels (that are associated with relatively less NO_x emissions) are more stringently regulated than solid and liquid fuels (that are associated with relatively more NO_x emissions). This relates to that a larger share of emission reduction is achievable in boilers that use less NO_x intensive fuels. Therefore we hypothesize that boilers that use relatively less NO_x intensive fuels are more stringently regulated.

Lastly, since abatement technologies enable larger emission reductions (e.g., SEPA, 2005), we hypothesize that boilers that have any type of abatement technology installed obtain more stringent standards.

3. Data

This section describes the selection of variables included in the empirical analysis and provides descriptive statistics.

3.1 Data selection

We have obtained data on the dependent and explanatory variables from various sources. The dependent variable (the boiler specific emission standards) was obtained from a dataset developed in the years 2013-2014 within the Optimal Regulation of Multiple Pollutants (ORMP) project at the University of Gothenburg. It includes boiler specific emission standards (so-called Emission Limit Values, ELVs), specified in the operating licences of combustion plants, obtained between the years 1992 and 2012.[4] These are expressed in different units and in order to perform our empirical analysis we only include emission

[4] The ORMP dataset includes 827 boilers. The total number of boilers with emission standards from the operating licences is unknown since there is no national register on this, however we find it reasonable to assume that the ORMP dataset has included almost all of them. The missing boilers may be recovery boilers in the pulp- and paper industry or small boilers that produce less than 25 GWh energy per year.

standards expressed in a common unit. Fortunately about 77 percent of the ELVs are expressed in one common unit, namely in mg NO_x per MJ added energy.[5]

County level variables were collected from different sources. A variable for the ambient NO_x concentration in a county was obtained from the IVL Air Quality Database (IVL, 2015). It includes data for most counties and years between 1992 and 2012.[6] Data for the unemployment level and the share of votes for the Green Party in a county was obtained from Statistics Sweden (SCB, 2015). A variable for the share of employees per sector per county was also obtained from Statistics Sweden, however this is not publically available.

Boiler level explanatory variables were obtained from a panel of boilers that have been part of the NO_x charge system at least one year between 1992 and 2012, collected by SEPA. It includes information about the size of the boiler (in terms of installed capacity), whether it has any abatement technology installed and the type of fuel it uses.[7]

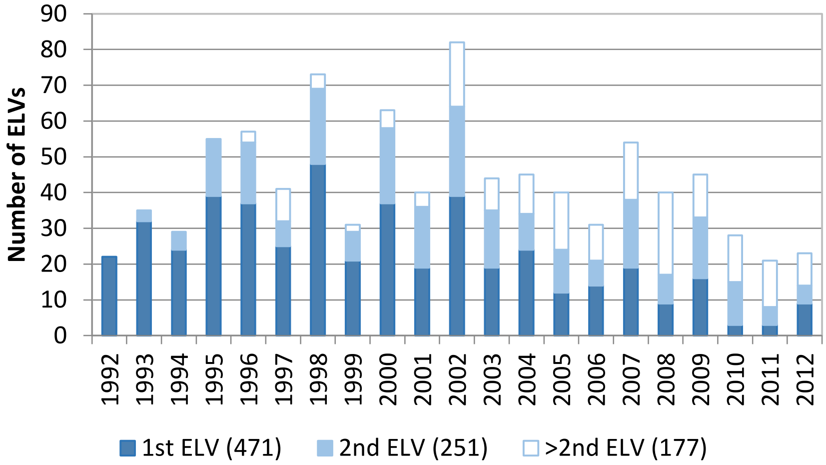
Our final sample consists of 471 boilers that have been part of the NO_x charge system at least one year. It includes boilers that operate in the power and heat, pulp and paper, wood, food, metal, and chemical sectors. Between the years 1992 and 2012, they have in total obtained 899 new ELVs expressed in mg NO_x per MJ added energy. The sample is an unbalanced panel, where boilers are observed the year that they obtain a new emission standard from the operating licence of the plant. This is visualized in Figure 1 below. From Figure 1, we see that a specific boiler could appear for the first time in the sample any of the years between 1992 and 2012. For example in 1992 about 20 boilers obtained their first new ELV and in 2012 about 10 boilers obtained their first new ELV. At the same time, in 2012 about 10 other boilers obtained their third or (at most) eighth ELV.

[5] Following praxis by SEPA (1995), we converted 9 percent of the Emission Limit Values expressed in mg NO_x per nm^3 into mg NO_x per MJ added energy. Thereafter 77 percent of the ELVs are expressed in mg NO_x per MJ added energy, 10 percent in ton NO_x per year, 5 percent in various other units and 8 percent are missing. The share of ELVs per sector expressed in mg NO_x per MJ added energy is 90 percent in power and heat, 99 percent in food, 82 percent in wood, 60 percent in metal, 38 percent in pulp and paper and about 26 percent in chemical.

[6] In some counties (Södermanland, Kalmar, Gotland, Blekinge and Dalarna) the information is missing for between 9 and up to 16 of the 21 years of our data. The information is missing because not enough statistical information about the concentration has been provided to the database.

[7] These variables are available for about 70 percent of the boilers that have been part of the NOx charge system at least one year. We complemented information about the size for 19 boilers from environmental reports of the plants.

