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Department of Economics

Emission Efficiency and the Swedish charge and refund system for nitrogen oxides

- An empricial firm level analysis of the development of NO_X emissions per unit of energy produced, 1992 - 2013

Sofia Larsson

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Sofia Larsson
June 2015

Abstract

According to the recently updated version of the framework of Planetary Boundaries, human society has crossed the sustainable level of four out of nine planetary boundaries. Two of those are beyond the zone of uncertainty and in the zone of high risk of serious impacts on the Earth System. It is an alarming situation. In prevailing economical system one way to handle emission abatement, overconsumption of natural resources and anthropogenic natural degradation is environmental policy.

The purpose of this study is to empirically evaluate whether the environmental policy the charge and refund system for nitrogen oxides on large industrial combustion and energy generating production units in Sweden had an impact on emissions of nitrogen oxides per unit of energy produced at a firm level, sector aggregated as well as on a sectorial analysis. Econometric regression models are used on panel data for 272 firms in seven different sectors covered by the charge and refund system for nitrogen oxides during the period 1992 – 2013 to estimate the effect of the real charge level and the increase in the charge in 2008.

The results from the study finds that in a sector aggregated analysis the estimations is a negative and statistically significant impact on NO_X emissions per produced unit of energy at a firm level for both the real charge as the increase in the nominal charge in 2008. In a sectorial analysis the estimations for the real charge and the nominal increase is negative and statistically significant for the wood industry.

Keywords: charge and refund system, emission abatement, environmental policy, nitrogen oxides, NO_X charge

Table of contents

List of Tables

List of Figures

Abbreviations

Below is a list of abbreviations and technical terms found in the thesis.

CO	Carbon monoxide
CO_2	Carbon dioxide
CPI	Consumer Price Index
GDP	Gross Domestic Product
GWh	Giga Watt Hour
HC	Hydrocarbon
MWh	Mega Watt Hour
NH_3	Ammonia
NO	Nitric Oxide
N_2O	Nitrous Oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
NO_X charge	Nitrogen oxide charge
NO_X emissions	Emissions of nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
PM	Particulate matter
PPP	Polluter Pays Principle
R&D	Research and Development
SEPA	Swedish Environmental Protection Agency
TWh	Terra Watt Hour

1 Introduction

According to the recently updated version of the framework of Planetary Boundaries, human society has crossed the sustainable level of four out of nine planetary boundaries (Steffen et al., 2015). Two of those are beyond the zone of uncertainty and in the zone of high risk of serious impacts on the Earth System. It is an alarming situation and the authors states that "*there is an urgent need for a new paradigm that integrates the continued development of human societies and the maintenance of the Earth system in a resilient and accommodating state*". In prevailing economical system one way to handle emission abatement, overconsumption of natural resources and anthropogenic natural degradation is environmental policy. Command and control policies legislate levels of pollutions firms are allowed to emit and policies as taxes and subsidies give economic incentives to firms and individuals to behave more sustainably. That politicians rely on environmental polices for emission abatement to a large extent is obvious when the revenue from environmental taxes constitutes on average around 2% of GDP in OECD countries (OECD, 2001). This is the case also in Sweden where the value of environmental taxes amounted to 89 064 million SEK in 2013 (SCB, 2015a) which was 2,36% of the Swedish GDP current year. But the question is: are those policies efficient enough in having a real impact on reducing emissions, overconsumption of natural resources and anthropogenic natural degradation? Evaluation of these polices is therefore of major concern. The purpose of this study is to evaluate one such environmental policy, the economic instrument the charge and refund system for nitrogen oxides (NO_X charge) for large combustion plants in Sweden. The NO_X charge is a combination of a tax and a subsidy; taxing production units based on emissions and recharges the same units based on energy output (SEPA, 2015a). Seven different sectors are covered by the charge and refund system for nitrogen oxides; food-, wood- and paper- and pulp industry, chemical production, metal manufacturing, waste incineration and power- and heat generation.

The Swedish NO_X charge have been studied by Höglund-Isaksson and Sterner (2000) where they provide a description of the scheme and an assessment of systems initially effectiveness. Höglund-Isaksson (2005) provides empirical estimates of abatement cost functions for NO_X emissions in three industrial sectors in Sweden and within a theoretical model of NO_X emissions Sterner and Höglund-Isaksson (2006) articulates the empirical findings. Sterner and Turnheim (2009) further test the effectiveness of specific abatement technologies in diminishing emissions under the Swedish charge and refund system for nitrogen oxides. In a European context the French system of air pollution control and its effectiveness have been analysed by Millock and Nauges (2003, 2006) and the Australian NO_X tax scheme have been analysed by Ancev, Betz and Contreras (2012). OECD (2010) provides an overview of a number of cases studies for environmental tax schemes in different countries such as UK, Spain, Korea and Japan where also the Swedish NO_X charge is included.

According to Baumol and Oates (1988) the monetary incentive from an environmental tax should translate into targeted actors implementing abatement measures to diminish their exposure to the tax until the marginal cost of emission abatement is equal to the tax. Höglund (2000) and Höglund and Sterner, (2000) finds that the abatement incentives are practically the same under a charge and refund system as under an equivalent Pigouvian tax when there are a large number of small and competitive firms. Höglund (2000) further states that the abetment cost per kilo NO_X emissions for the firms covered by the charge and refund system for nitrogen oxides in Sweden is approximately equal to the charge level. Therefore firms are theoretically expected to invest in emission abatement until the marginal cost equals the charge level. The question is; does the NO_X charge affect emissions and emission efficiency based on empirically research? A previous econometric study of the charge and refund system for nitrogen oxides is a discussion paper by Wikström (2015) in which no significant effect is found of the increase of the charge in 2008 neither on total emissions nor emission efficiency at a production unit level, neither on a sector aggregated nor as on a sectorial analysis. An evaluation of the increase in the charge level in 2008 by the Swedish Environmental Protection Agency (2012) neither finds any significant effect of the increase in the charge level neither on aggregated emissions nor emission efficiency. Still the system is internationally acknowledged as an efficient policy in terms of emission abatement (Wright and Mallia, 2003), (Sterner and Turnheim, 2009), (OECD, 2013). Cato (2010) also states that a tax and refund system works efficiently in a market with endogenous entry. In a comparison of the Swedish and the French system by Millock, Nauges and Sterner (2004) they find that the design of the Swedish charge and refund system for nitrogen oxides made it more efficient in terms of emission abatement than the French tax-system for nitrogen oxides. In comparison with other OECD countries, Sweden also performs well in terms of NO_X emissions per unit of energy produced (OECD, 2013). Still the industries are competitive on a global market, so it might not be a contradiction between environmental regulation and competitiveness, as Porter and van der Linde (1995) concludes when arguing that stringent, properly designed, environmental standards can trigger innovation that may partially or more then offsets the cost of complying to them and that environmental regulation can increase industrial competitiveness.

Previous econometric studies treat emission efficiency at a production unit level and not at a firm level. Decisions about emission abatement investments are taken by managers, they don't just happen. And it is reasonable to suppose that managers make decisions at the firm level, not the production unit level. The aim of this study is therefore to empirically investigate whether the charge and refund system for nitrogen oxides on large industrial combustion and energy generating production units in Sweden had any impact on nitrogen oxide emissions per unit of energy produced at a firm level. The data, consisting emissions and produced energy at a production unit level, is received from the Swedish Environmental Protection Agency (SEPA) and to estimate the effect of the NO_X charge on emission efficiency the econometric methods pooled, fixed effects as random effects model with panel data is used on a sector aggregated as well as on a sectorial analysis.

The econometrics result from the study finds that in a sector aggregated analysis the estimations from the pooled model is a negative and statistically significant impact on NO_X emissions per produced unit of energy at a firm level for both the real charge as the increase in the nominal charge in 2008. In a sectorial analysis the estimations for the real charge and the nominal increase is negative and statistically significant for the wood industry.

The structure of the thesis starts with a background about nitrogen oxides and the charge and refund system in section 2. Section 3 describes the data, followed by section 4 stating methodology and model. The study ends with section 5 describing results, followed by a discussion and finally section 7 concludes.

2 Background

Below will be given a brief description of nitrogen oxides and the charge and refund system for nitrogen oxides for large combustion plants in Sweden.

2.1 Nitrogen oxides

The term nitrogen oxides refers to a group of compounds denoted by the chemical abbreviation NO_X. Nitrogen is an essential element for all living organisms and is the most abundant gas in Earth's atmosphere. Nitrogen oxides are a group of chemical compounds, among the most important are the gases nitrogen oxide (NO) and nitrogen dioxide (NO_2), that are produced from a reaction between nitrogen and oxygen in the air during combustion, especially at high temperatures, as in engines and power station boilers (OECD, 2013). Main anthropogenic sources of emission are combustion of fossil fuels in automobile engines and power plants (Ahammad, 2013). Emissions from automobiles correspond to about three-quarters of global NO_X emissions. Further sources of NO_X emissions are the industrial sector as refineries and manufacturing facilities and residential sector as gas stoves and home heating units.

