

EVALUATION OF THE NORWEGIAN NOX-FUND

THE PERFORMANCE OF A TAX COMPARED TO A FUND
– A THEORETICAL AND EMPIRICAL ANALYSIS

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Summary

According to the Gothenburg protocol, Norway is committed to reduce its emissions of NO_x to a level 30% below the emissions in the base year 1990, by the end of 2010. Both Norwegian and foreign governments have made use of voluntary agreements with industries as a supplement or alternative to more traditional policy instruments. This thesis evaluates the Norwegian NO_x-fund, as an alternative method to reduce NO_x emissions compared to a standard tax system.

I start with a theoretical analysis using a standard tax model and compare it to a fund using an investment based funding system. If the tax is the same in the two cases, the investment in abatement technology would be greater in the fund system because of the subsidy for capital expenditures given to the firm. However, the two taxes are not equal, and the same optimal solution could be reached in the two cases. As we know that the subsidy given to the firms varies a lot, this suggests that a fund system will not provide equal marginal abatement costs between firms, and abatement will not be cost efficiently distributed.

Later on, I expand on the theoretical model and introduce hidden information about the firms marginal abatement cost. The main result in this model is that a first best optimum is impossible to reach when the firms have information power over the fund, and information rent has to be paid to the most efficient firm. Therefore a lower level of abatement is reached at a higher cost in the second best solution.

I analyze the fund by looking at the marginal abatement cost curve using data from both implemented and planned abatement projects. There are several types of new investments in NO_x reducing technology, which I classify into seven different categories. Here I find that the marginal cost of the projects differs a lot between different initiatives, and also within each category. I see that the most cost efficient initiatives which also contribute to high abatement levels are fuel saving, selective catalytic reduction (SCR) and motor technical rebuilding, and I focus my analysis on these categories of NO_x reducing technologies. We see that the most efficient initiatives also are among the majority of the funded projects from the NO_x-fund.

There could also be political explanations for not reaching the first best level of

abatement. As lobbying from interest groups might affect the government's preferences in maximizing welfare, this could lead to environmental policy not maximizing the NOx reduction at the lowest possible costs.

Finally, I present a few different scenarios for implementation strategies of NOx reduction technologies. I have looked at the three most cost efficient categories, and I assume it is possible to double the number of potential projects if one has a longer time perspective. This implies installing these NOx reducing technologies into 40% of the Norwegian trade fleet. I find that it would have been possible to reach the same level of abatement as what is reached today, at a total cost 39% lower than the present cost level, if twice as many of the SCR, motor technical rebuilding and change to gas projects were added to the already existing projects. Instead of reaching the level of 26 078 tons of NOx abatement at a total cost of 399 million NOK, it could have been reached at a total cost of 244 million NOK. In a more modest scenario, I find that the same level of abatement could be reached at a total cost of 321 million NOK, 20% cheaper than today. This is the case if only the same three projects were carried out. As new investments only are profitable when they are in dock for other maintenance purposes, this might suggest that one needs more time in order to reach a more cost efficient solution.

Preface

This thesis is a part of a project called "Diffusion of climate technologies", project-number 199911/E20, at Statistics Norway. I am deeply grateful for all the help from my supervisor Cathrine Hagem. I could not have asked for a better supervisor.

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All remaining errors are mine.

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1 Introduction

According to the Gothenburg protocol, Norway is committed to reduce its emissions of NO_x to a level 30% below the emissions in the base year 1990, by the end of 2010. Both Norwegian and foreign governments have made use of voluntary agreements with industries as a supplement or alternative to more traditional policy instruments, like an emission tax. One example is the Swedish refunded emissions payment program.¹ In this thesis I will analyze these voluntary agreements, using the Norwegian NO_x-fund as an example.

The Gothenburg Protocol was ratified in 1999 and entered into force 17th of May 2005 (MOE, 2005). The Protocol states that the emissions by the end of 2010 cannot be higher than 156 000 tons of NO_x, and should stay at this level from then on. In the base year 1990 the emissions were 191 000 tons NO_x (SSB, 2008). In order to fulfill these commitments a tax of 17 NOK per kg NO_x emission was introduced 1st of January 2007. As a reaction to the introduction of this pollution tax, a NO_x fund was established. The over 640 firms that have joined the fund are exempted from paying the tax on NO_x emissions to the government. Instead they have to pay a lower fee per kilo NO_x emission to the NO_x-fund. The fund finances emission reducing investments in the firms after applications from the members of the fund. Slightly more than 200 firms have been promised support from the Norwegian NO_x-fund, for around 520 NO_x reducing investment projects.² Total expected emission reductions are nearly 27 000 tons of NO_x, which includes both verified and planned projects.

As far as I know, no research has been done until now to try to evaluate the Norwegian NO_x-Fund, but theoretical studies of this type of policy design more generally is a large field in the literature (Lyon and Maxwell (2000), Hansen (1999), Arora and Cason (1996) and Khanna (2001)). Sterner and Turnheim (2009) is a study of the situation in Sweden, but the article is more of a study of the process of the technical change and a study of innovation, adoption and diffusion of

¹For more examples see chapter 2 about voluntary agreements.

²Updated lists over promised support shows that there are 533 projects in total.

technology.³

The rest of chapter 1 gives information on what NOx is and its implications for the environment, the background of the fund and a tax on NOx, and the work of establishing the NOx-fund. Chapter 2 gives a brief overview of the existing literature on voluntary agreements. In chapter 3 I put up a theoretical model comparing a standard tax system to the Norwegian NOx-fund, and describe the pro's, con's and the respective incentives of the systems. Chapter 4 is a short discussion of the political economy and its implications of the NOx-fund. In chapter 5 I use data from the NOx fund, for both implemented and planned initiatives, and compute their marginal abatement cost functions. In chapter 6 I expand on the theoretical model from chapter 3, and introduce hidden information about the firms marginal abatement cost. Chapter 7 concludes.

1.1 Background

Acid rain is caused by combustion of fossil fuels. It originates from the emissions of a variety of pollutants, that are subsequently chemically converted into acid form, particularly sulphuric and nitric acids (SO_2 and NOx). Its international dimensions arises from the property that some proportion of the pollutant emissions in question, the precursors of acid rain, are transported over national boundaries by natural processes, like wind, rain and rivers. Examples include oxides of nitrogen and sulphur, which can be moved over distances of several hundred miles. Unlike greenhouse gases, these substances are not uniformly mixed, so the impact is regionally rather than global (Perman and M.Common, 2003).

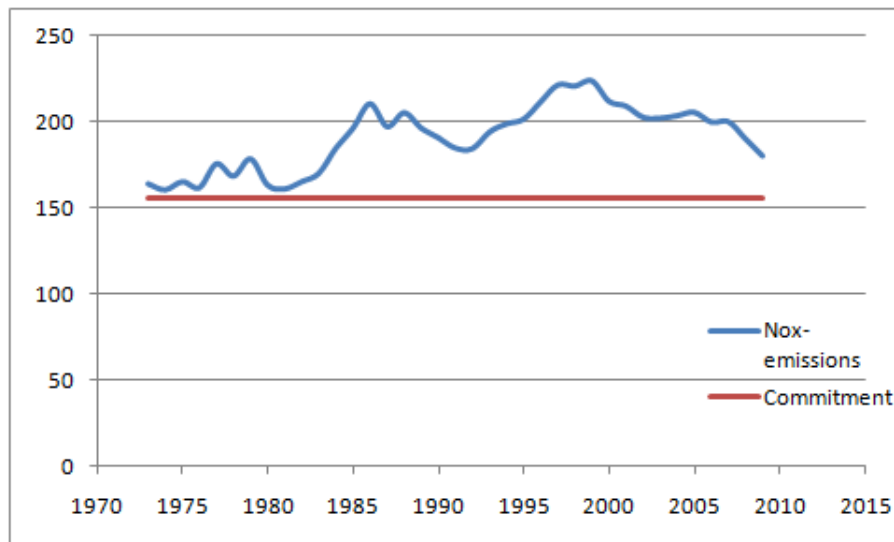
About 90 per cent of the sulfur and 80 per cent of the nitrogen deposited in Norway originates in other European countries. This means that the amount of acid rain falling on Norway is to a large extent determined by developments elsewhere in Europe(SOE, 2011), with the UK, Germany and Poland among the largest sources. Studies of consequences of acid rain pollution in Europe have been conducted by the Commission of the European Communities (CEC, 1983) and the World Conservation Union (WCU, 1990). These research programs have identified the following

³More on Sterner's article in chapter 2.

consequences (Perman and M.Common, 2003):

- Increased acidity of lakes, results in dead fish
- Increased acidity of soils, which reduces the number of plants that may grow
- Forest destruction
- Human health effects via acidification of domestic water supplies and sulphate pollution in general
- Building and infrastructure erosion
- Loss of visibility, causes by fine sulphate particles produced by airborne sulphuric acid

Graph 1.1: NO_x-emissions from Norway 1973-2009. Emissions are measured in 1000 tons. Source: Statistics Norway



Since acid rain does not respect national borders and is a problem for most European countries, international agreements are essential to reduce emissions, and most agree that this problem has to be solved internationally. The issue of transboundary pollution is the need to coordinate the environmental policies of national governments, who might ignore the damage to other countries by caused by domestically generated pollution (Ulph, 1998). The answer has been to reduce overall European emissions of sulfur and nitrogen through binding international agreements. Most European countries have agreed to reduce their emissions of acidifying substances

through the Convention on Long-range Transboundary Air Pollution.⁴ Several binding protocols have been adopted under the convention, including the Gothenburg Protocol, which entered into force in 2005. This protocol is being used to control emissions of sulphur and nitrogen (among others) in Europe from 2010(SOE, 2011).