Figure 1. Number and order of new Emission Limit Values per year (N=899)



Some boilers have only obtained one new ELV during the whole 21 year period. For the boilers that have received more than one, the number of years between the new ELVs varies. Some boilers have obtained a new ELV with only one year in between but on average the number of years in between is larger. For example, between the years 1992 and 2003, the boilers have on average obtained a new ELV every 8th year.

The reason why some boilers appear more frequently than others, i.e. why some plants obtain a new operating licence more often, is unobserved to us, however we identify that there may be several reasons for this.[8] Furthermore, just because a new licence is obtained does not necessarily mean that the boiler specific ELV has been changed or even been considered for a change. However we cannot rule out that the decision maker has made a consideration of the relevance of the ELV each time that an operating licence is revised.

3.2 Descriptive statistics

In the sample of 471 boilers, the counties with the largest numbers of boilers are Västra Götaland, Skåne and Stockholm with 81, 72 and 65 boilers respectively. Gotland, Jämtland and Uppsala are the counties with the fewest number of boilers with only 1, 3 and 7 boilers respectively. About 76 percent of the boiler observations operate in the power and heat sector

[8] From communication with decision makers at the CABs and from the legislation, we find that the reason why a new operating licence is obtained may be due to that (1) the plant is being built, (2) major changes to the production or technology at the plant is made, (3) the previous operating licence is too old (usually they should be changed at least every tenth year), (4) the regulating authority finds that the operating licence should be updated, (5) the plant has appealed the previous operating licence, (6) another stakeholder has appealed the previous operating licence or (7) a change has been made in the previous licence.

and about 11 percent in the pulp and paper sector whereas the rest operate either in the wood, food, metal, or chemical sector.

Table 1 below presents descriptive statistics for the included variables. The leftmost column shows the level for which the variable is described. These include county, plant and boiler level variables, as well as control variables for differences in the specification of the ELVs. After the table, the descriptive statistics are discussed separately for these categories.

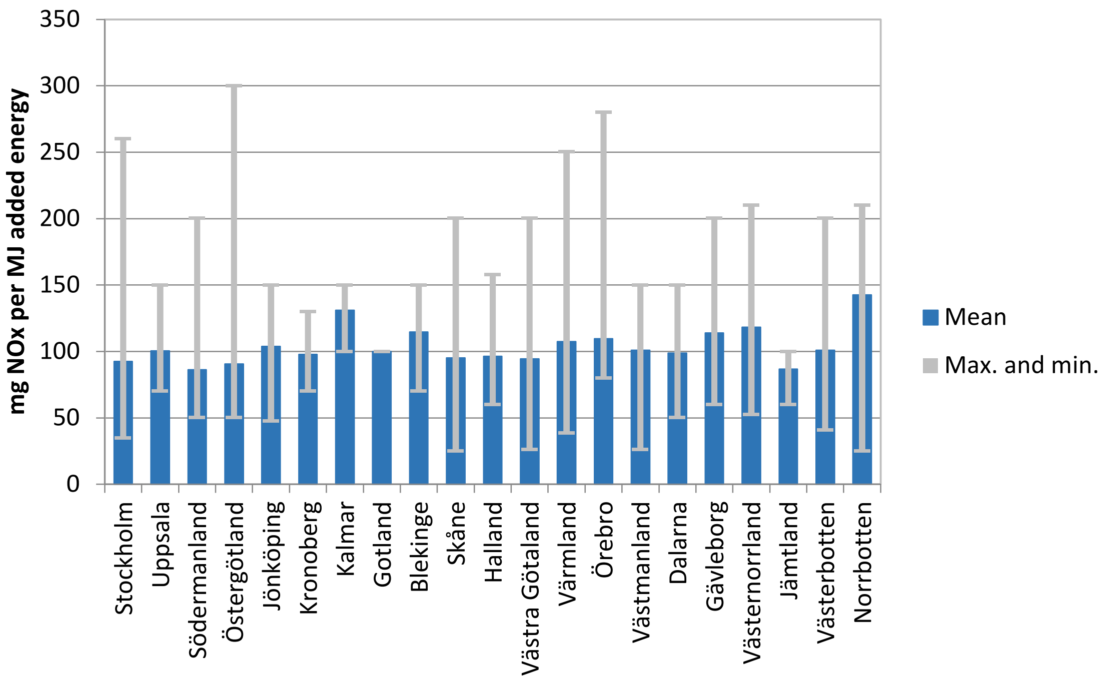
Table 1. Descriptive statistics (N=899)