During conventional combustion of petroleum or bio-based fuels atmospheric or molecular form of nitrogen is the main source of nitrogen of NO_X formation. In general combustion with biofuel reduces emissions as CO, HC and PM, but causes higher emissions of nitrogen oxides (NO_X). NO_X is generally formed in high temperatures on atmospheric nitrogen and does not come from an impurity in the fuel, for example like sulphur (Sterner and Köhlin, 2003).

2.1.1 Human and environmental impacts of nitrogen oxides

Nitrogen oxides form nitric acid when dissolved in atmospheric moisture, which is a component in acid rain. Nitrogen oxides further contribute to the formation of ground-level ozone, smog, that has a negative impact on vegetation and human health, such as respiratory and cardiovascular problems (OECD, 2013). Specific concentrations of some nitrogen compounds, in principal NO_2, have proven toxic effects. High concentrations can be fatal and low levels have effects on different physiological systems, particularly lung tissue. Long-term exposure of NO_X compounds weakens resistance to respiratory infections (Ahammad, 2013).

Environmental impacts from NO_X emissions are contribution to global warming, since NO is an important component in the formation of the potent greenhouse gas tropospheric ozone (Palash et al., 2013), acid rain in which NO_X constitute a key element and it also hampers plant growth (Ahammad, 2013). It causes acidification of land and water areas, as well as eutrophication of lakes, rivers and seas (Svärdsjö and Gustafsson, 2003). It further can react with other pollutants to form toxic chemicals (Ahammad, 2013).

2.1.2 Nitrogen emissions in Sweden

A large part of Scandinavia has old geological structures with low levels of calcium and due to this low buffering capacity. Sweden has a naturally acidic soil and is therefore sensitive to acid deposition (OECD, 2013). Sweden is one of the countries that have been largely affected by acid rain leading to considerable negative effects on land, lake and forest ecosystems. This is one of the reasons why Sweden has adapted a policy on nitrogen oxide emissions (Sterner and Höglund Isaksson, 2006).

In Sweden around 50 - 60 % of total NO_X emissions originates from the transport sector, or mobile sources. The largest share is from vehicle transportation sector and shipping sector. The industrial sector and working machines further contributes with a significant share. Below is a figure of total NO_X emissions in Sweden.

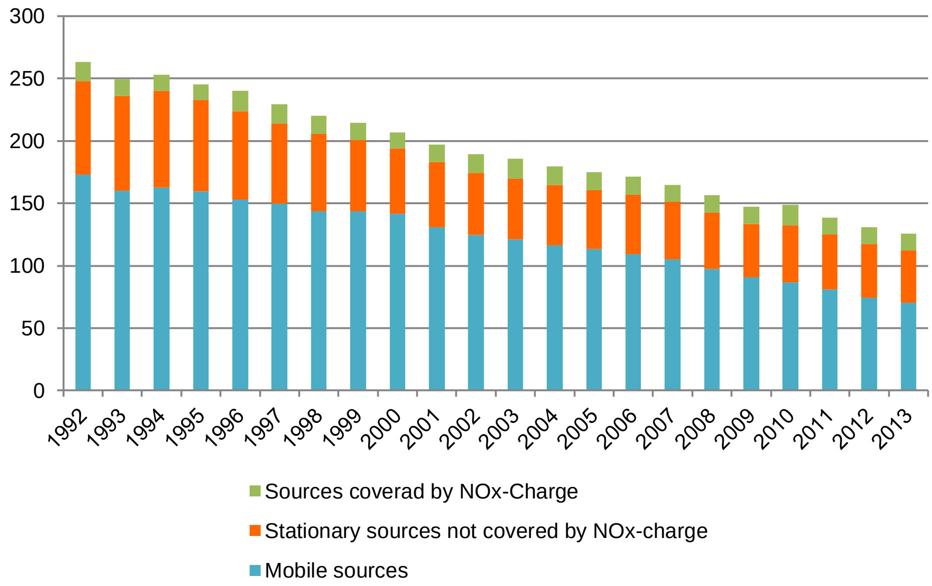

Figure 2.1 Total airborne NO_X emissions in Sweden 1992 -2013, thousands ton
Source: Swedish Environmental Protection Agency (SEPA, 2015)

Mobile sources have decreased NO_X emissions by 59% between 1992 and 2013, and the share of mobile sources has been decreasing from 66% to 56% of total NO_X emissions. Stationary sources have decreased emissions by 39%, and the share of stationary sources has increased from 34% to 44% of total NO_X emissions. Total NO_X emissions from stationary sources covered by the NO_X charge have decreased by 14%, while the share has increased from 6% to 10%. Stationary sources not covered by the NO_X charge have decreased emissions by 44% and their share has increased from 28% to 34%.

2.2 The Charge and Refund system for emissions of nitrogen oxides in Sweden

The charge and refund system for nitrogen oxides (referred as the NO_X charge from now on) for large industrial combustions plants in Sweden was one of the first and most important environmental taxes introduced in Sweden during the 1990s (Höglund, 2000). The NO_X charge was implemented the 1 January 1992 (Svärdsjö and Gustafsson, 2003). Heat and energy production units such as boilers, stationary combustion engines and gas turbines are obliged to pay the charge for NO_X emissions. The Swedish parliament had earlier implemented non-tradable permits, limits, as a strategy to combat NO_X emissions from stationary combustion plants, but it rapidly became clear that these limits would not reduce emissions quickly enough (OECD, 2013). Since NO_X emissions to a large extent depends on the technology used and the maintenance of combustion equipment, other strategies than just taxing fuel was needed (Sterner and Höglund Isaksson, 2006). A high tax rate was needed, but opposition and lobbying was expected. The equipment was quite expensive and was considered unreasonable for small production units (Sterner and Turnheim, 2009). If the tax was supposed to be implemented only on large firms, this could cause incentives for firms to switch to smaller, and hence less efficient, production units (Sterner and Höglund Isaksson, 2006). After a couple of years innovation enabled lower cost of monitoring equipment making it possible to include smaller production units (Sterner and Turnheim, 2009). Initially the system comprised production units with an annual useful output of energy produced larger than 50 Giga Watt Hours (GWh), in total 181 production unites. In the following three years mean emissions per unit of energy produced fell with 30% among these production units. A few years later, in 1996, the system was extended to comprise plants producing more than 40 GWh annually, and then including 274 production units. One year later, in 1997, it was further extended to comprise production units producing more than 25 GWh annually, totally 371 production units. In 2013 totally 422 production units at 280 plants were included. Figure 1.2. below shows the development of NO_X emissions per produced unit of energy per group of size of the production units that got covered gradually by the charge. The emissions per produced unit of energy decreased initially for all of the three groups but the emission reduction gradually levelled off.

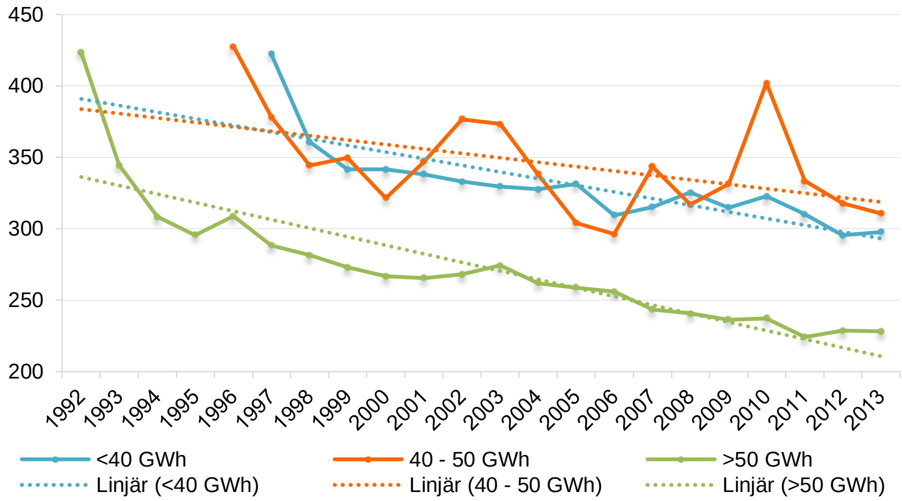

Figure 2.2. kg NO_X per produced GWh per extended group

The initial nominal charge was 40 SEK per emitted kilo of nitrogen oxide. In 2008 the charge level was increased to 50 SEK per kg NO_X, in nominal terms. The initial charge of 40 SEK/kg corresponds to about 4 300 €/ton or 6 300 USD/ton. This could be compared to permit prices that are around the hundreds of dollars in the US programs for NO_X permits. A few other countries in Europe have NO_X charges, like France, Italy and Galicia in Spain, and all these have charge levels about 150 USD/ ton (Sterner and Höglund Isaksson, 2006) and the charge levels in France was between 27 – 51 €/ton (Sterner and Turnheim, 2009).

The total revenue that the environmental charge generates, 668 million SEK in 2013 (SCB, 2015a), is refunded to the production units based on the amount of each unit's energy produced as a share of total useful energy production. Refunding reduces the incentives to switch to smaller and less efficient production units (Sterner and Höglund Isaksson, 2006). The idea of the system is to benefit emission efficient production units, with relatively low NO_X emissions compared to energy output. This means that firms emitting low levels of NO_X per unit of energy produced are net beneficiaries and firms with large NO_X emissions per unit of energy produced are net taxpayers. The whole value of the total charge are refunded to the firms, except for administrative costs that are appreciated to be 0,7% of the total charge (Svärdsjö and Gustafsson, 2003). The targeted group is therefore left financially neutral except from abatement and transaction costs.