1.2 Storyline

As previously mentioned the Gothenburg protocol was signed on the 17th of May 2005. Already on the 23rd of May the Ministry of the Environment asked The Norwegian Pollution Control Authority (Statens Forurensningstilsyn, SFT) to put down a working group together with the Norwegian Petroleum Directorate and Norwegian Maritime Directorate, to evaluate initiatives contributing to Norwegian reductions of NO_x, in order to fulfill the Gothenburg protocol within 2010.

SFT was asked to look at different ways of reducing the NO_x emissions so that Norway could reach their emission reductions according to the Gothenburg protocol.⁵ Their estimates varied hugely from sector to sector, from 7 to 700 NOK/kg NO_x reduction. The protocol committed Norway to reduce its emissions to a level of 156 000 tons per year, which at the time meant reducing the emissions yearly with around 45 000 tons below the emission prognosis for 2010 (SFT, 2006). At a later stage the emission factors were adjusted down, so that instead of reducing emissions with 45 000 tons, it meant reducing emissions with 16 000 tons(Flugsrud and Aasestad, 2010). The object of the analysis was to provide information so that the best decisions according to abatement costs and reduction potential were made. They looked at the different initiatives within shipping and fishing, energy installations offshore and the mainland industry.

For the oil and gas industry the analysis from SFT showed large differences in abatement costs between different installations. They only looked at installations of low-NO_x turbines called dry low emissions (DLE), as this is the only technology that is qualified offshore. The investment costs lies between 50 and 600 million NOK

⁴A convention under the United Nation Economic Commission for Europe, that has been extended by eight environmental protocols where the most recent one is the Gothenburg Protocol.

⁵SFT is now renamed KLIF(Climate and Pollution Agency), but as they were called SFT at the time of this report I will call them SFT in my thesis.

per turbine. 8 of the total judged 49 machines had a cost less than 50 NOK/kg NO_x reduction, and reduced emissions with 2500 tons NO_x. For a cost lower than 100 NOK/kg NO_x it could be possible to reduce emissions with 70 000 tons to a cost of around 3,5 billion NOK. By installing DLE at all 49 machines it would technically be possible to reduce emissions with 17 000 tons, to a cost of 19 billion NOK. The costs of each initiative offshore varied between 13 NOK/kg NO_x reduction and 700NOK/kg NO_x reduction, which is a large variation within one initiative.

For domestic shipping the total NO_x reduction potential was in the basis of ships with engines build after 1990, with a size larger than 100 brutto tonnage. The total emissions from these ships were in 2005 about 62 000 tons. In reality there are two possible initiatives possible to implement on board of excising ships, selective catalytic reduction (SCR) and motor technical rebuilding (MTR).⁶ If SCR is carried out on all of the domestic fleet, the emission reductions could be almost 43 000 tons NO_x, to a average cost of 7,46 NOK/kg NO_x and a total cost of 320 million NOK. Thus, by only implementing SCR initiatives one could reach the target and fulfill the Gothenburg protocol. Alternatively, if MTR was carried out on all ships, it would have reduced emissions with 10 000 tons to a cost of 50 million NOK, which gives an average cost of 4,8 NOK/kg NO_x. It is not possible to implement both initiatives at the same ship, so they must be seen as two alternatives.

After a more specific evaluation of the ships, SFT evaluated the possible distribution of projects between SCR and MTR, so that total possible reductions for domestic shipping is 26 000 tons NO_x.

Emission reduction for each sector of the mainland industry is very uncertain, and is restricted to a reduction of 5 500 tons to an average cost of 15 NOK/kg NO_x (SFT, 2006). Table 1.1 show the results of the estimated costs and their potential emission reductions; graph 1.1 and 1.2 represents it graphically.

As a reaction to this report, the Norwegian State introduced a tax from January 1st 2007 of 17 NOK/kg emission of NO_x on the following sources:

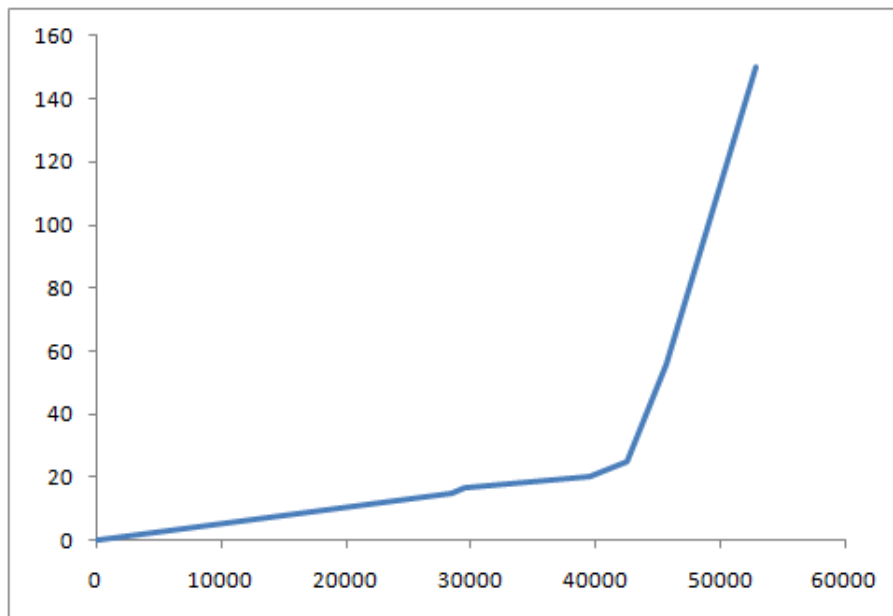
- propulsion machinery with a total installed capacity of over 750 kW
- motors, boilers and turbines with a total installed capacity of more than 10 MW

⁶An explanation of the different initiatives can be found in chapter 4.2

Table 1.1: SFT table. Average costs of abatement and corresponding NOx emission reduction, measured in tons.

Sector	Cost	Emission reduction	Aggregate emission reduction
Shipping/fishing ships	<15 NOK/kg	26 000	26 000
Mainland industry	<15 NOK/kg	2 500	28 500
Energy installation	<17 NOK/kg	1000	29 500
New ships	20 NOK/kg	10 000	39 500
Mainland industry	< 25 NOK/kg	3000	42 500
Energy installation	18-56 NOK/kg	3100	45 600
Energy installation	57-150 NOK/kg	7200	53 800

Graph 1.2: SFT analysis: Aggregated emission reductions measured in tons of NOx on the x-axis, increasing marginal cost measured in NOK/kg NOx reduction on the y-axis. Source: SFT



- flares on offshore installations and facilities on land

By this the tax on emissions covered domestic shipping and fisheries, aviation, railway operations, landbased activities and offshore activities on the Norwegian continental shelf (MOF, 2006).

This excise tax was introduced in order to fulfill the Gothenburg agreement by 2010, and stated that according to previous analyses (from SFT) this could lead to emission reductions up to 26 000 tons of NO_x. Thus, according to the new calculations of the emission factors performed by Statistics Norway, a tax of 15 NOK/kg NO_x emission would have been sufficient in order to reach the target of the Gothenburg protocol. The government also stated that the SFT report indicated that initiatives with a marginal cost up to 50-60 NOK/kg NO_x had to be carried out in order for the protocol to be fulfilled, because at that time fulfilling the agreement meant reducing the NO_x emissions with 45 000 tons. These are important findings of the analysis, as one of the reasons for establishing a fund was not having to face a marginal cost of 50-60 NOK/kg NO_x reduction. These initiatives would not have been followed through with an emission tax of 17 NOK/kg NO_x emission. If one would have continued with a tax of 17 NOK/kg NO_x emission, the new calculations that downscaled the needed emission reduction to fulfill the agreement, would have been sufficient in order to reach the goal by using the tax as policy instrument.

To compensate for the high marginal cost they introduced a NO_x-RED agreement at the same time, so that shipping could be compensated with up to 30-40 % of their additional cost, and fishing could be compensated with up to 100% of their additional costs.⁷ The purpose was to reduce the economic burden for the internationally exposed industry (MOF, 2006).

In 2007 the total tax revenue was 632 million NOK. The resolution also included an exemption from the tax if an environmental agreement with the state was agreed upon concerning the implementation of measures to reduce NO_x, in accordance with a predetermined environmental target. It also stated that "The Ministry may issue regulations limiting and imposing conditions on exceptions".

⁷The NO_x-RED agreement gave the possibility of giving investment support to initiatives that reduced their emissions in the shipping and fishing industry.