	Variable	Description	Mean	Std. Dev.	Min.	Max.
Dep.	ELV	Boiler specific ELV measured in mg NOx per MJ added energy	99.57	37.33	25.00	300
County	nox_conc	Average wintertime urban NOx concentration in the air measured in µg/m^3	15.62	4.08	7.15	29.00
	unempl	Share of unemployed individuals of all individuals in the working force (%)	6.65	1.94	2.47	11.83
	gp_votes	Average share of votes out of all valid votes for the Green Party in the general election (%)	4.25	0.93	1.99	7.58
Plant	empl_sector	Share of employees per sector out of all employed in the county (%)	0.99	0.95	0.21	5.47
Boiler	size	Installed boiler effect in MW	61.79	97.09	2.50	799
	techinst	1 if the boiler has any abatement technology installed; 0 otherwise	0.58	0.49	0	1
	liquidfuel	1 if the ELV is determined for liquid fuel; 0 otherwise	0.28	0.45	0	1
	solidfuel	1 if the ELV is determined for solid fuel; 0 otherwise	0.25	0.43	0	1
	biofuel	1 if the ELV is determined for bio fuel; 0 otherwise	0.35	0.48	0	1
	gasfuel	1 if the ELV is determined for gas fuel; 0 otherwise	0.12	0.33	0	1
ELV	yearlymean	1 if the ELV is expressed as a yearly mean; 0 otherwise	0.57	0.50	0	1
	othermean	1 if the ELV is expressed as less than a yearly mean; 0 otherwise	0.26	0.44	0	1
	unspecmean	1 if the ELV is expressed as an unspecified mean; 0 otherwise	0.17	0.38	0	1
	bindingtype	1 if the ELV is expressed as binding; 0 otherwise	0.29	0.45	0	1
	nonbinding	1 if the ELV is expressed as non-binding; 0 otherwise	0.53	0.50	0	1
	unspectype	1 if the ELV is neither expressed as binding or non-binding; 0 otherwise	0.18	0.38	0	1

3.2.1 Dependent variable

The dependent variable is the boiler specific ELV expressed in mg NO_x per MJ added energy (mg/MJ). As can be seen in Table 1 above, the average ELV stringency for all boiler observations varies between 25 and 300 mg/MJ, with a mean of about 100 mg/MJ. Figure 2 below visualizes the variations in ELV stringency both between and within counties.

Figure 2. Variation in ELV stringency between and within counties (N=899)



From Figure 2, we observe two things. First of all there seems to be some variation in the mean ELV stringency between counties. Boilers in Norrbotten seems to be most leniently regulated with a mean of about 140 mg/MJ, whereas boilers in Södermanland seems to be most stringently regulated with a mean of about 85 mg/MJ. Secondly we observe that there is a lot of variation in the stringency within the counties as well. In Östergötland, for example, the stringency ranges between about 50 and 300 mg/MJ. The smallest variation in stringency is observed in Gotland and Jämtland, however these are also the counties with the fewest number of observations.

In Appendix B, we show a figure that illustrates the mean ELV stringency between the years 1992–2001 and 2002–2012 separately. It indicates that the mean ELV stringency has increased in the latter period in most counties.

3.2.2 County level variables

As a proxy variable for the environmental status in a county, we use the average urban wintertime concentration of NO_x expressed in µg NO_x per m^3 (µg/m^3).[9] We argue that it is a good proxy variable since it captures differences in the environment's and people's exposure to NO_x emissions. However, a better variable would have been one that captures the resilience of the environment, but no such data was available. From Table 1, we observe that the ambient NO_x concentration for the boiler observations ranges between about 7 and 29 µg/m^3, with a mean of about 16 µg/m^3.[10]

In an attempt to capture the concern for economic activity and employment in the county, we use the unemployment level measured as the share of unemployed of all individuals in the working force in the county. We chose the unemployment level instead of for example the Gross Regional Product (GRP) per capita since we expect the decision maker to be more concerned about employment than the GRP in the county and hence, we consider employment level to be a more precise measure. The mean unemployment level for the boiler observations is about 7 percent. The lowest unemployment level is 2.5 whereas the highest is about 12 percent.

As a proxy for the environmental awareness in a county, we use the average share of votes for the Swedish Green Party in the general election. The variable is created taking the average share of votes across the municipalities in each county. For the years when there has not been an election, we use the share of votes from the previous election. We argue that this is the best available proxy for environmental awareness since voting for the Green Party could indicate that an individual is more aware of environmental questions. However it can of course be questioned whether it actually captures what we intend, since individuals may vote strategically rather than in accordance with their environmental concern in the general election. We argue though, that it is reasonable to assume that the share of votes on the Green Party is correlated with the level of general environmental awareness and hence that we

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[9] Per definition it is expressed in µg NO_2 per m^3, however since NO_x refers to both nitric oxide (NO) and nitrogen dioxide (NO_2) we use NO_x as the notation for this variable.

[10] We can relate the magnitudes to the Swedish Environmental Quality Standards, where the binding upper limit for the ambient NO_2 concentration is 40 µg/m^3 as a yearly average (SEPA, 2014).

capture the intended effect. The share of votes for the Green Party ranges between about 2 percent to about 7.6 percent, with a mean of about 4.3 percent.

3.2.3 Plant level variable

As a variable intended to capture the potential bargaining power of a plant, we include the share of employees per sector out of all employed in the county. The assumption is that in counties where the sector in which the plant operates is of relatively large importance as an employer, the plant has a higher bargaining power vis-à-vis the decision maker. The importance of a single plant would have been a more direct measure, however it was not possible to use due to lack of data. From Table 1, we see that the mean share of employees per sector per county is about 1 percent and that it varies between about 0.2 percent of all employed and about 5.5 percent of all employed for the boiler observations.

3.2.4 Boiler level variables

From Table 1, we see that the size of the boilers vary a lot, ranging from 2.5 MW to 799 MW. In the analysis, we divide the size into quartiles.[11] Furthermore, we see that about 60 percent of the boiler observations have some abatement technology installed.[12] We separate fuels following categorization made in the EU Directive (Directive 2001/80/EC) into liquid, solid, bio and gas fuels. We can see that about 28 percent of the boiler observations have the ELV determined for the most NO_x intensive fuels, i.e. liquid fuels. The most common fuel for which the ELV is issued is bio fuel (35 percent) and about 25 percent have the ELV issued for solid fuel. About 12 percent have the ELV determined for the relatively least NO_x intensive fuels, i.e. gas fuels.