3 Data

The original data used for the analysis is secondary data provided by the Swedish Environmental Protection Agency (SEPA) containing individual production unit data for the period 1992 to 2013. It is multiple time period panel data that contains 7 989 observations between the years 1992 and 2013, a period of T=22 years. Each observation is quantity kilo (kg) NO_X-emission and Mega Watt Hours (MWh) energy produced for each production unit. It is also information about sector, plant number, firm and cleaning method. Some information is confidential and is for this reason never exposed publicly.

Production units covered by the charge have more then doubled during the period of observation; it has been increasing from 181 production units in 1992 to 422 in 2013. Some plants have several production units and some firms have several plants. Production units enter and exit the market during the period of observation. Some production units have observations for all 22 years, some for several years and a few for just a couple or one year. This implies that the original panel data is unbalanced, which means that there are missing observations for some periods for some entities.

There are seven different sectors covered by the charge and refund system that appears in the data; food-, wood- and paper- and pulp industry, chemical production, metal manufacturing, waste incineration and power- and heat generation. Power and heat generation is the largest sector in the data and metal manufacturing the sector with fewest production units and therefore fewest observations appearing in the data.

To calculate the real value of the NO_X charge and the global oil price data about Consumer Price Index (CPI) from Statistics Sweden (SCB, 2015b) between the years 1992 and 2013 is used.

To be able to do the stated analysis on how the NO_X charge have affected the emissions efficiency on a firm level the data have been collapsed to firm level. Observations of production unit information have been summarized to firm level per year of observation and the observed emissions per produced unit of energy is therefore a mean of kilo emitted NO_X per produced GWh for all different production units per firm. In the original data different firms have different number of production units and some firms may even just have one production unit. The mean per firm then consists of different numbers of production units, depending on the quantity production units per firm in the original data. Since 14 of the firms had less then 2 observations, those have been excluded from the data. The modified data set consists of observations for n=272 different firms for the time period of observation between 1992 and 2013, T=22, with a total of 272x22 = 5 984 observations. Some firms have production in different sectors, in total 21 nr of firms, out of the total 272 nr of firms. To be able to do the analysis these firms have been separated and treated as two different firms, since decisions probably are taken differently in production in different sectors. The new panel data set is unbalanced with several missing values for some or several years for a majority of the firms. Out of the total 272 firms, 80 have observations for all 22 years. The data set has 3 629 observations and hence 2 292 missing values since firms enter and exit the data set during the period of observation.

The figure below shows firms per sector during the period of observation, in total 272 firms.

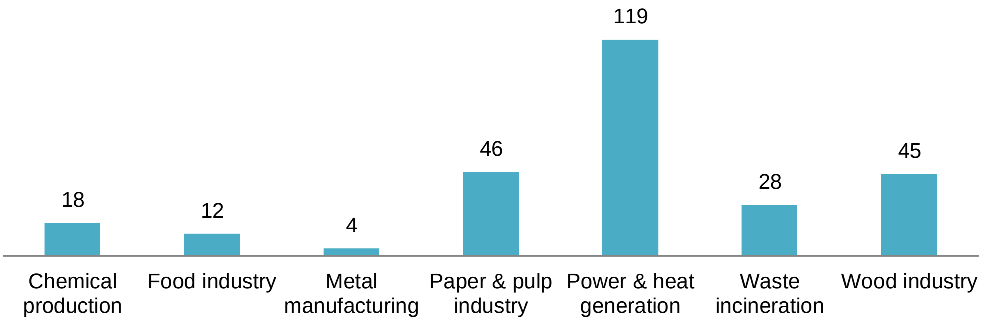

Figure 3.1 Firms per sector, total number for all years 1992 - 2013

3.1 Energy production, emissions and emission efficiency

Total energy output by firms covered by the NO_X charge has doubled during the period of observation. It has increased by 94% from 37 465 GWh in 1992 to 72 909,2 GWh in 2013. Emissions is fluctuating a lot from year to year but has decreased by 13,5% from 15 249,58 ton NO_X in 1992 to 13 185,3 ton in 2013. Emission efficiency, which is emitted kilo NO_X per GWh produced energy, has increased by 55,6% during the period from 407,04 kg NO_X per GWh in 1992 to

180,8 kg NO_X per GWh in 2013. Most of the increase in emission efficiency takes place in the first five years. The best firms have cut their emission efficiency by more then 70% and the median firms have caught up with best practice, both the best and the worst performance level have improved, but the worst has improved faster (Sterner and Turnheim, 2009). Figure 3.2 to 3.4 shows this information graphically.

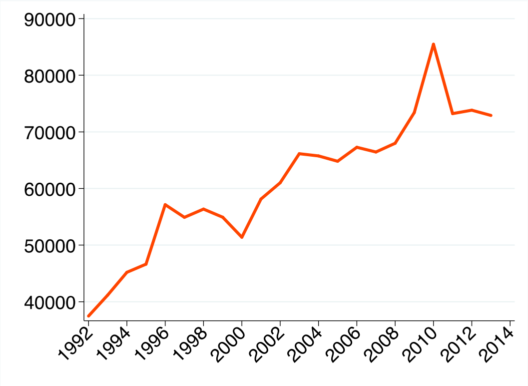

Figure 3.2. Total GWh per year, all sectors

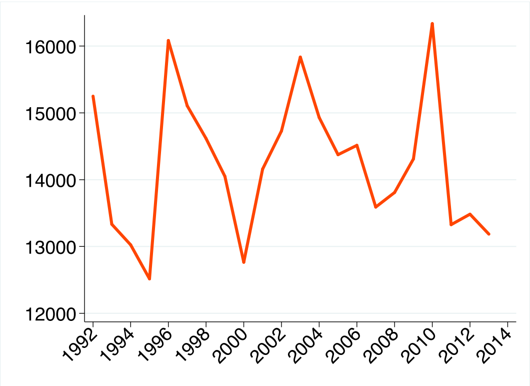

Figure 3.3. Total NOx emissions per year, ton, all sectors

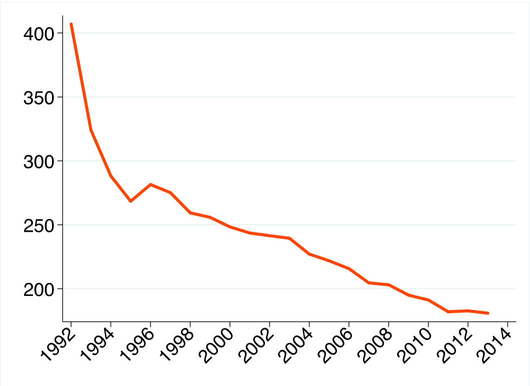

Figure 3.4. Mean kg NOx per GWh, all sectors

3.1.1 Energy production, emissions and emission efficiency per sector

Energy production, emissions and emission efficiency differs between the seven sectors. Power and heat generation, which is the largest sector covered by the NO_X charge, has increased energy production by 123% from 18 151,45 GWh in 1992 to 40 475,32 GWh in 2013. Emissions is almost the same by a decrease by less then 1% from 6 731,1 ton in 1992 to 6 684,5 ton in 2013. Emission efficiency has increased by 55,5% from 370,8 kg NO_X per produced GWh to 165,2 kg NO_X per produced GWh.

Waste incineration, which is the third largest sector covered by the NO_X charge, has increased energy production by 166% from 4 936,8 GWh in 1992 to 13 148,1 GWh in 2013. Emissions has decreased by 25% from 2 557,2 ton in 1992 to 1 916,8 ton in 2013. The largest increase in emission efficiency has occurred in this sector by an increase of 71,9%, from 518 kg NO_X per produced GWh to 145,8 kg NO_X per produced GWh.

Pulp- and paper industry, which is the second largest sector covered by the NO_X charge, has increased energy production by 15% from 10 609 GWh in 1992 to 12 229 GWh in 2013. Emissions has decreased by 34,6% from 4 531 ton in 1992 to 2 964,3 ton in 2013. Emission efficiency has increased by 43%, from 427 kg NO_X per produced GWh to 242,4 kg NO_X per produced GWh.

Wood industry had the largest increase in energy production by 3 405,8% increase from 70,9 GWh in 1992 to 2 485,63 GWh in 2013. Correspondingly emissions has increased by 2 065,7% from 37,2 ton in 1992 to 805,5 ton in 2013. Emission efficiency has increased by 38%, from 524,6 kg NO_X per produced GWh to 324,067 kg NO_X per produced GWh.

Chemical industry has increased in energy production by 34% from 2 299,4 GWh in 1992 to 3 080,75 GWh in 2013. Emissions has decreased by 50% from 1 051,4 ton in 1992 to 525,3 ton in 2013. Emission efficiency has increased by 62,7%, from 457,3 kg NO_X per produced GWh to 170,5 kg NO_X per produced GWh.

Food industry has increased the energy production by 9,8% from 937,8 GWh in 1992 to 1 029,23 GWh in 2013. Emissions has decreased by 50% from 264,6 ton in 1992 to 171 ton in 2013. Emission efficiency has increased by 41%, from 282,2 kg NO_X per produced GWh to 166,2 kg NO_X per produced GWh.