In 2008 the "NOx Agreement" and the "Participation Agreement" were signed. The NOx agreement is the agreement of establishing the fund, and is a collective environmental agreement between fourteen business organizations who represented undertakings emitting NOx, and the Ministry of Environment on behalf of the Norwegian Government.⁸ The objective of the agreement was to fulfill specific reduction obligations in 2008, 2009 and 2010, and the fourteen organizations committed themselves to ensure the implementation of measures that would reduce the annual emissions of NOx by 30 000 tons by the end of 2011. These fourteen business organizations are not themselves producing NOx nor subject to the NOx tax, so the "Participation Agreement" created the rights and obligations between the individual undertakings and the NOx Fund. According to this agreement, the undertakings that have signed the agreement pay 11 NOK/kg NOx emission to the firm if they are offshore petroleum industry, and 4 NOK/kg if they are from other sectors such as shipping, supply vessels, fishing and aviation, instead of paying 17 NOK/kg NOx emission in form of the tax to the government. These fees are set by the fund itself, not the government. According to the agreement the NOx Fund shall be operated in accordance with the non-profit principle and has the purpose of supporting the business organizations in fulfilling their obligations under the agreement, and stated that the state and the Business Organizations are committed to working together to survey, develop and provide information on possible emission reducing measures for the implementation of the NOx Agreement. The agreement also stipulated that the annual reductions in emissions are as follows:

- reduce annual NOx reductions by 2000 tons with measures implemented in 2008
- reduce annual NOx reductions by additional 4000 tons with measures implemented in 2009
- reduce annual NOx reductions by additional 24 000 tons with measures implemented in 2010

⁸Byggevarerindustriens Forening, Fiskebåtredernes Forbund, Fiskeri og Havbruksnæringens Landsforening, Fraktestøtøyenes Rederiforening, Hurtigbåtenes Rederiforbund, NHO Luftfart, NHO Reiseliv, Norges Fiskarlag, Norges Rederiforbund, Norsk Fjernvarme, Norsk Industri, Næringslivets Hovedorganisasjon, Oljeindustriens Landsforening and Rederienes Landsforening

Altogether this means that they undertake to implement measures that sum up to 30 000 tons NOx emissions lower than business as usual level. The emission factors mainly from shipping and fishing were downscaled, so that these sectors got their total emissions reduced by 14 000 tons of NOx.^{9 10} This meant that instead of the fund having to reduce their emissions with 30 000 tons of NOx, they had committed themselves to only reducing 16 000 tons of NOx. December 14th 2010 a new NOx Agreement was signed for the period 2011 - 2017 on a further NOx emission reduction of 16 000 tons of NOx by the end of 2017.

⁹When calculating the total NOx reductions, the use of fuel is multiplied by an emission factor(NOx emission per liter use of fuel).

¹⁰Because of analysis performed by Statistics Norway.

2 Voluntary Agreements

One of the most striking developments with regards to environmental policy design in the 1990's was the progress of a "voluntary approach" to pollution abatement, where firms make commitments to improve their environmental performance above and beyond the level required by law (Lyon and Maxwell, 2000). According to Lyon and Maxwell there exists three different types of voluntary agreements; unilateral commitments by industrial firms, public voluntary schemes and negotiated agreements created out of a dialog between government authorities and industry. The NOx-fund is an example of an agreement of the last type. This type of agreement typically contains a target and an associated timetable. These types of agreements also take on the status of legally binding contracts if legislation empowers the government to sign them, and both business and government are active participants.

The negotiated agreements are more common in Europe than in the United States. Some would say this is because of the tradition of relatively cooperative business/government relations. Some examples of government-industry negotiated agreements include the French agreement of end-of-life vehicles, the Swedish REPA-scheme, the Swedish REP-system and the Dutch policy of a specific emission target level in the chemical industry.^{11 12}

Hansen (1999) divides voluntary agreements into three different groups which he calls a) voluntary instruments that do not involve the public directly, b) voluntary instruments involving the public and c) voluntary instruments that allow firms to choose from different regulatory schemes. In the first category promotion of energy savings is included, and could be understood as subsidizing development or supply of preferred technologies and subsidies for provision of costly information to firms. These subsidy based instruments have non-negative net income effects for the polluting firms, and thus implies that the regulator accepts that firms have the right to pollute. In this case the polluting firms have no reason to oppose implementation of policies like this, and they may be said to be more voluntary for

¹¹The REPA-scheme is an agreement to produce responsible packaging and concerns the collection, recycling and material recovery of waste from packaging.

¹²The REP-system is a refunded emission programs, concerning NOx-emissions.

firms than others. The NOx-Fund share several of the same type of descriptions as Hansen states, and one might suggest that the agreement is a pure gain for the firms. The term voluntary agreements is also used for advanced versions of hard regulatory instruments, that specify that a firm may be exempted from standard regulation if it agrees to undertake alternative measures to achieve the same goals. Firms implicitly reveal private information about their costs to the regulator, by choosing from a menu of regulatory contracts. Depending on how these contracts are constructed, different schemes may induce different behavior that in some cases can increase efficiency of the regulator.

Hansen (1999) also presents a model where voluntary agreements involve a direct negotiation between the industry and a regulatory body (government), and thus avoiding the legislative process. Voluntary agreements produce no tax revenue compared to standard environmental regulation, and compliance with these voluntary agreements may be more or less costly than compliance with legislative requirements. He also presents an extension of the model where he includes various interest groups, who are publicly criticizing the actors responsible for their decisions. The result here is that legislators are scared of public criticism and thereby delegate too much power to regulators, who may lack incentives to maximize welfare. In light of his analysis, this suggests that the government is scared of public criticism if they don't manage to reach their environmental goal, and therefore give too much responsibility to the NOx-fund.

The empirical literature on voluntary environmental agreements is thin, and the few papers that undertake quantitative analyses of corporate environmental actions have dealt with discrete choice decisions, for example Khanna and Damon (1999), Henriques and Sadorsky (1996) and Arora and Cason (1996). Such econometric models look at a pollution-reduction program with two possible choices, to join or not. They estimate the following model $y_i = \beta x_i + u_i$, where $i = 1, 2, \dots, n$ firms, using standard probit or logit models, where $y_i = 1$ if the firm chooses to join the program and 0 otherwise.¹³ x_i is a vector of explanatory variables, where

¹³See Kenneth E. Train: Discrete Choice Methods with Simulations, Cambridge University Press; Second Edition (2009).

these typically are firm level data such as financial data, advertising intensity, R&D intensity, firm size, previous emission levels and so on. u_i is a random error term with mean zero. What they want to find in these models is $E(y_i|x_i) = \beta x_i$, which is interpreted as the probability that a firm with characteristics x_i will join the voluntary program. In my analysis I do not have this type of firm level data and is unable to do a similar analysis. Also, I only have data on the firms that are members of the fund and applies for funding, so a more thorough econometric analysis is unfortunately not possible.

Karamanos (2001) divide voluntary environmental agreements into four defining characteristics: 1) They are voluntary, 2) the primary objective is to improve environmental conditions, 3) they are based on some type of formal or informal agreement and 4) they can be developed between various sectors such as corporate and government sector, corporate and non-profit sectors, government and non-profit sectors or between all three sectors. He points out that although industry associations are non-profit organizations, his study treats them as part of the corporate sector because they represent corporate interests. In terms of his definition, the NOx-fund would be characterized as the corporate sector, although the fund is a non-profit organization. He uses the definition of what a voluntary environmental agreement is from Long and Arnold (1995), who suggests that voluntary environmental agreements are *"agreements among the corporate, government, and/or non-profit sectors not required by legislation that aim to improve environmental quality or natural resource utilization"*. He chooses to use this definition as it captures all four of his own characteristics. He agrees with Lober (1997), which says that *"The environmental solutions that voluntary environmental collaborations seek are an extension of those occurring or likely to occur in the regulatory arena rather than a dramatic departure"*, and states that voluntary environmental agreements do not represent a radical change from the existing regulatory framework.

Arora and Cason (1996) examines why firms participate in voluntary environmental programs and look at the US EPA 33/50 program.¹⁴ They conclude that

¹⁴The goal was to reduce the releases and transfers of 17 toxic chemicals by 50% between 1988 and 1995.

this voluntary agreement approach may have the potential to become an effective means of achieving environmental protection and argues that over compliance may result from irregular/uneven investments in pollution abatement, which could result in substantial cost savings in the long run.

The main analysis of their article is an econometric specification like the one presented above, and their main findings is that the largest firms with the greatest toxic releases are the most likely participants of the voluntary agreements. Also there is no evidence that firms free-ride when comparing to the emission reductions prior to the program's initiation.

Sterner and Turnheim (2009) have done a study of the Swedish REP-program. They study the process of the technical change and innovation, adoption and diffusion of technology. They find that the best firms¹⁵ have reduced their emissions by 70% and the median firms have caught up with best practice. However, the Swedish NOx policy is different from the NOx-Fund. In Sweden, taxes are paid to the government and then distributed back to the firms depending on their relative output levels (Fredriksson and Sterner, 2005). The firms with the lowest emission intensities become net beneficiaries of the system, whereas those with above-average emission intensities make a net payment. In Norway, this is not the case, depending on industry they pay different tax to the NOx fund, and get different funding or no funding for investing in new capital equipment that reduce the NOx emissions.

¹⁵Defines best as the firms with the lowest emission intensities.

3 Theoretical Model

3.1 A Model for Emission Reduction

We look at a sector consisting of firms that produce the same commodity, for instance say we either just look at the fishing industry or the shipping sector. The production causes emission, combustion of fuel that creates NOx emission, denoted e , that has a negative impact on the environment. Emissions is a function of investment in capital equipment I , where the firm can invest in new technology that can reduce its emissions. We consider all investments as abatement activities that have a durable effect on emissions.