3.2.5 ELV control variables

In addition to the explanatory variables, we include ELV control variables. These are characteristics defined in the ELV itself and include whether the ELV is expressed as a yearly mean or not and whether it is a binding type of ELV or not. ELVs that are defined as yearly means are on average more strict than ELVs defined as monthly or daily means, since emissions can fluctuate more during a shorter period. Furthermore, binding standards (in

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[11] The first quartile includes boilers of a size smaller than 13 MW, the second for size between 13 and 29 MW, the third between 30 and 75 MW and the last for boilers larger than 75 MW

[12] The abatement technology installed can either be a post-combustion technology, a combustion technology or both types.

terms of that sanctions will be imposed if they are violated) will on average be less strict than non-binding standards. About 57 percent of the ELVs are expressed as yearly means, whereas about 26 percent are expressed as monthly or daily means and about 17 are unspecified. The majority of the ELVs are not binding (53 percent) whereas a large share (29 percent) are. For about 18 percent of the ELVs, the type is unspecified.

4. Empirical analysis

In this section, we present our empirical model and motivate the estimation technique to use. We also present our empirical results.

4.1 Empirical model specification

In order to identify the determinants of NO_x emission standard stringency, we estimate the following model:

$$\mathrm{ELV}_{\mathrm{it}} = \alpha + \beta \mathrm{nox\_conc}_{\mathrm{jt}} + \beta \mathrm{unempl}_{\mathrm{jt}} + \beta \mathrm{gp\_votes}_{\mathrm{jt}} + \beta \log(\mathrm{empl\_sector}_{\mathrm{kjt}}) + \mathbf{X}_{\mathrm{it}}\beta + \mathbf{W}_{\mathrm{it}}\beta + \beta \mathrm{year}_{\mathrm{it}} + e_{\mathrm{it}} \quad (1)$$

Where the subscript *j* indexes a county, *k* indexes a sector and *i* indexes a boiler. The dependent variable is the boiler specific ELV expressed in mg NO_x per MJ added energy. The main determinants of interest are the county level variables for the ambient NO_x concentration ($\mathrm{nox\_conc}_{jt}$), the unemployment level (unempl_{jt}), the share of votes on the Green Party ($\mathrm{gp\_votes}_{jt}$) and the plant level variable for the share of employees per sector per county ($\mathrm{empl\_sector}_{jt}$). The latter is used in its logarithmic form in order to reduce the potential influence of extreme values.

The vector $\mathbf{X}_{\mathrm{it}}$ represents boiler level variables, including dummy variables for the size of the boiler, the type of fuel used for which the ELV is determined and whether it has any abatement technology installed. The vector $\mathbf{W}_{\mathrm{it}}$ includes ELV control dummy variables for whether the ELV is expressed as a yearly mean or not and whether the ELV is binding or not. Finally we also include a time trend (year_{it}), to control for that the stringency of the ELVs are likely to have increased over the years due to increased stringency in legislation.

We estimate our model using pooled OLS. It provides unbiased and efficient results if the assumptions of exogeneity, no heteroscedasticity and no autocorrelation are fulfilled (e.g., Wooldridge, 2002). The exogeneity criterion in panel data estimations relies heavily on that there should be no unobserved time-invariant boiler characteristics omitted from the model that are correlated with any of the included regressors. Since boilers are machines we argue that there are practically no such time-invariant omitted variables. Potentially one such variable could be the age of the boiler. However, since boilers can be rebuilt in terms of size, technology and the fuel used, we argue that the age of the boiler is uncorrelated with the included regressors.

Furthermore the efficiency of OLS relies heavily on the assumption of no heteroscedasticity and no autocorrelation. The structure of our data is likely to violate both and in order to obtain reliable results we need to use robust-clustered standard errors. We argue that the error terms are correlated across boilers located at the same plant and therefore cluster the standard errors at plant level.

4.1.1 Potential problems with the model specification

Important to discuss are the potential problems of simultaneous causality and omitted variables bias that the model specification may give rise to. In our analysis we hypothesize that the ambient NO_x concentration has a causal impact on the ELV stringency and not the other way around. Generally, however, it is not unreasonable that the causality may run the other way, i.e. that the stringency of the ELV affects the emissions from a boiler and thereby the NO_x concentration in a county. We would however argue that the latter is not very likely since the emissions from one single boiler probably has a minor effect on the ambient NO_x concentration, due to the many other sources of NO_x emissions in a county (for example the transport sector and plants located outside of the county). A similar argument can be made for the unemployment level in a county. The emission standard stringency could cause large costs to the plants and affect employment decisions and thus the unemployment level in the county. However since the regulated plants present only a small share of the overall working force in the county, we do not think that this reversed relationship is plausible.