Metal industry has almost the same energy production with less than 1% increase, from 459,3 GWh in 1992 to 461 GWh in 2013. Emissions have increased by 53% from 77 ton in 1992 to 117,8 ton in 2013. Emission efficiency has decreased by 52%, from 167,6 kg NO_X per produced GWh to 255,4 kg NO_X per produced GWh. The results from the metal industry should be interpreted with caution since there are very few observations from this sector since there are only 4 firms represented during the period of observation. Figure 3.5 – 3.8 shows the information graphically.

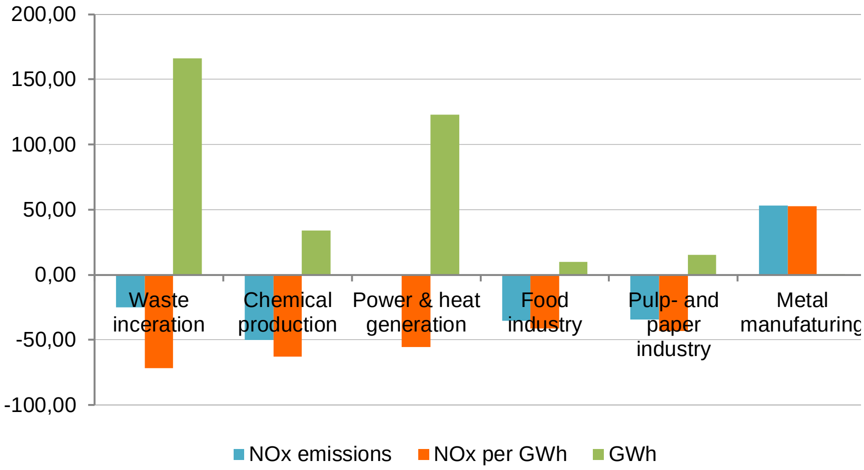

Figure 3.5. Changes in % of energy production, emissions and emission efficiency per sector

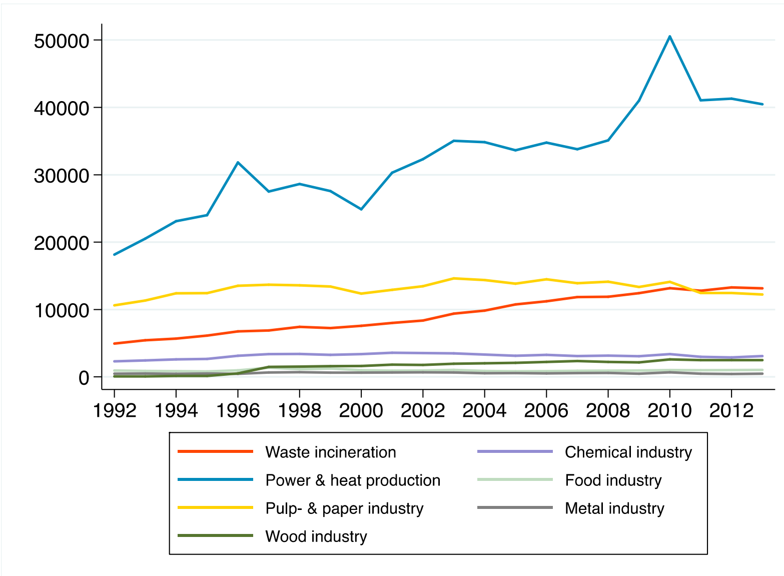

Figure 3.6. Total energy produced per sector, GWh

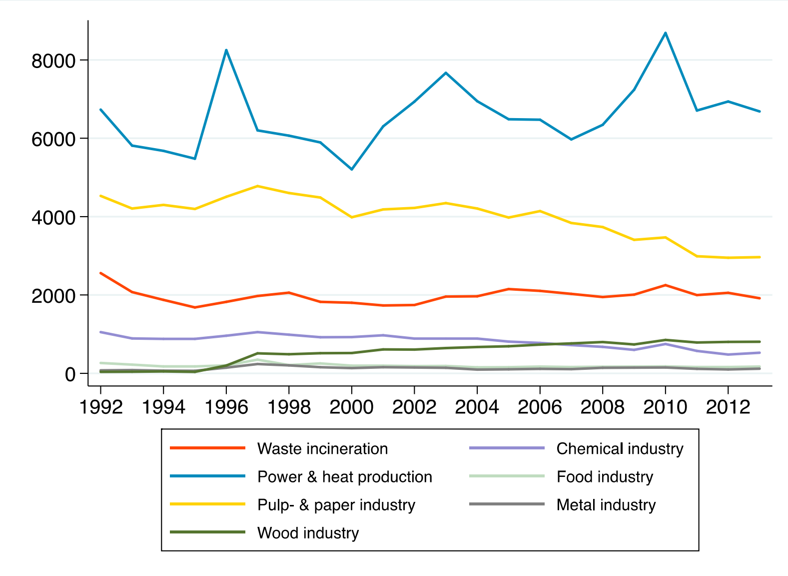

Figure 3.7. Total NO_X emissions per sector, ton

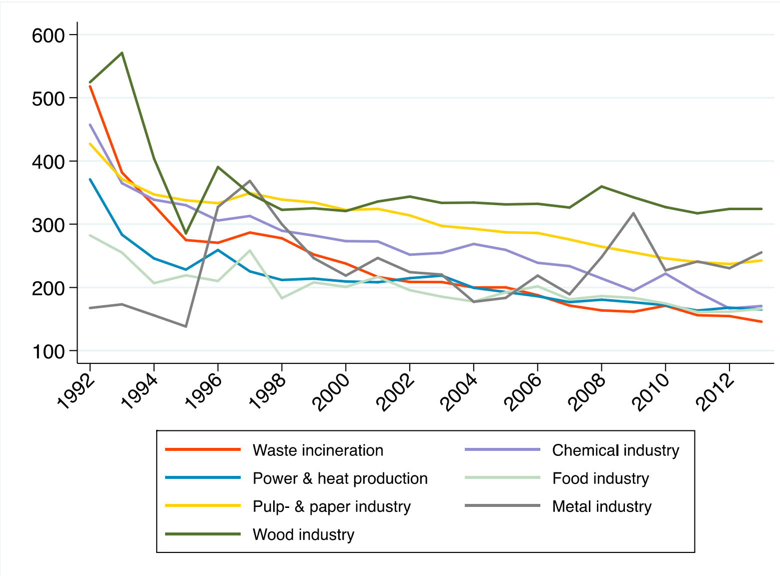

Figure 3.8. Mean emission efficiency per sector, kg NO_X per GWh

4 Methodology

A common problem for evaluations of environmental policies, and polices in general, is the absent of a control group. In the case of the NO_X charge the measure of NO_X emissions started together with the implementation of the policy. Therefore it is difficult to know the effect of the policy since we don't know how the emission efficiency would have developed in the absent of the policy. Methods for trying to evaluate these types of problems could be found in econometrics and is used to test the null hypothesis that the NO_X charge didn't have any effect on emission efficiency[1] on a firm level, on all sectors aggregated as well as a sectorial analysis.

4.1 Panel Data

Three different kinds of data can be used when applying an econometric quantitative analysis; cross-sectional, time-series and panel data (Stock and Watson, 2011). Cross-sectional data are collections of data for one specific point in time across a sample of different individuals, countries, regions, firms, households or other entity of observation. Time-series data on the other hand is data collected for several periods, or points in time for one specific individual, country, region, firm, household or other entity of observation. Panel data is the combination of cross-sectional and time-series data. Panel data consist of observations for different (*n*) entities (individuals, countries, households, firms, regions or other entity of observation) for two or several different time periods (*T*) (Baum, 2006). An example of an econometric model with panel data is;

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + u_{it}$$

where i=1, 2, …,N different entities and t=1,2,…,T different time periods.

[1] Emission efficiency is NO_X emissions per produced unit of energy. When efficiency increase, NO_X emission per produced unit of energy decrease.

A way to eliminate the effect of omitted variables that differ across entities but are constant over time is to study changes in the dependent variable over time (Stock and Watson, 2011), this could be done with panel data. A panel data set can control for unobserved variables that differ from one entity to another but does not change over time. It can also control for variables that vary over time but are equal across entities.

4.1.1 A fixed effects model

A fixed effect regression is used to test the effect of the NO_X charge on emission efficiency. Fixed effects regression is the main tool for regression on panel data and is an extension of the multiple regression tool that enables for controlling for omitted variables that differ across entities but are constant over time (Stock and Watson, 2011). Fixed effect regressions can be used when there are two or more time observations for each entity. The fixed effect regression model has one different intercept for each entity. An example of a panel data model with fixed effects is:

$$Y_{it} = \alpha_i + \beta_1 X_{it} + \beta_2 Z_i + u_{it}$$

where i=1, 2, …,N different entities and t=1,2,…,T different time periods, α is an entity specific intercept and Z_i is an unobserved variable that varies across entities but does not change over time.