3.1.1 Standard Tax System

I assume that all firms are price-takers and will maximize their profit. I will set up the minimization problem for each firm and they will minimize their costs according to

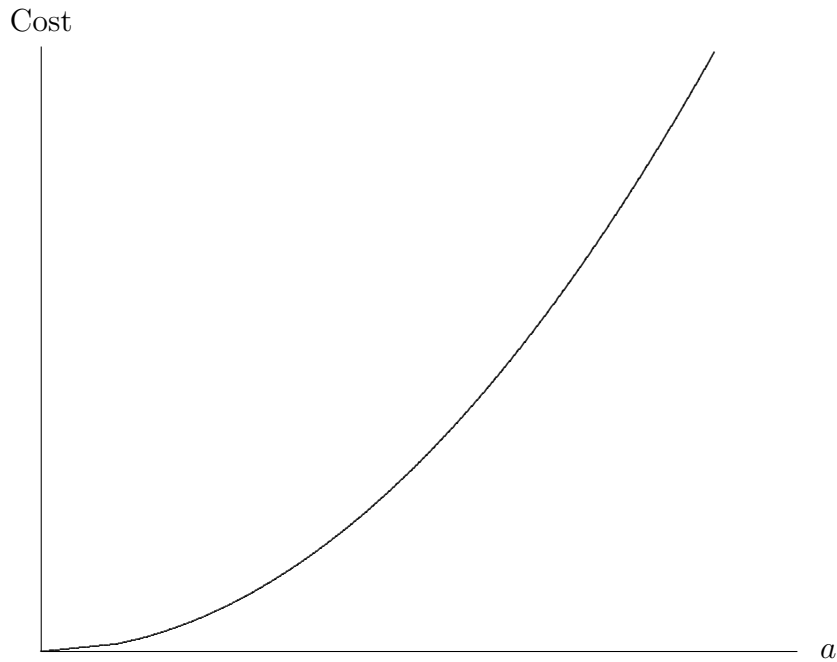
$$\text{Min } c_i(a_i) + te_i \tag{1}$$

with respect to e_i , where $a_i = E^0 - e_i$. a_i is abatement and E^0 is the business as usual level of emissions, which is the firm's emission level if there is no environmental policy. We assume that the production is given and unaffected by investments in abatement technologies. t is the unit price of emission per kilo and $c_i(a)$ is the abatement cost function, which is increasing and convex in abatement, $c'(0) = 0$, $c'(a) > 0$ and $c''(a) > 0$. We do not look at abatement as a reduction of the firms quantity produced, as we have assumed that this is constant, but only as abatement when the firm is investing in new capital equipment.

We differentiate with respect to e_i to get the first order condition for interior maximum.

$$\begin{aligned} c'_i(a)(-1) + t &= 0 \\ c'_i(a) &= t \end{aligned} \tag{2}$$

Figure 3.1: The abatement cost function



If $t = 0$, there is no regulation. Firms would behave with setting $c'_i(a) = 0$, meaning that $E^0 = e_i$. The firm would have emissions at the firm's optimal level (profit maximizing level of emissions), setting their emission equal to the business as usual level of emissions. A consequence when there is no regulation is that there will be zero abatement, $E^0 = e_i$ and hence $a = 0$. There will be no new investments in new capital equipment, $I = 0$. When there is a tax on emissions $t > 0$, emissions are costly due to the emission tax. The cost minimizing firm will reduce its emissions and choose $c'(a) > 0$. The higher the tax is, the more will the firm reduce its emissions.

Emissions are reduced by increasing the investment in capital equipment. $a_i(I_j)$ is abatement as a function of investment in capital equipment. The abatement function is increasing and convex in investment, $a'_i(I_j) > 0$ and $a''_i(I_j) > 0$.

3.1.2 Investment Based Funding: The Norwegian NOx-Fund

Now we assume that each firm can apply for funding that will cover parts of their investment expenditures. We include this funding as a subsidy, s , for durable abatement investments. s is a share of the total investment subsidy that the firm

gets funding for, so $(1 - s)p_j I_j$ is the part of the investment that the firm has to cover. There are different projects to invest in, I_j , where $j = 1, 2, \dots, n$ represents the different projects. Each project has different prices p_j .

We assume that $c(a) = p_j I(a)$ so that, $c'(a_i) = p_j I'_j(a_i)$. The firms apply for funding from the NOx-fund, which is the same as the one's charging the tax. The budget constraint for the NOx-fund is $t \sum e_i = s \sum p_j I_j$.

In this case we have two different approaches. Either s could be fixed and the investment support could be rationed, or s could be endogenous according to the budget constraint of the NOx-fund. In fact, considering s as fixed and the investment support rationed is quite close to the current design of the Norwegian NOx-fund, and is hence what I will focus on further. Investment projects will be approved until the total budget $t \sum e_i$ is spent. It appears unlikely that this mechanism has implied that the best investment projects have been realized. I will expand further on this topic later by introducing hidden information about the firms abatement cost into the model in chapter 5, and a theoretical evaluation of the fund follows. The cost minimization problem for the firm is:

$$\text{Min}(1 - s)p_j I_j(a_i) + t e_i \quad (3)$$

and we differentiate with respect to e_i and assume we have an interior solution, to get:

$$\begin{aligned} (1 - s)p_j I'_j(a_i)(-1) + t &= 0 \\ p_j I'_j(a_i) &= \frac{t}{(1 - s)} \\ c'(a_i) &= \frac{t}{(1 - s)} \end{aligned} \quad (4)$$

(4) is the optimality condition for a fund system. If we compare the first order condition for the standard tax system to the investment based funding, (2) and (4), we see that if the tax is the same in the two cases, the investment in abatement technology would be greater in the fund system because of the subsidy. When t is equal, the marginal abatement cost is increased by a factor $\frac{1}{(1-s)}$, and thus

investments will amplify. This happens when $s_i = s_j$.

We know that t is not equal in the two systems. In the tax system $t = 17$ NOK/kg NOx emission, and in the fund system either $t = 4$ NOK/kg or $t = 11$ NOK/kg NOx emission. By adjusting s according to the level of t , one could reach the same solution in both the tax and fund systems, for example $t = \frac{t}{(1-s)} = 17$ NOK/kg NOx emission.

Although it is possible to reach the same solution in the two systems, we know that different subsidies are given to different projects in the fund system, $s_i \neq s_j$, and some do not receive a subsidy at all. In that case the marginal abatement cost will differ across firms, $c'(a_i) \neq c'(a_j)$, and abatement is not cost effectively distributed.

3.2 Comparing a tax, fund and subsidy system

I want to look at the advantages and disadvantages between different environmental policy designs and analyze their implications. It is known in environmental economics that an emission tax and abatement subsidy gives different incentives, and I want to compare a tax, a fund and a subsidy system.

Starting out with the revenues of the three methods, if assuming that all three designs have the same target of abatement, a , we know that a tax on emissions will lead to a tax income of $t^* \sum e_i$, whereas a fund system will have zero public revenue and an abatement subsidy will have an income of $-s \sum a_i$, where $s = t$ and hence an income of $-t \sum a_i$.

Now we do not look at a given level of abatement, a . If the number of firms in the industry are endogenous, when using an abatement subsidy the industry will now be more profitable compared to no policy, and this will attract more firms to the industry and the total number of firms will rise. On the other side, when the number of firms are endogenous, an emission tax will make the industry less profitable and the total number of firms will decrease. The effect on total emissions is an unambiguous reduction, as the tax both reduces emissions from existing firms and could decrease the total number of firms. The effect on total emissions when using an abatement subsidy is uncertain, but what we know is that total emissions

are higher with a subsidy than with a tax, and it might even be higher than with no regulation. Thus an abatement subsidy will prevent that non-profitable firms fail, because it makes the industry as a whole more profitable (Perman and M.Common, 2003).

When looking at revenue to the government, a fund system is neutral in the way that it neither creates income nor expenditures, and at the same time reduces emissions by the same amount. When comparing a tax system to a subsidy, both can reach the same level of emission reduction, but the tax creates revenue and the subsidy creates expenditures.

In a way one can analyze the fund system as an earmarked tax. Buchanan (1963) defines earmarking as the practice of dedicating specific revenues to the financing of specific public services. Some argue that earmarking tend to reduce the willingness of taxpayers to approve expenditures on specific public services (Margolis, 1961), while others sees earmarking as a device for generating taxpayer support for expansion in particular services (Rolph and Break, 1949).

Oates (1995) states that if pollution taxes are drained off into trust funds, this will result in increased spending, which in turn means that certain environmental projects are likely to be undertaken simply because there is unused money in the fund. He argues that environmental projects should have to be met by the same economic and budgetary tests as other projects, and not be undertaken simply because of the availability of some earmarked funds.

Oates (1995) states that rather than an environmental trust fund, a more appealing approach is a revenue neutral tax package which works in a way that new taxes on pollution can be combined with reduction in other taxes, that will generate support for the proposed reform. He uses the Swedish environmental tax reform as an example (Sterner, 1994), where taxes on CO_2 and sulfur emissions were introduced, and he suggests that such revenue-neutral reforms also can address equity issues. Pollution taxes play a positive and significant role in the revenue system, reduce levels of polluting activities and provide important incentives for research efforts into new and improved abatement technologies (Oates, 1995), and therefore Oates argues that it is better to use a pollution tax, and if necessary combine the

tax with other policy instruments.

3.3 Theoretical evaluation of the NOx-Fund

We have seen that if the same tax level is applied in a fund- and tax system, abatement would be higher in the case of a fund because investment in new abatement technology is higher when a subsidy is given to the firms. However, the tax is not the same as it is 17 NOK/kg NOx emission in the case of a tax, and in a fund system it is either 4 or 11 NOK/kg NOx emission. By adjusting the subsidy according to the level of the tax, one could reach the same solution in both the tax and fund systems. As the subsidy differs between different types of investment, it is thus unlikely that one reaches the same solution as in a tax system.