Due to lack of data, we omit several plant level variables that we previously identified to potentially be important determinants of NO_x emission standard stringency. These include the geographical location and the size of the plant. Since the location of the plant is a time-invariant variable, one way to take this into account in our model would be to include a dummy variable for each plant. However since some plants are only observed one year we cannot use this approach. We assume that the closer the plant is located to areas where many individuals are exposed to the emissions, the more stringent ELVs are issued for boilers that operate at the plant. At the same time, these boilers may be the ones that are more likely to have any abatement technology installed. Thus the omission of this variable is likely to cause the coefficient of the technology variable to be downward biased. Furthermore, larger plants (both in terms of installed capacity and economic turnover) are expected to be subject to more stringent emission standards. At the same time, also these boilers are more likely to have any abatement technology installed. Consequently, the omission of these variables is also likely to bias the technology variable downwards.

Another potential problem is that the reason why some boilers appear more frequently in the sample than others, i.e. why some plants obtain a new operating licence more often, is unobserved to us. This omission would be problematic if the reason why some boilers appear more frequently is systematic, for example if larger plants are more likely to apply for a new operating licence more frequently and at the same time are more likely to bargain for less stringent standards. However, we find two arguments for that there is no such systematic reason. First because the average number of years between obtaining a new licence is high which implies that it follows the expiration of a previous licence.[13] Second, because there are several various reasons why a new operating licence is obtained (see footnote 9), which decreases the probability of the reason being systematic.

4.2 Empirical results

The main results from the regression analyses are reported in Table 2 below. All estimations are made using pooled OLS, with the standard errors clustered at plant level. The results remain robust to an alternative specification of the dependent variable.[14]

Column 1 presents the results from when the model is applied to all boilers in the sample. As was indicated in an interview with one of the decision makers at the County Administrative Boards, boilers in the power and heat sector may traditionally have been more strictly regulated than boilers in the other sectors. Therefore we also estimate the model for boilers in the power and heat sector and all other sectors (i.e. the pulp and paper, wood, food, metal, and chemical) separately. Column 2 and 3 presents these results. A negative sign of the coefficient indicates that the determinant makes the ELV more stringent.

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[13] The average number of years between obtaining a new operating licences in our sample is about eight, whereas licences are generally valid for ten years (information received from personal communication with an administrator at the County Administrative Board 2015.04.23)

[14] In order to see if our results are affected by the large spread in the dependent variable, we also perform the estimations with the dependent variable in its logarithmic form (see Appendix C Column 4 and 5 for results). We find no meaningful difference in the results implying that our results are robust.

Table 2. Results

Variable	(1) All sectors	(2) Power and heat sector	(3) Other sectors
	Dependent variable: ELV		
nox_conc	-0.869**	-0.949**	-0.659
	(0.386)	(0.451)	(0.675)
unempl	2.309**	2.590**	1.077
	(0.954)	(1.103)	(1.743)
gp_votes	-5.092**	-3.920*	-8.271*
	(2.097)	(2.342)	(4.246)
log(empl_sector)	2.911	4.518	9.744***
	(2.617)	(6.382)	(3.237)
techinst	-4.866	-2.505	-4.332
	(3.594)	(4.602)	(5.769)
size 13–29 MW[a]	-9.229**	-7.292	-18.41**
	(4.289)	(5.412)	(7.281)
size 30–75 MW[a]	-17.44***	-18.83***	-22.73**
	(5.830)	(6.765)	(8.921)
size > 75 MW[a]	-17.18***	-20.53***	-17.58*
	(5.599)	(6.766)	(8.940)
liquidfuel[b]	44.12***	42.43***	50.29***
	(6.390)	(7.992)	(10.90)
solidfuel[b]	33.44***	27.00***	47.99***
	(5.449)	(6.626)	(10.83)
biofuel[b]	33.85***	29.53***	34.99***
	(4.452)	(4.981)	(9.515)
year	-1.471***	-1.706***	-0.416
	(0.361)	(0.531)	(0.525)
Constant	3,043***	3,512***	940.2
	(719.1)	(1 053)	(1 048)
Observations	899	685	214
Boilers	471	352	119
ELV control variables	Yes	Yes	Yes
R-squared	0.212	0.212	0.345

Note: The standard errors are clustered at plant level. Included in all estimations, but not reported, are the ELV control variables. The results can be found in Appendix C. [a]Size < 13 MW is the reference dummy variable. [b]Gas fuel is the reference dummy variable. *** indicates significance at the 1% level,** indicates significance at the 5% level; * indicates significance at the 10% level.

The results in Column 1 indicate that the county level variables for the NO_x concentration (nox_conc), the unemployment level (unempl) and the share of votes for the Green Party (gp_votes) are statistically significant determinants of ELV stringency. Also, the boiler level dummy variables for the size and type of fuel used seem to be important determinants. Furthermore the coefficient of the year variable (the time-trend) is negative and significant.

The results remain robust for the subsample of boilers in the power and heat sector. However, for the subsample of boilers in all other sectors, the results are different, indicating that the determinants of ELV stringency may be different between the sectors. Therefore, we will focus on interpreting the results for the sectors separately. We start off by interpreting the coefficients of the county, and plant level variables and thereafter move on to the boiler level variables. We end with a discussion about the time-trend.

4.2.1 County and plant level determinants for boilers in the power and heat sector

By first looking at the results from the estimation including only boilers in the power and heat sector (Column 2), we observe that the ambient NO_x concentration in the county seem to have a significant effect on the ELV stringency. The magnitude of the coefficient indicates that as the NO_x concentration increases by one standard deviation (i.e. 4.08 µg/m3), there is an increase in the ELV stringency of about 3.9 mg/MJ on average. This effect is rather small considering that the mean value of ELV is about 100 mg/MJ but the significance implies that the variable is an important determinant. The effect is in line with our hypothesis. According to the Swedish Environmental Code, the regulations should be determined after what is environmentally motivated, implying that boilers that operate in counties with relatively more severe environmental damages associated with NO_x emissions should be more stringently regulated.