Using fixed effect implies that any characteristic that does not vary over time for each unit cannot be included in the regression model, for example an individuals gender or a firm’s sector code (Baum, 2006). This implies that it’s not possible to use sector dummies in the model for the seven different sectors. Even though fixed effects model is straightforward to apply, it expensive in terms of degrees of freedom when having several cross section units (Gujarati, 2002). This is certainly the case with the firms covered by the NO_X charge, when the firms are 272 while the periods only are 22. The underlying reasoning of the fixed effects model is that when specifying the regression model there is failure to include relevant explanatory variables that doesn’t charge over time and that including dummy variables is a cover up for the inability to specify a correct model. Therefore another model, a random effects model, could be worth testing.

4.1.2 A random effects model

In a generalized least squares (GLS) random effects model the u_i term is treated as a random variable and we assume that there is no correlation between u_i and X (Gujarati, 2002). Instead of treating β_{1i} as fixed, this model assumes that it is a random variable with mean value of β_1, without entity specific subscription i. Therefore the intercept value for an entity can be expressed as $\beta_{1i} = \beta_1 + \varepsilon_i$, where ε_i is a random error term. This model assumes that the included entities are a random sample of a much larger population of such entities and that their intercepts have a common mean value and that the differences in the value of their intercepts are reflected in the error term ε_i. An example of a panel data model with random effects is:

$$Y_{it} = \beta_1 + \beta_2 X_{2it} + \beta_3 X_{3it} + w_{it}$$

where i=1, 2, …,N different entities and t=1,2,…,T different time periods and $w_{it} = \varepsilon_i + u_{it}$. The composite error term w_{it} consists of the two components ε_i, which is the cross-section, or entity-specific, error component and the u_{it}, which is the combined time series and cross-section error component.

The random effects model, as described above, assumes that the sample is a random draw from a larger population, but this might not always be the case.

If the number of time series data (T) is large and the number of cross-sectional units (N) is small, then it might not be so large differences between the estimations of the variables estimated by the random and the fixed effects model. But when T is small and N is large the estimates obtained by the two methods can differ significantly. In this thesis the both methods will be tested.

4.2 The Model

To test whether the NO_X charge level had an impact on the emission efficiency on a firm level, on a sector aggregated as well as sectorial analysis, three different regression methods are used. First an OLS pooled model, second a regression with fixed effects and third a regression with random effects. Six models are going to be tested. Three of them testing the effect of the real charge and three the increase in the nominal charge level in 2008, both controlling for the variables time, inflow to hydropower plants, global oil price and a lags in emission efficiency. The inflow and the global oil price is used in the study by Wikström (2015) and the inflow and partly the real charge in the evaluation of the increase of the NO_X charge in 2008 (SEPA, 2012). Time is used in a study by Sterner and Turnheim (2009). The following six models are regressed:

$$(NO_X\,/GWh)_{it} = \beta_1 + \beta_2 D08_{it} + \beta_3 time_t + \beta_4 inflow_t + \beta_5\, real\ oil\ price_t + \beta_6 (NO_X\,/GWh)_{it-1} + u_{it} \tag{1}$$

$$(NO_X\,/GWh)_{it} = \beta_1 + \beta_2 real\ charge_t + \beta_3 time_t + \beta_4 inflow_t + \beta_5\, real\ oil\ price_t + \beta_6 (NO_X\,/GWh)_{it-1} + u_{it} \tag{2}$$

$$(NO_X/GWh)_{it} = \alpha_i + \beta_1 D08_{it} + \beta_2 time_t + \beta_3 inflow_t + \beta_4\, real\ oil\ price_t + \beta_5 (NO_X/GWh)_{it-1} + u_{it} \tag{3}$$

$$(NO_X/GWh)_{it} = \alpha_i + \beta_1 real\ charge_t + \beta_2 time_t + \beta_3 inflow_t + \beta_4\, real\ oil\ price_t + \beta_5 (NO_X/GWh)_{it-1} + u_{it} \tag{4}$$

$$(NO_X/GWh)_{it} = \beta_1 + \beta_2 D08_{it} + \beta_3 time_t + \beta_4 inflow_t + \beta_5\, real\ oil\ price_t + \beta_6 (NO_X/GWh)_{it-1} + w_{it} \tag{5}$$

$$(NO_X/GWh)_{it} = \beta_1 + \beta_2 real\ charge_t + \beta_3 time_t + \beta_4 inflow_t + \beta_5\, real\ oil\ price_t + \beta_6 (NO_X/GWh)_{it-1} + w_{it} \tag{6}$$

where *i* is firm, *i* =1, 2, …, 272, *t time, t*= 1, 2, …, 22. $u_{it}$is the error term, w_{it} is the combined error term and α_i is the entity (firm) specific intercept for fixed effects. D08 is a dummy that is 0 before 2008 and 1 after, when the charge was increased. $(NO_X/GWh)_{it-1}$ is a term for a lag in the emission efficiency, interpreted as that emission efficiency in current period depends on the emission efficiency in the last period. The control variables real charge, inflow and the real oil price are explained below. The variable time shows that it is a continued improvement of emission efficiency over time, in addition to that captured by other variables. Equations 1-2 are tested with a pooled model, 3-4 with fixed effects and 5-6 with a random effects model.

4.2.1 Analysis on a firm level

The main assumption in the analysis is that decisions about investment in emission abatement technology are taken on a firm level, and not on a production unit level. The charge does affect decision makers, managers, and not production units. Therefore the analysis is made on a firm level, and not on a production unit level as previous studies. A firm with several production units and even several plants might decide to increase production on the more efficient production units or plants and decrease production on the less efficient production units or plants to decrease mean emissions per unit of energy produced for the firm and hence reduce the exposure of the charge for the firm. The firm might also decide to invest in more efficient abatement technology on the less efficient production units or plants to decrease overall emissions from the firm. Firms might even decide to shut down production from old inefficient production units and build new more efficient production units. Analysing the data on a production unit level these changes does never appear. Then a inefficient production unit with decreased production does not change the emission efficiency per production unit, it just appears as decreased production, but looking at a firm level it appears as a decreased mean of emissions per produced unit of energy for the firm. When a production unit is taken out of function due to a firm decision to invest in a new more efficient production unit, looking at a per production unit level this does just appear as a scrapped production unit and not as decreased emissions per produced unit of energy. But looking at a firm level this does appear as decreased mean of emission per produced unit of energy for the firm. That's why the result on a firm level is different from on a production unit level.

4.2.2 The refunding mechanism

Analyse the charge and refund system for NO_X emissions only focusing on the charge might seem a bit remarkable. Specifically when for example Sterner et al., (2004) argue that refunding was necessary to be able to implement the policy, to cover small production units, diminish incentives for large production units to switch to smaller less efficient production units and Sterner and Höglund Isaksson, (2006) further argues that the refund mechanism have enabled a charge on a higher level then would otherwise be politically feasible to have a significant abatement effect. Further according to OECD 2013), the mechanism have stimulated to technological development. But following the reasoning by Höglund (2000) and Söderholm (2013) we can easily conclude that the refunding is not necessary to take into consideration. Introducing a simple model, where C_i is the production costs for a representative firm i, we get;

$$C_i = f(e_i, y_i)$$

where e_i is unit NO_X emissions and y_i is energy production. Introducing the charge t per unit NO_X emissions and the refunding, the representative cost function changes and the firm has to pay for the emissions with te_i and receives refunding depending on the revenue from the aggregated collected charge, $t\Sigma e_i = E$, and the firms' energy output as a share of total output, $y_i/\Sigma y_i = y_i/Y$. This implies that the total production costs for the firm now becomes;

$$C_i = f(e_i, y_i) + \ te_i - t\Sigma e_i(y_i/Y)$$

assuming that the firm wants to minimise the production costs, which is reasonable for both private as publicly owned firms, the first order condition for a cost minimization w.r.t. e_i and set this equal to zero we get;

$$-\partial C_i/\partial e_i = t(1 - y_i/Y)$$

this expression shows that if the firm wants to minimise its cost it will reduce NO_X emissions until the marginal cost for abatement is equal to the charge times the factor that corrects for the firms' share of the total energy output for all firms. One conclusion is hence that the cost for the firm to emit one extra unit of NO_X emissions is lower than the level of the charge since a part of the charge is refunded. If there were only one firm on the market the incentive to emission abatement would equal zero since all the refunding accrues to that single firm. The larger the number of firms covered by the charge, the more insecure and less important the refunding mechanism becomes. When the market share for the firm approach zero, when the number of firms covered by the charge approach infinity, we get the solution that the firm choses to reduce its NO_X emissions until the marginal abatement cost is equal to the charge t. So when there are a large number of small and competitive firms targeted by the refund charge, the marginal abatement cost for reduction of emissions are approximately equal as under a equivalent Pigouvian tax. The number of firm's covered by the NO_X charge is relatively large, 272 in the sample in the data and only two firms had a larger market share than 4% during all years of observations, and the two largest firms market shares were 5% and 6% respectively in 2013. This result is confirmed in a study by Höglund (2005). Since the market for firms covered by the NO_X charge consists of many and relatively small firms this implies that the refunding mechanism should give a marginal incentive to emission abatement, given the assumption about cost minimisation.