At the same time a fund system is neutral in government revenue, as it neither creates income nor expenditures. As the total budget of the firm, $t \sum e_i$, is likely to be used, it appears unlikely that this leads to only investment in the most cost efficient projects. This is also pointed out by Oates (1995).

Another point worthy of mention is that from a public revenue point of view the oil and gas industry has a marginal income tax of 78%, while the other industries have a marginal income tax of 28%. This means that expenditures from the oil industry to a large extent is paid by the government. The oil and gas industry pay the largest share of the total income to the fund, as their fee is higher.¹⁶ This implies that the NOx fund to a large part is funded by lost revenue from the oil and gas industry.

¹⁶11NOK/kg NOx emission is paid to the fund only by the oil and gas industry. The rest of the members pay a fee of 4NOK/kg NOx emission.

4 The political economy of the NOx-fund

Environmental policy reform often faces stiff resistance from industry lobby groups (Fredriksson and Sterner, 2005). In Norway there has been hard resistance from lobby groups against having to pay taxes on pollution and other taxes in general.¹⁷ When the tax on NOx emissions was introduced in Norway in 2007, this received a wave of protests especially from the cruise and shipping industry (Axelsen, 2007).

The argument used by the industry is that if they have to face higher taxes in Norway than elsewhere, this would be a great economic burden for an internationally exposed industry. Thus, rather than having to pay high taxes on emissions, the shipping industry would decide to register its entire fleet abroad. As it is important for the Norwegian government to implement policies to make Norwegian companies competitive on the world market, this resistance affects the preferences of the politicians. There is thus a trade off between political feasibility and cost efficiency.

The analysis in chapter 3 showed that when the number of firms in the industry are endogenous, an emission tax will make the industry less profitable, some firms will go bankrupt and the total number of firms will decline. This is an unwanted policy implication for the government, and might be an explanation to why implementability of abatement is prioritized over cost efficiency.

Fredriksson and Sterner (2005) examine how lobbying from the industry affect the refunded emissions payment programs (REPs) in Sweden, where the pollution tax proceeds are refunded to the collective tax-paying polluters in proportion to their output shares. The generated tax revenues are returned to firms based on their relative output levels, and firms cleaner than the average receive refunds that are larger than their tax payments. This could possibly be more than enough to compensate for abatement costs. Fredriksson and Sterner (2005) put up a model where they assume the existence of a REP program and looks at how two types of lobbying firms with different abatement technologies affects the pollution tax.

¹⁷The resistance showed itself particularly when Norges Rederiforbund sued the Norwegian government because of a tax that had to be paid back to the government, and won the case in Supreme Court in 2008.

They find that without a REP system the two firms exert resistance towards the pollution tax, as reflected by the unambiguously negative political pressure from the two lobbies. When comparing this to the case where a REP system is present, it reduces the political lobbying on the pollution tax, meaning that the REP program creates a powerful constituency in support of a higher pollution tax. In a REP program, equilibrium firms with relatively low pollution intensity may lobby for a higher tax, because it benefits sufficiently from the refunds to outweigh its abatement cost.

Sterner and Turnheim (2009) argues that in a REP system, one benefit of combining a tax with a refund is its political economy. Although the abatement incentives are practically the same as for a tax of the same value, polluters are less averse to the REP scheme. This can be explained by the fact that the marginal cost of abatement is essentially the same as the fee level, but the average net payment is much lower due to the refund. Potential resistance is defused and lobbying from the polluters is reduced. Some of the same arguments can be applied to the NO_x fund, and at the same time the marginal cost of abatement is even lower than for a tax, which make polluters even less averse to the fund system.

Fredriksson (1997) argues that one reason for why governments do not internalize fully the environmental externalities is that they do not maximize welfare, but rather maximize a utility function which also includes the influence of a special interest group. Governments thus set up environmental policy which differ from the first best solution. The result is that the political equilibrium tax rate on pollution differs from the Pigouvian tax rate, because of lobby groups and the government's weight on social welfare relative to lobbying activities.

5 The Marginal Abatement Cost Function

5.1 Description of the data

The data used to evaluate the NOx fund comes from the NOx-fund itself and Det Norske Veritas (DNV).¹⁸ Firms that apply for funding must report what kind of initiative they are applying for, how much NOx reduction they expect, how much fuel they believe they will use after the new investment has been completed, how much money they are applying for and the private cost of the investment. This data is available on the website of the NOx-fund together with a detailed description of each initiative.

The role of DNV is to secure the quality of each application, give recommendations to the NOx-fund about what kind of initiatives they should prioritize in order to reach their agreed volume of abatement, and to find the most cost efficient use of the money from the fund.¹⁹ Thus, DNV has a regulating role.

The rest of the data I have used stems from DNV's calculations about the cost of NOx reduction per project, and the cost of NOx reduction per project in total. Here I focus only on the total costs, as I am interested in looking at the total use of resources in this case, and not only on the money used from the fund. The reason for doing this is because I want to look at the total cost of the NOx reduction, and not the total cost of the NOx fund.

One great disadvantage with using this type of data is that I have not been able to do the calculations on the costs myself. These calculations contain data both from projects that will be carried out within the two next years, and verified projects. The assumptions about life expectancy of the investment, the annuity factor and interest rate are all made by DNV, and this limits the analysis of the data. However, as DNV is an expert in this field, I assume that it is safe to trust their assumptions and rather use my thesis to analyze their calculations in an economic perspective.

¹⁸www.dnv.no

¹⁹www.nho/norx

5.2 Description of the initiatives

In this part I will briefly explain the different initiatives that receive funding from the NOx fund in order to reduce the emissions. Hence, the following measures are examples of new investment projects.

Selective Catalytic Reduction(SCR):

SCR is the most widely used measure in cleansing of NOx in exhaust. By adding urea or ammonia to the catalytic process it converts NOx to N_2 and H_2O . A SCR installation consist of a SCR-reactor, a tank, pump and control system to dose ammonia/urea. It is technically possible to reach a NOx-reduction on over 95% by installation SCR, and SCR are installed at all different type of ships and vessels such as offshore supply vessels, fishing vessels, offshore special vessels and anchor handling thug supply vessels.²⁰

Exhaust Gas Recirculation(EGR):

EGR is a NOx emission reduction technique used in petrol and diesel engines by recirculating exhaust gas into the engine's cylinders. This is installed mainly on offshore special vessels and passenger vessels. The exhaust gas that is used is cooled over a heat exchanger, and the NOx reduction depends on the temperature in the combustion chamber.

Fuelsaving:

Fuel saving could be installation of supply meter, fuel meter, change of screw and other similar installations to optimize the loading plan of the cargo on the ship or reduce the use of fuel, that is installed mainly on fishing vessels and passenger ships/ferry's.

Gas:

Gas (land based and offshore/shipping) is investment in new capital equipment to change from existing technology to gas. One separates between land based industry

²⁰Many of these vessels supply oil rigs and offshore oil platforms, others ships used to catch fish in the sea and some are merchant ships to transport different type of cargo.

and others, which are chemical- and shuttle tankers, bulk cargo and offshore supply vessels.

Change of the engine and motor technical rebuilding:

Change of engine is an initiative that consists of changing the engine to a new one that has lower NOx emissions, and are installed at fishing vessels and passenger/car ferry's. Motor technical rebuilding is almost the same as change of the engine, only that parts of the engine is changed and not the whole engine, and is also installed at fishing vessels and passenger ferry's, but also on bulk vessels, cargo ships, drilling rigs and shuttle tankers. This also contains initiatives that rebuild the fueling system in order to use less rich oil and more diesel, which emits less NOx.

Process optimizing:

Process optimizing are initiatives mainly made by energy companies such as Statoil-Hydro and landbased industry. Process optimizing are investments that optimizes the excising process in turbines, heating furnaces, raw material installations etc.

Injection and emulsion of water:

Water injection is a method used in internal combustion turbines to secure a lower and more even temperature in the combustion chambers of engines, by adding water so that the production of NOx is reduced. By waterinjection the emissions of NOx will depend upon what kind of volumes of water that is injected in the turbine. Water emulsion entails improved combustion with lower use of burning oil, cleaner engine and reduces the emissions of NOx and other particles. Both are installed at offshore supply vessels, fishing vessels and chemical tankers.

5.3 Method used

I want to find the aggregate marginal abatement cost curve over all the firms and ships that are members of the Nox-fund. However, not all the firms that are members of the fund apply for funding, and there are a lot of uncertainty concerning the firms that no not apply, as we do not have much information about them.