On the other hand, we find that the unemployment level in a county seem to cause a significant, but rather small, decrease in ELV stringency. The magnitude of the coefficient indicates that an increase in the unemployment level by one percent leads to a decrease in ELV stringency of about 2.6 mg/MJ on average. This is in line with our hypothesis that the decision maker may not only care about the environmental status in a county but also about the economic activity and employment and therefore impose less stringent standards.

We furthermore observe that the share of votes for the Green Party in a county seem to be a determinant of ELV stringency. As the share of votes increase by one percent, the ELV becomes about 3.9 mg/MJ more stringent on average. This is also in line with our expectations. We argued that in counties where the environmental awareness is higher, the stringency of the ELV may increase either because stakeholders affected by the emissions from the plant may be more involved in the determination of the ELV or that plants may be more acceptant to more stringent standards.

4.2.2 County and plant level determinants for boilers in the other sectors

Moving on to the estimation results for the subsample of boilers in all other sectors (Column 3), we find that the share of votes for the Green Party in a county and the share of employees per sector per county (empl_sector) seem to have a significant effect on the stringency of the ELVs. In contrast to the results for the boilers in the power and heat sector, the NO_x concentration and the unemployment level in a county do not seem to be statistically significant determinants of ELV stringency. However, we should interpret these results with caution because the number of boilers in these other sectors are rather small, which potentially could affect the validity of the results.

The share of votes for the Green Party in a county seems to have a slightly larger impact on the stringency of the ELVs for boilers in other sectors than for those in the power and heat sector. An increase in the share of votes on the Green Party by one percent implies an increase in the ELV stringency by about 8.3 mg/MJ.

Furthermore a one percent increase in the share of employees per sector seem to make the ELV 0.1 mg/MJ less stringent on average. This effect is small in magnitude but gives an indication that this variable may be an important determinant due to the statistical significance. That the ELV stringency may decrease with the share of employees in a sector is in line with our hypothesis. A larger share of employees in a sector implies that the sector is an important employer in the county. From this, we argue that plants in an economically more important sector have a higher bargaining power vis-à-vis the decision maker and therefore can bargain for less stringent ELVs.

4.2.3 Boiler level determinants

Moving on to the boiler specific determinants we find, as expected, that the size of the boiler and the type of fuel used seem to be important determinants of ELV stringency. The results remain fairly robust in all estimations.

Boilers with an installed capacity below 13 MW (i.e. the smallest boilers) is the reference dummy for the size dummy variables. The results indicate that larger boilers on average obtain more stringent ELVs. However there does not seem to be a strict increase in ELV stringency with the size of the boiler, but rather some threshold in the boiler size after which the ELVs becomes more stringent. From Column 2, we observe that boilers in the power and heat sector with an installed capacity above 30 MW on average obtain between 18.8 and 20.5 mg/MJ more stringent ELVs compared to boilers with an installed capacity less than 13 MW. For the other sectors, the threshold is found to be at 13 MW installed capacity, after which larger boilers obtain about 18.4, 22.7 or 17.6 mg/MJ more stringent emission standards on average for increasing size categories respectively. The results are in line with our expectations that larger boilers on average obtain more stringent regulations since they in general have better capacity to reduce emissions.

Using the least NO_x intensive fuels (gas fuel) as the reference dummy variable, we observe that the more NO_x intensive fuels (liquid fuel, solid fuel and bio fuel) are on average less strictly regulated. For boilers in the power and heat sector, liquid fuel is on average 42.4 mg/MJ less strictly regulated than gas fuel. For boilers in the other sectors the difference is even larger, where liquid fuel is on average 50.3 mg/MJ less strictly regulated than gas fuel. Boilers in the power and heat sector that use solid or bio fuel seem to obtain on average between 27 and 29.5 mg/MJ less strict ELVs than boilers that use gas fuel. Boilers in the other sectors seem to obtain between 34 and 48 mg/MJ less strict ELVs if they use bio or solid fuel rather than gas fuel. These results are in line with our expectations since fuels associated with less NO_x emissions are more stringently regulated in the legislative framework.

Neither of the estimations indicates a significant effect on the ELV stringency from having a NO_x abatement technology installed in the boiler. This is unexpected since abatement technology was explicitly defined as an important determinant by the interviewed decision makers at the CABs. However, the reason why we do not observe a significant effect may be because both the abatement technology required and the ELVs may be determined simultaneously in the operating licence of the plant. Hence, it may be that the ELV that we observe is determined for a technology that is not yet installed at the boiler.

4.2.4 Time trend

The last result to discuss is for the year variable i.e., the time trend. We observe that the coefficient is negative and statistically significant in the estimation for boilers in the power and heat sector. The magnitude of the coefficient indicates that the average ELV stringency increases by 1.7 mg/MJ per year. The finding is in line with our expectations since we argued that the stringency of the environmental legislation is likely to have increased over time and that the average ELV stringency should follow this trend.