4.2.3 The NO_X charge in real and nominal value

The regressions estimate the effects of the real charge and the increase in the charge 2008 on the NO_X emissions per produced unit of energy. The value of the charge has decreased during the period of observation and not been inflation adjusted until the increase in the charge 2008. Since the only change in the nominal charge is 2008, the regression analysis is therefore limited to test the effect of the

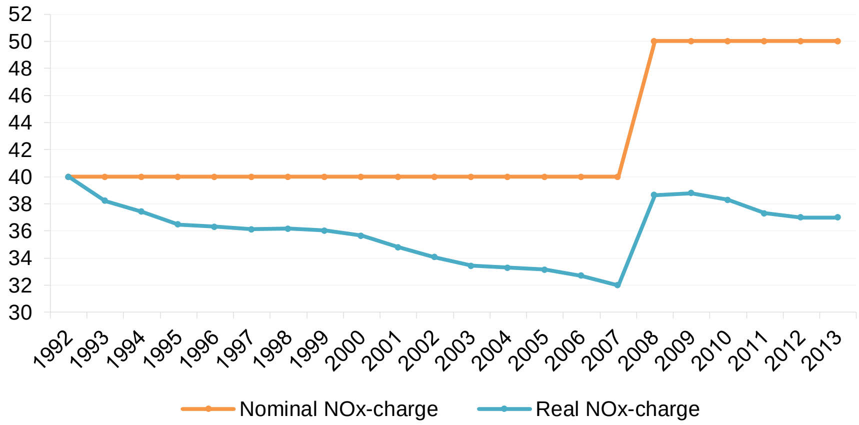

Figure 4.1. Nominal and real NO_X charge, 1992 years value, SEK/kg

nominal charge level by the increase in the charge 2008. The initial level of the nitrogen oxide charge was 40 SEK per emitted kilo of NO_X in year 1992 when the charge was implemented. The nominal value of the charge was constant until 2008 when the charge was increased to 50 SEK per kg of NO_X emissions in nominal terms. The real value of the charge has been calculated in 1992 years price value using the Consumer Price Index (CPI) (SCB, 2015b). The real value of the charge has been decreasing with 20% from 1992 until 2007. The new nominal level of 50 SEK did however never exceed the real value of the initial level of the charge in 1992 years value, but it instead was 38,65 SEK in real value in 1992 years value. Therefore the increase of the charge in 2008 was rather an inflation adjustment to compensate for several years of falling real value, than a real increase in the charge. After 2008 the real value of the charge has been decreasing again. Below is a figure of the real and nominal value of the charge during the period of observation, between the years 1992 – 2013.

4.2.4 Inflow to hydropower plants

Weather is one variable that could explain NO_X emissions, since the weather and the climate affect the energy production. Annual mean temperature could be one such variable explaining changes in energy production. In Sweden data about annual mean temperature is only found at a regional level and not on a national level. Unfortunately information about the firms region is not available. Further more even if regional data were available on production unit level from the original data set, one firm can have production units in different regions and when collapsing data to firm level this further complicates the situation. Therefore annual mean temperature is hard to use. However cold winters in combination with low hydropower production capacity leads to increases in emissions (SEPA, 2012). Under those circumstances the demand of charge-obliged energy will increase and production units that are usually not in use, and less emissions efficient, will be resumed. How the weather is affecting NO_X emissions is therefore best captured by the production capacity by the hydropower, which in turn depends on the precipitation and is best described by the inflow, also called runoff, that is a measure of the flow during a certain period. According to this the variable inflow is used for controlling for fluctuations in the weather and how it affects the emission efficiency. Statistics about annual quantity of the runoff for hydro power plants in Sweden, for the period 1992 – 2013, is received from Swedish Energy (Svensk Energi, 2015) and is expressed in Terra Watt Hours (TWh) per year. The inflow, or the runoff, from the hydropower plants in Sweden is shown in the figure below. The inflow has been annually fluctuating between 50,3 and 83,8 TWh.

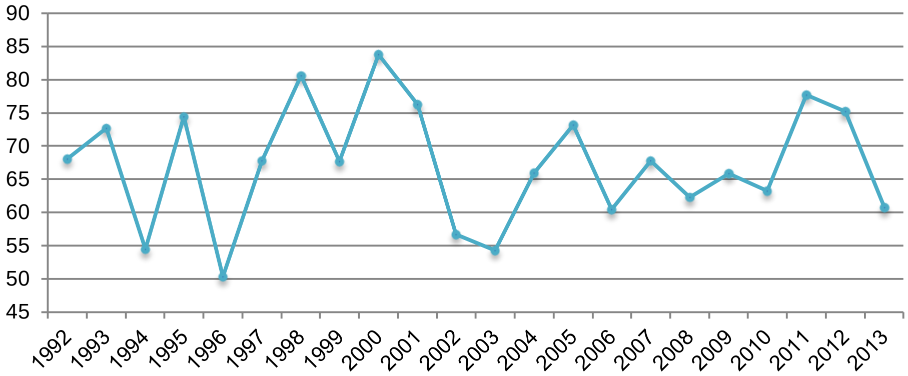

Figure 4.2 Inflow to hydro power plants, TWh

4.2.5 The global oil price

The price on oil is another variable used as a control variable in the regression analysis. The price is the annual mean price of oil inclusive the Swedish tax on oil, collected from The Swedish Petroleum and Biofuel Institute (SPBI, 2015). The oil price has been recalculated to real price in 1992 years price value using CPI. Prices on other fuels as bioenergy could be used, but the price on bioenergy is to a large extent determined locally in Sweden and could therefore be affected by the NO_X charge (Wikström, 2015) and then biased. That's why it is not used. The price on oil is, on the other hand, to a large extent determined on the global oil market and not particularly affected by Swedish local taxes and regulations.

The oil price has been increasing with 147,5% in nominal terms and 83% in real terms during the period of observation.

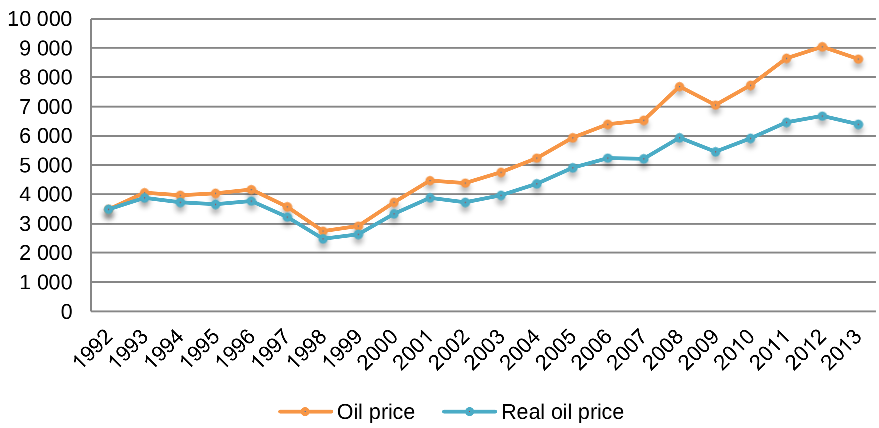

Figure 4.3 Nominal and real oil price, SEK/ton

5 Results

The results from the regressions that estimates the effect of the real charge and the increase on the nominal charge 2008 is presented below, in a sector aggregated analysis as well as a sectorial analysis from the models 1-6 stated in the methodology section. All variables are estimated in natural logarithms.

5.1 Sector aggregated analysis

Below are the results from the pooled, fixed effects and random effects model regressions. Table 5.1 presents the estimations for the coefficients for the real charge and table 5.2 presents the estimations for the coefficients for the increase in the nominal charge 2008. The estimation for the real charge from the pooled, linear, regression model, (table 5.1) is – 0,1 and statistically significant at a 10% level. All other variables are significant at a 1% level, except the inflow that is significant at a 5% level. This means that an increase in the real charge with one unit reduces NO_X emissions per unit of produced energy by 10%. A correspondingly increase in the inflow decrease the emissions by 5,8% and a one unit increase in the real oil price decrease the emissions by 8,3%.

The estimation of the real charge from the fixed effects model is negative with an estimation of – 0,05, but not statistically significant. The estimation for the control variable time is – 0.003 and significant at a 5% level. The estimation for the inflow is – 0,05 and significant at a 10% level. The estimation for the lag is 0,7 and significant at a 1% level. The estimation for the real oil price is negative but not statistically significant. The estimation for the real charge from the random effects model is negative but not statistically significant. The estimations for the real oil price and the lag in emission efficiency are negative and positive respectively and both significant at a 1% level. The estimator for time is positive and significant at a 10 level and the estimation for the inflow is negative and significant at a 5% level.