We start out with the abatement cost curve for the firms that have applied for funding. This curve both includes the verified projects and projects that have applied for funding and will be undertaking investments in the near future. The average abatement cost for each project is calculated in the following way:

$$\overline{C}_i = \frac{I_i * f + c_i - S_i}{a_i} \quad (5)$$

$$f = \frac{i[(1+i)^T]}{(1+i)^T - 1} \quad (6)$$

Where \overline{C}_i is the mean cost per kilogram NOx reduction in project i , I_i is investment in new technology, f is the annuity factor, c_i is yearly extra production costs due to the investment, s_i is yearly savings due to the investment and a_i is yearly abatement measured in kilos of NOx. In order to calculate the annuity factor a discount rate of $i = 7\%$ is used and the lifetime, $T = [15, 30]$, is assumed to be either 15 years or 30 years. Thus, when the lifetime is 15 years the annuity factor is 10,98% and a lifetime of 30 years gives an annuity factor of 8,06%. As mentioned, these assumptions are made by DNV. If one requires a higher rate of return than 7%, f will increase and this makes the average costs higher. If i is higher than 7% we are thus underestimating the actual costs of the capital investments. SFT are also using $i = 7\%$, so our estimates of the costs are in accordance with their predictions. We see that by using the annuity method we get the average cost of each project measured in NOK per kilo Nox reduction. I assume that the condition for a firm to apply for funding is

$$(I_i - F_i)f + c_i - S_i \geq t\Delta e_i \quad (7)$$

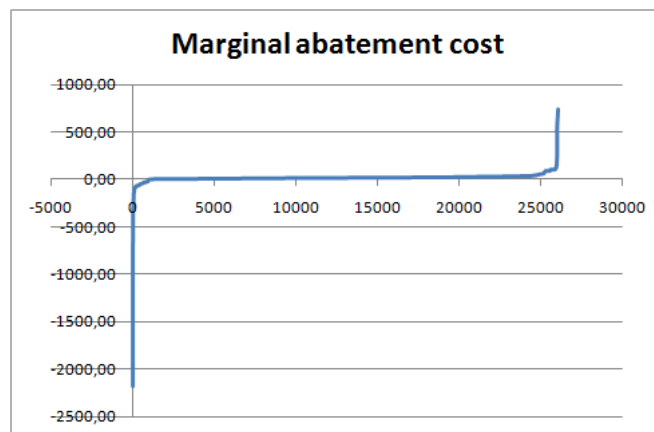
which states that the present value of the private cost of the investment for project i , $(I_i - F_i)f$, where F_i is the funding received from the NOx-fund, must be at least as high as the taxes they would have to pay yearly on their emissions. This condition thus states that a firm will not apply for funding if it is not in its own interest to

do so. The ships that implement new investments are at the same time in dock for other maintenance purposes. This suggests that the present value of the private cost of the investment do not exceed the taxes they would have to pay on emissions yearly, if the cost of off-hire was included.

5.4 Graphical Representation

The average cost per project is calculated, and when I put all of these together in one graph I call it the marginal abatement cost curve, as it shows the marginal cost of a new project measured in NOK per kilo NOx reduction. In all the graphs the projects are sorted by increasing costs per unit abatement, and plotted against each other with accumulated NOx-reduction on the x-axis. Graph 5.1 is a representation

Graph 5.1: Total marginal abatement cost curve, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis.



of all the projects. It shows us that there are several projects with a negative average cost, and some with an average cost above 500 NOK per kilo NOx reduction. When the average abatement cost is negative, this means that there is a positive gain represented by increased profit for the firm by investing in the new technology. At the same time we see that there are many projects with an average cost between 0 and 100 NOK/kg NOx reduction. In total there are 102 projects with a marginal cost below or equal to 0 NOK. As the minimum observation is -2177.71 and the maximum observation is 734.22, we see that there is a great spread in the data, and

Table 5.1: Data from DNV. Average abatement cost is measured in NOK/kg NOx reduction, total NOx reduction measured in tons.

Initiative	Number of projects	Average abatement cost	Total NOx reduction	Percentage of NOx-red.
SCR	163	19.6	13 935	53.4
Fuelsaving	118	-47.5	1 697	6.5
EGR	7	95.4	103.9	0.4
Gas	23	25.1	3 423	13.1
Gas -Landbased	16	75	261	1
Change of engine	16	35.6	390	1.5
Motor technical re-building	119	14.3	4 772	18.3
Process Optimizing	21	1.9	1 142	4.4
Emulsion of Water	8	15.1	243	0.9
Injection of Water	4	3.8	110	0.4
Sum	495	23.8	26078	1

this makes it difficult to draw conclusions out of this graph. Still, it might suggest that the projects with a negative marginal cost should have been carried out without needing support from the fund, as they give a positive result to the firm. At the same time there are some projects that have a very high positive average abatement cost, and we want to look closer into what might characterize these projects. In table 5.1 I have sorted all the projects according to the different initiatives and calculated the average abatement cost, total NOx reduction of each initiative and the percentage of total NOx reduction. Table 5.1 show that SCR contribute to over 50% of the total emission reduction and is the initiative that is most represented among the projects. This suggests that we should analyze these projects further. As there are 163 measures of SCR, this adds up to 33% of all the projects. The initiatives fuel saving, motor technical rebuilding, process optimizing, emulsion and injection of water all have an average abatement cost lower than the emission tax of 17NOK/kg NOx. Fuel saving, process optimizing and injection of water all has an average cost lower than the fee of 4NOK/kg NOx. This suggests that rather than paying the fee to the NOx fund, it would have been cost minimizing to undertake investments in new capital equipment. In table 5.2 I have calculated the standard

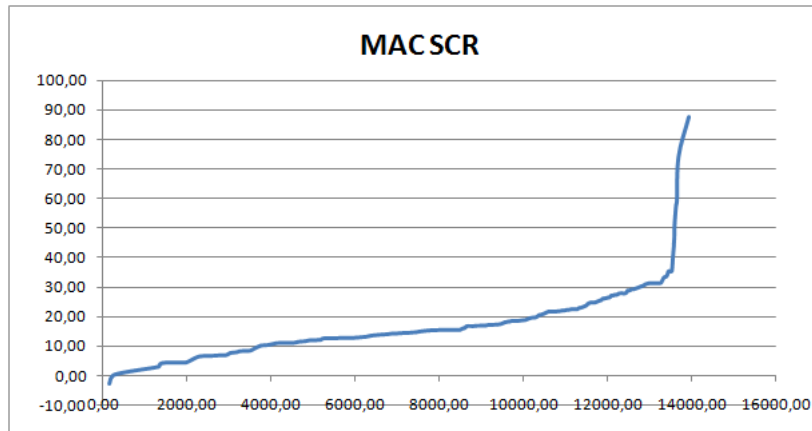
Table 5.2: Descriptive Statistics. Average abatement cost for each initiative is measured in NOK/kg NOx reduction.

Initiative	Average ab.cost	Std. Dev.	Min value	Max value	CV
SCR	19.6	11.8	-2.97	87.7	0.6
Fuelsaving	-47.5	237.7	-2177.7	734.2	5
EGR	95.4	162.3	15.83	460.9	1.7
Gas	25.1	23.7	1.93	124.4	0.9
Gas-Landbased	75	109.2	-146.2	289.7	1.5
Change of Engine	35.6	39.1	-0.12	142.3	1.1
Motortechical re- building	14.3	24.2	-119.7	110.5	1.7
Process Optimizing	1.9	243.3	-611.2	548.95	127.4
Emulsion of Water	15.1	18.1	1.71	50.8	1.2
Injection of Water	3.8	2	2.4	6.7	0.5

deviation and put up the minimum and maximum value for each initiative. The last column CV is the coefficient of variation, calculated $CV = \frac{\sigma}{|\mu|}$, and it gives the standard deviation as a proportion of the mean. Coefficient of variations are often more meaningful than standard deviations, as it is a normalized measure of the disparity of the distribution of the data (Rice, 2007). Here we see that there are great differences between the projects, for instance the minimum and maximum values differ a lot between the categories. As the coefficient of variation shows how large spread there is within each of the initiatives marginal cost, a large coefficient of variation suggests that the marginal cost for that initiative varies a lot. This is the case for optimizing the process, where we see that the average cost ranges from -611.19 to 548.95, and for fuel saving where it ranges from -2177.71 to 734.22. These two are the measures that stand out with a particular high coefficient of variation, while rebuilding of the engine has the third highest measure. Because we are comparing within categories, this suggests that some projects are more efficient than others, or use their resources in a better way than others. Another explanation could be that we are comparing planned and verified projects.

In graph 5.2 only the marginal cost of each SCR initiative is plotted against the accumulated NOx reduction for this initiative. We see from graph 4.2 that the

Graph 5.2: Marginal abatement cost SCR, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis. 163 observations

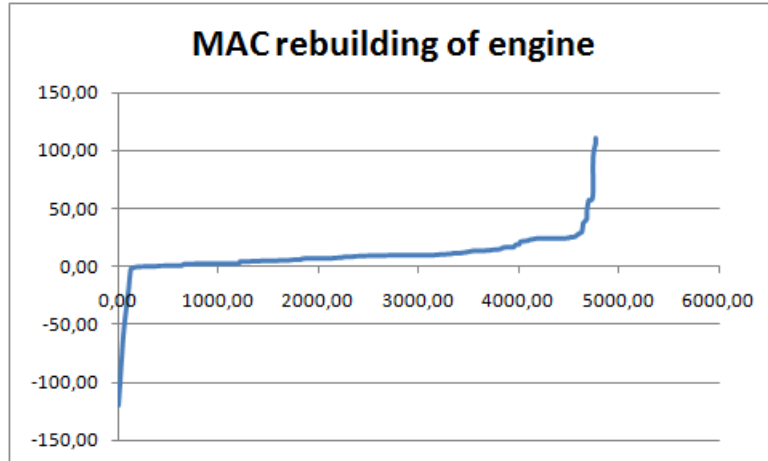


marginal abatement cost curve for SCR is steadily increasing (with some positive extreme values, 7 observations with a value above 40 NOK/kg NOx reduction), and the average abatement cost for this measure is 4 NOK below the total average. SCR is an end of pipe type of cleaning, because it is installed near the end of the engine exhaustpipe to reduce the emissions that have already been formed in the engine. It could potentially be installed in the majority of the ships, and SFT suggested that if SCR were installed on all the potential ships it would have reduced the NOx-emissions by 43 000 tons. Therefore one could look further into the aggregate marginal abatement cost function assuming that, as a modest estimate, there are twice as many ships left that can invest in SCR and reduce their emissions.²¹