The coefficient is smaller in magnitude and not statistically significant in the estimation for boilers in the other sectors, which implies that there is no clear time-trend in the ELV stringency for these boilers. One possible explanation for this is that boilers in the power and heat sector have traditionally been more stringently regulated (as was implied in the interview with one of the decision makers at the County Administrative Boards). Therefore over time, regulation of these boilers may have increased relatively more in stringency compared to boilers in the other sectors. Another possible explanation is the small sample size of boilers in the other sectors, which may entail too little variation in ELV stringency to capture the time trend.

5. Conclusions

The main objective of this thesis has been to identify the determinants of NO_x emission standard stringency for boilers at Swedish combustion plants. Due to lack of data this has not been possible before. By using a recently collected dataset from the ORMP project at the University of Gothenburg, we are provided with an opportunity to fill this gap. Our sample consists of 471 boilers that operate in the power and heat, pulp and paper, wood, food, metal, and chemical sectors that are observed between the years 1992 and 2012.

As has been indicated by the regulated plants, the stringency of the emission standards may vary between counties (SEPA, 2012). By presenting the average standard stringency per county in Figure 2, we show that there does seem to be some variation in stringency between counties but also a lot of variation within the counties. In order to understand the causes of variation, we perform regression analyses using pooled OLS. We hypothesize that different variables at county, plant, and boiler level may be important determinants of emission standard stringency and that these can explain differences in stringency both between and within counties.

Firstly the results suggest that there are some determinants that explain differences between the counties. We find that boilers located in counties with more severe NO_x associated environmental damages obtain more stringent standards. This implies that there could be an efficiency gain from having decentralized case-by-case determined standards rather than a uniform standard. On the other hand, we find that less stringent standards are imposed on boilers in counties where the concern for employment is higher and that more stringent standards are imposed in counties where the environmental awareness among the inhabitants is higher. The last two findings indicate that there may be some space for interpretation of the law which could cause unjustified competitive advantages for plants located in counties where the stringency of the emission standards are more lenient. This suggests that there may be a need for a more uniform enforcement of the environmental legislation across Swedish counties.

A second finding is that the above results may only be valid for boilers that operate in the power and heat sector. We find that the environmental damage and the concern about employment in a county do not seem to be important determinants of emission standard stringency for boilers in the pulp and paper, wood, food, metal, and chemical sectors. Instead we find that plants with higher bargaining power vis-à-vis the decision maker obtain less stringent standards, a finding which further suggests that a more uniform enforcement of the environmental legislation is needed. However, considering the small sample size of boilers in these other sectors the results should be interpreted with caution. Further research is needed to make any detailed conclusions about why the determinants of emission standard stringency may be different between the sectors.

Lastly we find, as expected, that boiler level variables for the type of fuel used and the size of the boiler have a significant and large impact on the emission standard stringency, which can explain the variations in standard stringency within the counties. Boilers that use less NO_x intensive fuels (e.g., gas) are significantly more stringently regulated than boilers that use more NO_x intensive fuels (e.g., oil). There also seems to be a threshold in boiler size after which larger boilers obtain more stringent standards compared to smaller boilers.

Important to emphasize is that these results may only be valid for boilers that have been part of the NO_x charge system at least once. Other potential drawbacks of our study are that we omit plant level explanatory variables such as the geographical location and the size of the plant. Furthermore, we do not identify the reason why some boilers obtain new operating licences (and thereby new emission standards) more often than others, which potentially could be a source of endogeneity. Finally, one can always also discuss whether the variables included actually captures the intended effect, for example a better variable for the environmental damage in a county would be one that identifies the resilience of the ecosystem. These are potential problems or sources of bias to consider in future research on the topic.

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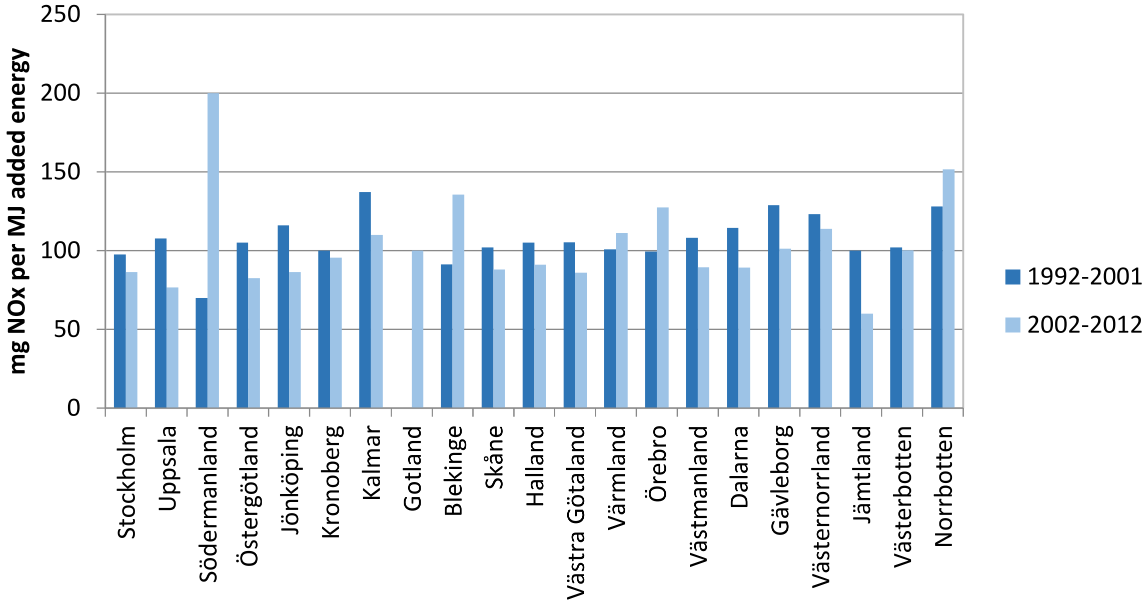
Appendix A