	Pooled Model	Fixed Effects Model	Random Effects Model
Real charge	-0.101*	-0.0516	-0.0830
	(0.0537)	(0.0596)	(0.0541)
Time	0.00415***	-0.00345**	0.00238*
	(0.00122)	(0.00164)	(0.00123)
Inflow	-0.0583**	-0.0484*	-0.0554**
	(0.0275)	(0.0260)	(0.0271)
Real oil price	-0.0831***	-0.0357	-0.0711***
	(0.0229)	(0.0247)	(0.0225)
Previous period	0.902***	0.702***	0.856***
	(0.0129)	(0.0305)	(0.0159)
Constant	1.770***	2.361***	1.868***
	(0.298)	(0.285)	(0.290)
Observations	3629	3629	3629
R^2	0.817	0.588	0.583
Wald-test / χ^2	1069.6	173.7	3273.52

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.1. Regression estimators for the real charge, sector aggregated analysis

The model for the impact of the real charge on NO_X/GWh with the results from the pooled model, then becomes:

$$(NO_X\ /GWh)_{it} = 1.77 - 0.1 real\ charge_t + 0.004 time_t - 0.06 inflow_t \\ - 0.08 real\ oil\ price_t + 0.9(NO_X\ /GWh)_{it-1} + u_{it}$$

To illustrate the model for the emission efficiency for example the emissions per produced unit of energy from the district heating plant in Haparanda for year 2002 can be calculated;

$$(NO_X\ /GWh)_{Haparanda,2002} \\ = 1.77 - 0.1 real\ charge_{2002} + 0.004 time_{2002} - 0.06 inflow_{2002} \\ - 0.08 real\ oil\ price_{2002} + 0.9(NO_X\ /GWh)_{2001} + u_{Haparanda,2002}$$

$$6.615 = 1.77 - 0.1 * 3.53 + 0.004 * 11 - 0.06 * 4.03 - 0.08 * 8.26 + 0.9 * 6.73$$

The estimation of the model corresponds well with the actual value in the data, which is 6.674 (in natural logarithm), which is 791.8 kg NO_X emissions per GWh.

The results for the models for the increase in the nominal charge in 2008 (table 5.2), on a sector aggregated analysis, shows that regressing a pooled model the difference between before and after 2008 the difference is -0.023, significant at a 5% level on a firm level. The control variables time, the real oil price and the emission efficiency lag are statistically significant at a 0,1% level and the estimator for the inflow is significant at a 5% level. This means that the increase in the charge level in 2008 decreased emission per produced unit of energy by 2,3%.

The estimator for the increase in the charge is negative but not significant in the fixed effects model. The model neither shows significant results for none of the estimators except the lag that is significant at a 1% level.

The estimation for D08 in the random effects model is negative with a value of – 0,02 and significant at a 10% level. The estimations for the variables time and inflow are significant at a 5% level and the estimations for the real oil price and the efficiency lag are significant at a 1% level. This means that the increase in the charge in 2008 decreased emissions by 1,9%.

	Pooled Model	**Fixed Effects Model**	**Random Effects Model**
D08	-0.0231^{**}	-0.0132	-0.0193^{*}
	(0.0110)	(0.0123)	(0.0111)
Time	0.00533^{***}	-0.00279	0.00335^{**}
	(0.00135)	(0.00186)	(0.00137)
Inflow	-0.0593^{**}	-0.0486^{*}	-0.0562^{**}
	(0.0274)	(0.0259)	(0.0270)
Real oil price	-0.0787^{***}	-0.0327	-0.0671^{***}
	(0.0231)	(0.0248)	(0.0227)
Previous period	0.902^{***}	0.702^{***}	0.856^{***}
	(0.0129)	(0.0305)	(0.0160)
Constant	1.367^{***}	2.148^{***}	1.537^{***}
	(0.245)	(0.241)	(0.239)
Observations	3629	3629	3629
R^2	0.817	0.588	0.583
Wald-test / χ^2	1070.2	173.2	3264.78

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.2. Regression estimators for D08, sector aggregated analysis

Using the results from the pooled model the model for NO_X/GWh and the increase in the charge in 2008 becomes;

$$(NO_X\,/GWh)_{it} = 1.37 - 0.023D08_{it} + 0.005time_t - 0.06inflow_t \\ - 0.08real\ oil\ price_t + 0.9(NO_X\,/GWh)_{it-1} + u_{it}$$

The Wald-test, the F-statistic test, tests if the coefficients on the regressors are all jointly zero. The Wald test for the pooled and the fixed effects model shows that all coefficients are highly statistically significant for both the real charge model as well as the D08 model. So the models are significant. Leading to the rejection of the hypothesis that together the coefficients have no effect on the emission efficiency, since the critical value is about 3,15 with 5% significance level and 4,98 with 1% level (Gujarati, 2002). The χ^2 that is obtained for the random effects model indicate that jointly the coefficient in the model are significant in both the real charge and the D08 model.

The multiple coefficient of determination, R^2 that measures the goodness of fit of the equation, gives the proportion or percentage of the total variation in the dependent variable Y explained by the explanatory variables X_1, …X_n jointly (Gujarati, 2002). The value of R^2 lies between 0 and 1 and the closer R^2 is to 1 the "better" is the fit of the model. The R^2 in the sector aggregated analysis with the pooled and fixed effects models are 0,8 and 0,6 respectively both for the real charge as the D08 model.

In conclusion the estimations for the real charge and the increase in the nominal charge in 2008 are all negative in their impact on NO_X emissions per produced unit of energy on a firm level in both the pooled, fixed effects and random effects model. A statistically significant estimation is attained from the pooled model for the real charge and from the pooled and the random effects model for the increase on the charge on 2008.

5.2 Sectorial analysis

The seven different sectors covered by the NO_X charge are diverse to their nature and it's irrational to presume that the charge would affect them equally. Doing a sectorial analysis these differences between the sectors appears. All sectors are regressed with a linear OLS model, a pooled model, and all control variables; the real charge or D08, time, the inflow to hydro power plants the real global oil price and the lag for the emission efficiency. The inflow is not of significant weight for all sectors, but controlling for an extra variable that is not important does not disturb the regression results significant, and the variable is therefore kept for all sectors. Table 5.3. on page 28 presents the coefficient estimations for the real charge and table 5.4. on page 29 presents the coefficient results for the increase in the charge 2008, both for a sectorial analysis.

The result from the regression for the real charge shows that the estimation for the real charge is negative for the sectors chemical production, power- & heat generation, food industry, paper- & pulp industry and wood industry. But the only sector that the real charge have a statistically significant negative effect on is the wood industry. The estimation for the impact of the real charge on NO_X emissions per produced unit of energy in wood industry is – 0,36, significant at a 1% level. The control variable emission efficiency in previous period is statistically significant at a 1% level. This means that a one unit increase in the real charge reduced emission with 36% in the wood industry. For the power- and heat generation all other control variables except the real charge are significant at a 1% level, except the inflow, which is significant at a 5% level.

In the results from the D08 regression the estimation for the increase in the charge in 2008 is negative for all sectors except the waste incineration and the metal manufacturing. But the only sector in which the increase in the charge had a negatively statistically significant is, again, the wood industry with an estimation for the impact on NO_X emissions per produced unit of energy of – 0,076. The lag in emission efficiency is the only significant control variable with an estimation of 0,7, significant on a 1% level. This means that the increase in the nominal charge level in 2008 reduced NO_X emissions per produced unit of energy by 7,6%. For the sector power- & heat production estimators for all variables except the increase in the charge are significant at a 1% level, except inflow that is significant at a 5% level.

The variable inflow shows the highest significance for the power- and heat generation both in the regression for the real charge as in the regression for the increase in the charge level in 2008. This is expected, since this is the sector that to the largest extent is affected by the hydropower production.

The control variable for emission efficiency in previous period is significant for all sectors at a 1% level in both the regression for the real charge as for the D08. This shows that the current emission efficiency to a large extent is determined by the emission efficiency in the previous period. This also concludes that including a lag for emission efficiency is important in a regression model analysing the NO_X charge.

The sectors food industry, metal manufacturing and chemical all have low number of observations since there are very few firms in these sectors, only 12 in the food industry, 4 in the metal manufacturing and 18 in the chemical production. Therefore some variables are omitted and Wald-test could therefore not be calculated for the metal manufacturing. Therefore no conclusions could be drawn from the regression for these sectors.

Probably also the sector aggregated regression analysis would benefit from excluding the sectors food industry, metal manufacturing and chemical production. In a sectorial analysis these sectors shows low significance, specifically the metal manufacturing. From this result it is probably a good idea in further research to exclude the metal manufacturing and the food industry and perhaps also the chemical production from the sector aggregated analysis.