Table 5.1 also shows that the motor technical rebuilding contributes with 18,3% of the total NOx-reduction, while changing the use from fuel to gas contributes with 13,13%. 119 of the projects are motor technical rebuilding, and graph 5.3 shows that there are both projects with positive and negative average abatement costs. The average abatement cost of these initiatives are 14.29. 8 of the 119 initiatives have a average cost below or equal to zero, whereas the remaining 111 initiatives has a positive average cost. The average cost of these 111 initiatives measured in NOK/kg NOx reduction is 17.17, which still is below the total average and also

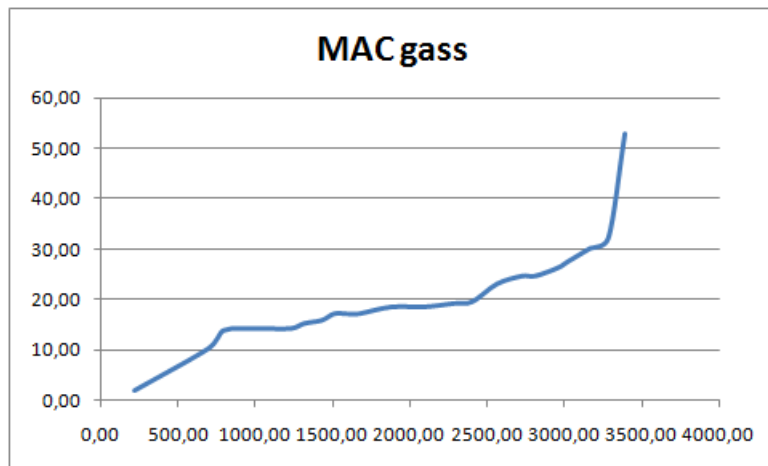
²¹This means installing SCR at 326 ships. SFT assumes that SCR is installed at 576 ships in their analysis.

Graph 5.3: Marginal abatement cost curve for motor technical rebuilding measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis. 8 observations below or equal to zero, 9 observations above 40 NOK/kg NOx reduction.



still below SCR. At the same time, it has the third highest coefficient of variation. Summing up, the initiative motor technical rebuilding thus has a fairly low average cost and also contributes to 18% of the total NOx reductions.

Graph 5.4: Marginal abatement cost for changing from fuel to gas, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis.



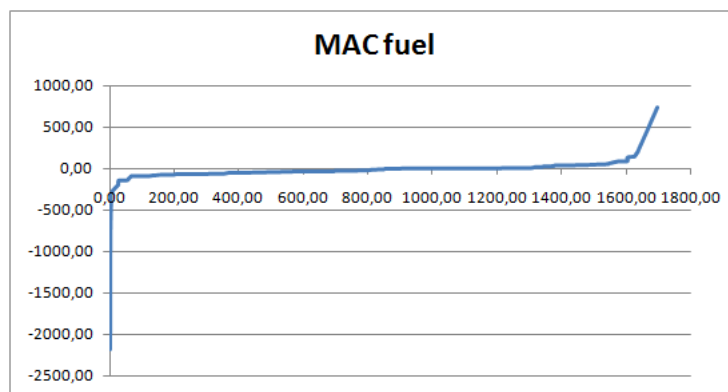
There are 23 projects changing from existing technology to gas on ships. Most of these are carried out at offshore supply vessels, which is a ship used to sup-

ply offshore oil platforms, and bulk vessels which is a merchant ship to transport unpackaged bulk cargo. I have excluded the last observation, because it had an average abatement cost 2,5 times higher than the previous observation.²² All of these measures were either implemented by the end of 2010 or will be installed in 2011 and 2012. We could assume that there will be more initiatives of ships switching to gas in the coming years, which could contribute to increasing the NOx-reductions at a reasonable price, as the average cost is 25 NOK/kg NOx reduction.²³ The updated lists on the web page of the NOx-Fund shows that since December 2010 there has been five new applications for investment in gas.

In total 85% of the total NOx-reduction come from these SCR, gas and motor technical rebuilding. From table 4.3 we see that they also have an average abatement cost around or below the total average abatement cost.

The measure with the lowest average cost is the initiative fuel saving. This initiative has such a low average abatement cost that one could start questioning why they need a subsidy for their investments in new technology, as this investment should have been profitable for the firm.

Graph 5.5: Marginal abatement cost curve for fuelsaving, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis.



84 of the 118 fuel saving measures has a negative average abatement cost, which shows that the majority of the projects which has a negative average abatement

²²The reason for doing this is to make the picture clearer. It is easier represented in a graph like this, and has no other purpose.

²³In conversation with Geir Høyby, leader of the NOx-fund, he assumed that there will be more of this type of measures in the future.

cost is a result of fuel saving initiatives.

5.4.1 Analysis of the initiatives

The fuel saving measures are mostly carried out on passenger ships and fishing vessels. They pay a fee to the NOx-fund of 4 NOK/kg NOx-emission and at the same time receive funding for investments that benefit themselves, as it has a negative average cost, meaning that they will benefit directly from the investment. How much is invested of the money from the NOx-fund into each project? This question remains unanswered, as we do not have the exact information about their investment costs and support given from the NOx-fund, but I will try to estimate how large the costs are.

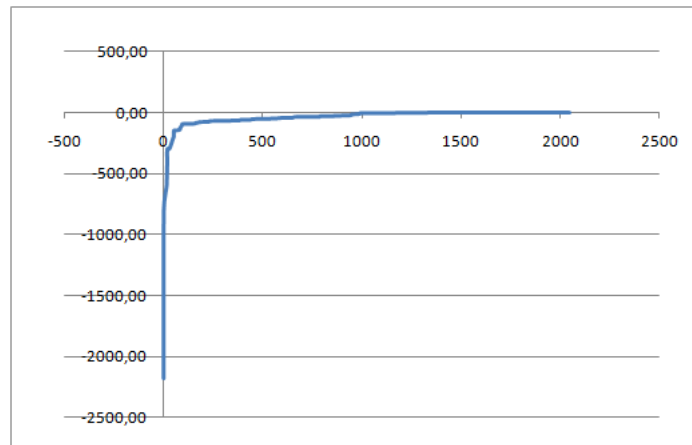
Many firms operate with a required rate of return of 7%. When risk is greater they operate with a higher required rate of return, which could be the case for the shipping industry. Therefore, it is likely that investing in new capital equipment would not be profitable for the firms if they did not receive funding. The majority of the projects have an expected lifetime of 15 years. From the firms point of view, the question is not only about cost efficiency in the long run, but also about liquidity constraints in the short run and the alternative costs of the private investment cost. If we assume that the firm has no preferences for a clean environment, it is hard to believe that they would prioritize these projects before other projects, which could give them higher returns in the short-run.

One possible explanation for why some average costs are so much higher than others is that they have granted funding to almost all applying projects. As new investments only are profitable when they are in dock for other maintenance purposes, this might suggest that one needs more time in order to reach a more cost efficient solution. If the fund had a longer time horizon, then one would have the possibility to prioritize the most cost efficient investments over others. This also suggests that if one uses a tax on emissions, it is necessary to announce the tax in advance, in order for investments to be undertaken when it is profitable for the firm.

5.4.2 Splitting up the abatement cost

As the total marginal abatement cost curve in graph 5.1 has such a wide spread, I will divide it into three parts, according to the increasing costs. Graph 5.6 shows the initiatives with an average cost up to NOK 0, graph 5.7 shows the initiatives with a average cost up to 70 NOK/kg NOx reduction and graph 5.8 shows the last 34 observations with a cost above 70/kg NOx reduction. In graph 5.6 I have plotted

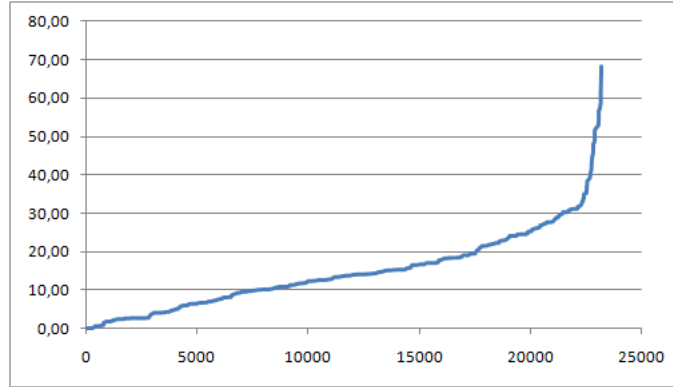
Graph 5.6: Part 1 of the marginal cost function, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis. Observation 1 to 102 out of the total 495 variables, 102 observations.



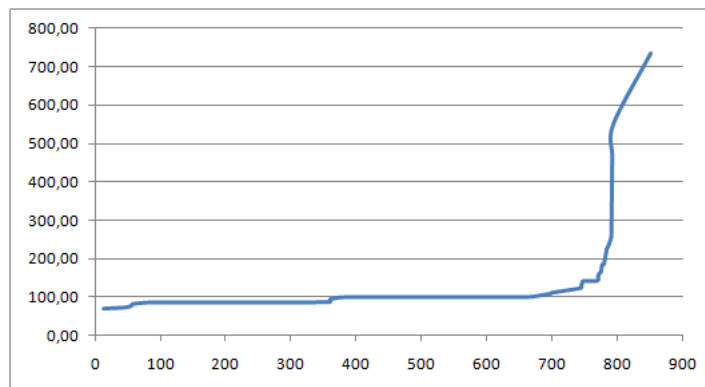
observation 103 to 461, which are the values which has a cost between 0 NOK and 70 NOK/kg NOx reduction.