Interview questions to decision makers at the County Administrative Boards

1. Do NO_x emissions have to be regulated in the operating licence of combustion plants?
    - If not; what determines whether NO_x emissions are regulated or not?
2. Which factors affect how you determine the Emission Limit Values for a certain combustion plant?
3. Which type of information do you utilize in order to identify these factors?
4. Do you have any cooperation with other County Administrative Boards in order to reduce the emissions or the environmental problems?
5. To what degree do the County Administrative Board control that the Emission Limit Values are not exceeded?
6. What are the sanctions if a plant exceeds the Emission Limit Values?
7. Do you consider any of the following factors when determining the Emission Limit Values?
    - Environmental Quality Standards (EQS)
    - Action programs
    - Environmental Quality Objectives (EQO)
    - Polluter Pays Principle (PPP)
    - Best Available Technology (BAT)
    - Emission Limit Values in the EU directive of large combustion plants
    - Consultation during the application process
    - Emission Limit Value proposals from the application process
    - Environmental effects
    - Health effects
    - Sectoral classification
    - The size of the plant
    - Emission Limit Values of plants in the same county and in nearby counties
8. Do you have anything to add?
9. What is your opinion about the system?

Appendix B

Average ELV stringency between counties and time periods (N=899)



Appendix C

Results including ELV control variables

Variable	(1) All sectors	(2) Power and heat sector	(3) Other sectors	(4) Power and heat sector	(5) Other sectors
	Dep. var.: ELV			Dep. var.: log(ELV)	
nox_conc	-0.869**	-0.949**	-0.659	-0.00868*	-0.00605
	(0.386)	(0.451)	(0.675)	(0.00482)	(0.00624)
unempl	2.309**	2.590**	1.077	0.0227**	0.0170
	(0.954)	(1.103)	(1.743)	(0.0111)	(0.0163)
gp_votes	-5.092**	-3.920*	-8.271*	-0.0378*	-0.0741*
	(2.097)	(2.342)	(4.246)	(0.0218)	(0.0403)
log(empl_sector)	2.911	4.518	9.744***	0.0565	0.0733**
	(2.617)	(6.382)	(3.237)	(0.0639)	(0.0331)
techinst	-4.866	-2.505	-4.332	-0.0284	-0.0132
	(3.594)	(4.602)	(5.769)	(0.0430)	(0.0546)
size 13–29 MW[a]	-9.229**	-7.292	-18.41**	-0.0934*	-0.184**
	(4.289)	(5.412)	(7.281)	(0.0513)	(0.0748)
size 30–75 MW[a]	-17.44***	-18.83***	-22.73**	-0.235***	-0.238**
	(5.830)	(6.765)	(8.921)	(0.0688)	(0.0919)
size > 75 MW[a]	-17.18***	-20.53***	-17.58*	-0.266***	-0.173*
	(5.599)	(6.766)	(8.940)	(0.0632)	(0.0891)
liquidfuel[b]	44.12***	42.43***	50.29***	0.449***	0.496***
	(6.390)	(7.992)	(10.90)	(0.0840)	(0.109)
solidfuel[b]	33.44***	27.00***	47.99***	0.257***	0.469***
	(5.449)	(6.626)	(10.83)	(0.0765)	(0.109)
biofuel[b]	33.85***	29.53***	34.99***	0.318***	0.372***
	(4.452)	(4.981)	(9.515)	(0.0615)	(0.0936)
othermean[c]	10.20**	13.09**	1.634	0.123***	0.0402
	(4.410)	(5.115)	(7.689)	(0.0469)	(0.0816)
unspecmean[c]	0.156	1.139	2.004	0.0144	0.0618
	(4.665)	(5.751)	(8.062)	(0.0564)	(0.0821)
bindingtype[d]	3.120	2.401	8.043	0.0168	0.0598
	(4.568)	(5.375)	(8.853)	(0.0494)	(0.0868)
unspectype[d]	0.553	-0.613	-0.274	-0.0326	-0.0299
	(5.995)	(6.837)	(10.15)	(0.0634)	(0.107)
year	-1.471***	-1.706***	-0.416	-0.0174***	-0.00447
	(0.361)	(0.531)	(0.525)	(0.00522)	(0.00517)
Constant	3,043***	3,512***	940.2	39.29***	13.49
	(719.1)	(1,053)	(1,048)	(10.37)	(10.31)
Observations	899	685	214	685	214
Boilers	471	352	119	352	119
R-squared	0.212	0.212	0.345	0.276	0.359

Note: The standard errors are clustered at plant level. [a]Size < 13 MW is the reference dummy variable. [b]Gas fuel is the reference dummy variable. [c]Yearlymean is the reference dummy variable. [d]Nonbinding is the reference dummy variable. *** indicates significance at the 1% level,** indicates significance at the 5% level; * indicates significance at the 10% level.