	Waste incineration	Chemical production	Power & heat generation	Food industry	Paper & pulp industry	Metal manufacturing	Wood industry
Real charge	0.0402	-0.323	-0.0175	-0.132	-0.153	0.0468	-0.363***
	(0.161)	(0.252)	(0.0846)	(0.203)	(0.108)	(1.230)	(0.109)
Time	0.00379	0.00242	0.00696***	-0.00297	0.00157	-0.000565	0.000168
	(0.00347)	(0.00562)	(0.00183)	(0.00721)	(0.00205)	(0.0139)	(0.00438)
Inflow	-0.0284	-0.309*	-0.112**	0.158	0.00244	0.0389	0.0594
	(0.0634)	(0.160)	(0.0446)	(0.139)	(0.0348)	(0.421)	(0.0479)
Real oil price	-0.127*	-0.201*	-0.116***	0.0566	-0.0640	0.0180	0.0324
	(0.0625)	(0.102)	(0.0330)	(0.127)	(0.0423)	(0.227)	(0.0693)
Previous period	0.876***	0.919***	0.879***	0.919***	0.882***	0.722***	0.697***
	(0.0291)	(0.0323)	(0.0251)	(0.0364)	(0.0253)	(0.0726)	(0.0651)
Constant	1.627**	4.490**	2.055***	-0.242	1.717***	1.051	2.519***
	(0.724)	(1.576)	(0.446)	(1.683)	(0.518)	(1.263)	(0.733)
Observations	470	256	1559	142	731	45	426
R^2	0.814	0.834	0.789	0.839	0.798	0.615	0.605
Wald-test	252.9	505.4	270.0	463.6	500.2	.	53.62

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.3 Regression estimators for the real charge, sectorial analysis

	Waste incineration	Chemical production	Power & heat generation	Food industry	Paper & pulp industry	Metal manufacturing	Wood industry
D08	0.00862	-0.0675	-0.00582	-0.0537	-0.0330	0.00989	-0.0755***
	(0.0333)	(0.0509)	(0.0172)	(0.0471)	(0.0223)	(0.277)	(0.0223)
Time	0.00335	0.00595	0.00725***	-0.000565	0.00328	-0.00108	0.00410
	(0.00415)	(0.00550)	(0.00206)	(0.00769)	(0.00237)	(0.00214)	(0.00441)
Inflow	-0.0278	-0.315*	-0.112**	0.161	0.00000757	0.0395	0.0548
	(0.0622)	(0.159)	(0.0447)	(0.141)	(0.0350)	(0.407)	(0.0470)
Real oil price	-0.129**	-0.191*	-0.115***	0.0752	-0.0586	0.0163	0.0451
	(0.0620)	(0.101)	(0.0335)	(0.131)	(0.0428)	(0.281)	(0.0713)
Previous period	0.876***	0.919***	0.879***	0.918***	0.881***	0.722***	0.697***
	(0.0290)	(0.0323)	(0.0251)	(0.0373)	(0.0253)	(0.0709)	(0.0652)
Constant	1.784***	3.253***	1.975***	-0.893	1.122***	1.233	1.106
	(0.632)	(1.090)	(0.370)	(1.419)	(0.362)	(3.778)	(0.693)
Observations	470	256	1559	142	731	45	426
R^2	0.814	0.834	0.789	0.839	0.798	0.615	0.606
Wald-test	246.4	422.5	269.9	471.0	496.8	.	53.12

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.4. Regression estimators for D08, sectorial analysis

6 Discussion

Scale of production is affecting emission efficiency. The data shows that all large firms are efficient, small firms can be both efficient and inefficient, but all inefficient firms are small. It seems that size does matter for the firms' emission efficiency of emitted NO_X per produced unit of energy. Below is a plot in logarithmic scale of emission efficiency per size of the firm. Size of the firm is measured in annual produced GWh. The scale advantage could be explained by that capital intensity increase in larger firms and by the existence of indivisibilities in technological options as well as a higher technological capacity of larger firms (Sterner and Turnheim, 2009). Technology absorption and the acquirement of knowledge to a large extent depends on access to information, finance and the level of engagement in R&D and innovation activities, which all seems to be dependent on scale. Further the price of abatement technology is not a linear function of unit size, which leads to disadvantages for smaller firms. Some technological devices are not even commercially available under a certain size level (Sterner and Turnheim, 2009). The firm size is not included in the regression models, since it is correlated with the dependent variable, but it is an important factor to take into consideration.

Without the refund the charge would function as a conventional Pigouvian emis-

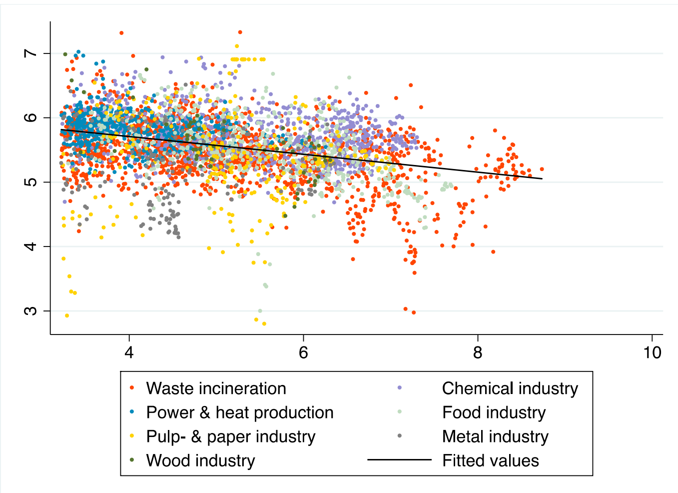

Figure 6.1. Scatter of log kg NO_X emissions per GWh on log GWh, fitted line is mean for all sectors

sion tax and the abatement incentives are practically the same under a charge and refund system as under an equivalent Pigouvian tax (Höglund, 2000), however firms are less opposed to a charge and refund system. This can be explained by the fact that the marginal cost of abatement is almost the same as the charge level but the average net payment is much lower due to the refund mechanism (Sterner and Höglund Isaksson, 2006). Even though the refund mechanism does not distort the abatement behaviour of the firms, is does affect the output level and may therefore indirectly lead to a higher overall emission level from targeted plants than would have resulted from a conventional emission tax (Höglund, 2000).

The refund mechanism further counteract a price increase of the polluting produced good, even though this leads to benefits for the consumer this is however one of the disadvantages of refunding. By having little impact on the relative prices of products whose production involves high levels of emissions, it does not discourage demand for these products. Polluters further does not pay the full environmental cost of the pollution that their production processes causes. This since the charge and refund system does not follow the polluter pays principle (PPP) with respect to unabated pollution. Since too many productive resources are allocated to emission intensive production relative to cleaner production this leads to a welfare loss for the society.

In year 2010 it was a decrease in emission efficiency. The same year it was a dip in the global oil price. So the lower emission efficiency could be explained by increased production due to cheaper fuel costs, but it was also an unusually cold winter. In the data it appears production units that are usually not covered by the NO_X charge, since they normally produce less then 25 GWh annually. Production from several firms usually covered by the NO_X charge did also increase. The decrease in emission efficiency could also be due to higher production on smaller production units that on average are less efficient. It could also be explained by the fact that there was a higher production in general than normally causing higher emissions per produced unit of energy since the technical device of the production units not was adjusted for that level of production. So the temporary decrease in emission efficiency could be explained by both the decease in the global oil price or the unusually cold winter, or the combination of them.

Another aspect to take into consideration is the conflict between NO_X abatement and abatement of other emissions. NO_X abatement often implies increases in emissions of carbon monoxide (CO), dinitrogen oxide (N_2O) and ammonia (NH_3) which partly offset the social environmental gain from reduction in NO_X emissions (Höglund, 2000). Optimal combustion, which occur in high temperatures, lower the levels of for example CO_2 emission and leads to higher energy efficiency, but NO_X

emissions increase by temperature and it is therefore a trade off between NO_X abatement and abatement of other pollutions and energy efficiency.

The decrease of the real value of the NO_X charge has lowered the incentive for emission abatement and to avoid undermine of abatement incentives it is important to adjust the charge level for the inflation.

The distribution of ownership, public- and private ownership, is uneven in the different sectors. Publicly owned firms can have other abatement reasons than pure cost minimization, as political policies and resolutions. Waste incinerating and power and heat generating firms are to a larger extent publicly owned then other sectors and this is also one of the sectors with the largest increase in emission efficiency, a result also found by Bonilla et al., (2015). Ownership is one other aspect that could affect emission efficiency, an aspect which in future studies could be interesting to estimate, whether ownership has an significant impact on emission efficiency.

The majority of the production units, and the firm's, are subjected to pollution permits, as stated in the background, therefore the reduction of emission intensity per produced unit of energy is a result of a combination of the two environmental policies the NO_X charge and the pollution permits.

So in conclusion, there are several other aspects affecting the emission efficiency then the ones stated in this study, some of them are the pollution permits, ownership as well as fuel choices and environmental policies for other pollutions.

7 Conclusions

Energy output has increased, emissions decreased and emission efficiency remarkably increased during the period 1992 to 2013 for the firms covered by the charge and refund system for the nitrogen oxides in Sweden. The sectors with the largest increase in emission efficiency are waste incineration, chemical industry and power- and heat generation.

In a sector aggregated analysis the estimations from a pooled regression model is negative and statistically significant impact on NO_X emissions per produced unit of energy on a firm level for both the real charge as the increased in the nominal charge in 2008, controlling for the variables time, inflow from hydro power plants, the global real oil price and a lag for emission efficiency. The random effects model also provides a significant negative effect of the nominal increase in the charge level. The result demonstrates that a one unit increase in the real charge level decreased emissions per produced unit of energy by 10% during the period 1992 to 2013. The nominal increase in the charge reduced emissions by 2,3%.

In a sectorial analysis the estimations for the real charge and the increase in the nominal charge in 2008 is negative for the sectors chemical production, power- & heat generation, food industry, paper- & pulp industry and wood industry. A statistically significant estimation for the real charge and the increase in the nominal charge is provided for the wood industry. A one unit increase in the real charge decreased emissions by 36% and the increase in the charge level decreased emissions by 7,6%.

In conclusion, referring to the results from the pooled and the random effects model, we can reject the null hypothesis that the NO_X charge did not have any impact on emission efficiency in a sector aggregated analysis and in the wood industry in a sectorial analysis.

Several other aspects affect the emission efficiency that has not been taken into consideration in this study. Some of them are the pollution permits, ownership as well as fuel choices and environmental policies for other pollutions.

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