Here we see that the projects with negative average costs contribute with a NOx reduction of around 2000 tons, the projects with average costs between 0 to 70 NOK/kg NOx contribute with 23 000 tons of NOx, and the projects with an average cost above 70 NOK/kg NOx contribute with 850 tons of NOx. This might suggest that graph 5.6 shows the projects that do not need funding, as they give a positive profit to the firms, and graph 5.8 shows the projects that one can argue should not have been granted funding for their investments because they have too high average abatement costs. Graph 5.7 shows that the majority of the projects are represented in the group that reduce NOx the most. This suggest that the majority of the implemented projects are among the most cost efficient.

Graph 5.7: Part 2 of the marginal cost function, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis. Observation 103 to 461 out of the total 495 variables, 359 observations.



Graph 5.8: Part 3 of the marginal cost function, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis. Observation 462 to 495 out of the total 495 variables, 34 observations.



5.5 The total costs

5.5.1 Total cost of the investments

I have made an overview of the total costs of the investment and expected total funding from the fund, using the data presented on the website of the NOx-fund (stemming from only applications, and not the verified projects as in table 5.1). This table includes total costs of the investment, which is based on expected investment costs and total funding, which is the expected support from the fund.²⁴ In this

²⁴We see that there are some differences between the two tables when it comes to number of projects, as table 5.3 includes 24 more observations and is only based on applications and not on

section I argue why this cost is not suited as an estimate of the total cost for NOx-reduction, but we can use the expected funding as an approximation.

Table 5.3 is based on applications from the NOx fund from 2008 to December 13th 2010. Total funding is summed to be 2 billion NOK, while total cost of the investment is 9.3 billion. The total cost of investment does not include benefits of the investment, such as reduction of fuel use and hence also reduced fuel expenditures. These would be high, at least for some of the categories such as fuelsaving, rebuilding- and change of the engine. The benefits in this case are savings in terms of less use of fuel, as the reason for why these projects reduce their NOx emissions are due to a reduction in fuel use. Hence, the total investment cost is large, but as there are great expenditure savings due to less use of fuel, the "total costs of the investment" is not an accurate measure of the total costs of the NOx reduction.

Table 5.3 shows that they get funding that corresponds to the percentage of NOx reduction. The measure SCR contributes with 55% of the total NOx reduction and get 39,4% of the total funding. The initiative fuel saving have a 6,2 % share of the total emissions and receive 7,1% of the total funding. However, we know that fuel saving is a measure with a negative cost for the majority of the projects. 143,4 million NOK from the NOx fund is used on projects giving the firms a positive net result. These applications show that the firms themselves have a cost of 1.26 billion, which is unrealistic when we know that the cost for each project, when taking the lifetime and other benefits into account, is negative.²⁵ Thus, not taking into account what the firm gains from this investment, is clearly not a realistic measure of the actual costs for the reduction of NOx, but the expected funding can be used as an approximation.

As the emission reductions are 1862 tons, their total savings over a 15 years period from not having to pay the fee of 4 NOK/kg NOx would be 111,7 million NOK. This makes it even clearer that it is not rational behavior to invest 1.26 billion NOK to save 111,7 million NOK. For the analysis of total costs these numbers can obviously not be applied. As this is the only information that is put on the web by verified projects.

²⁵Total cost minus total funding: 1,4 billion NOK - 143,4 million NOK = 1.26 billion NOK.

Table 5.3: Data from applications from the NOx Fund

Initiative	Number of projects	Total cost of the investment	Total funding	Total NO_x reduction	Percentage of NO_x reduction	Percentage of total funding
SCR	158	1 189 354 601	795 383 274	16 488	55	39.4
Fuelsaving	113	1 403 569 833	143 426 621	1 862	6.2	7.1
EGR	7	31 114 000	14 729 540	110	0.4	0.7
Gas	28	880 935 243	440 836 628	3 472	11.6	21.6
Gas-Landbased	12	42 231 187	28 499 230	248	0.8	1.4
Change of engine	16	106 635 062	41 931 219	417	1.4	2.1
Motortechanical re-building	122	2 379 694 871	399 960 263	5 020	16.8	19.8
Process Optimizing	50	3 334 796 819	145 881 931	1 976	6.6	7.2
Emulsion of Water	8	9 786 070	7 010 643	248	0.8	0.3
Injection of Water	4	3 718 528	2 788 897	110	0.4	0.1
Sum	518	9 381 836 214	2 020 448 246	29 952	100	100

the NOx-fund, one might get the impression that the shipping industry have high investment costs and are cooperating in order to reduce their total emissions, when they actually have a negative cost in the long run. The data in table 5.3 is thus an overview of the total cost, but it is very difficult to get an accurate measure of the total costs, as detailed micro level data is needed.

However, costs such as expenditures on labor, the loss of income when off-hire, among others should also be taken into consideration in the total economic costs. But as the workers on the ships/platforms need to be paid anyway, these are not stated in the information from the NOx-fund, and hence neither taken into account here.

Also, the ships that have completed new investments have been in-dock while doing maintenance, which suggest that the loss of income when off-hire probably would have happened anyway. Nevertheless, benefits such as reduced fuel expenditures and other types of savings are not taken into consideration in the value total cost. The total cost is just I_i in equation (10), and we do not have the values of s_i and c_i in the expression, therefore it is difficult to draw conclusions just out of the value I_i , as s_i potentially could be very high as it contains savings of fuel expenditures. Therefore, the numbers are clearly not suited for looking at the total cost of NOx reduction, as there are other benefits for the firm due to the new investments.

5.5.2 Calculating the total costs according to the average costs

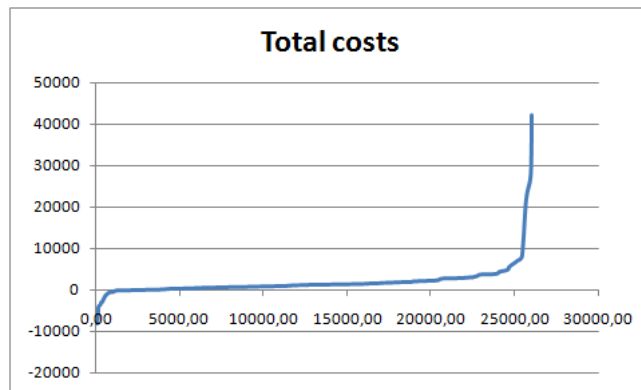
In order to find a good estimate of the total costs of the NOx reduction I multiply the average cost of each project, \overline{C}_i , by the respective NOx reduction, a_i . The result is then total cost of the project for the corresponding NOx reduction, and takes into account both extra cost of the investment (urea costs if SCR) and savings (less fuel expenditures), because this is reflected in the average cost. When summing the costs for each project, we get the total costs of the NOx reduction for the given level of abatement achieved. The total costs can be found in table 4.4, and are plotted in a graph.

From graph 5.10 we see that at a total cost of 399 million NOK a NOx reduction of 26 078 tons is reached. According to SFT's analysis a NOx reduction of 43 000

Table 5.4: Total costs of reducing the NOx emissions. Cost are measured in 1000 NOK.

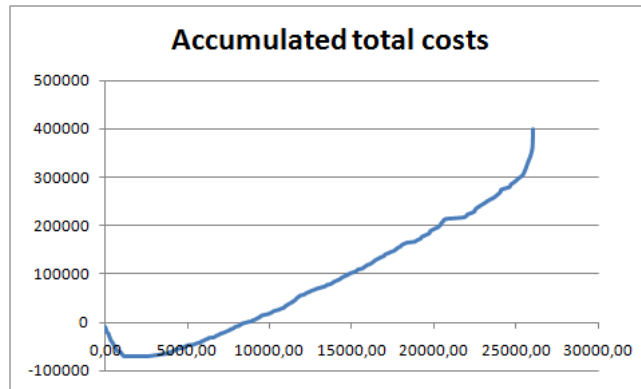
Initiative	Sum costs	Percentage of total costs
SCR	228 230.89	57.18
Fuelsaving	10 974.52	2.75
EGR	3 657.13	0.92
Gas	67 542.79	16.92
Gas-mainland	3 357.71	0.84
Change of the engine	9 069.88	2.27
Motortechnical rebuilding	47 217.88	11.83
Process optimizing	27 641.94	6.93
Emulsion of water	1 019.96	0.26
Injection of water	408.26	0.10
Sum	399 120.95	100.00

Graph 5.9: Total costs measured in 1000 NOK. Accumulated NOx reduction measured in tons on the x-axis.



tons could be reached at a total cost of 320 million NOK, if SCR was implemented on all domestic ships and give an average cost of 7.44NOK/kg NOx reduction. This corresponds to a total cost of 194 million NOK to reduce the NOx emissions with 26 078 tons. Up to a reduction of 8578 tons of NOx, the accumulated costs are negative. This means that in total, the emission reductions up to around 8500 tons gives a net positive result to the firms. It is clear that the NOx fund have reached their emission reductions at a much higher total price than what SFT predicted.

Graph 5.10: Accumulated total costs, measured in 1000 NOK. Accumulated NOx reduction in tons at the x-axis.



5.6 Aggregate Marginal Abatement Cost Function

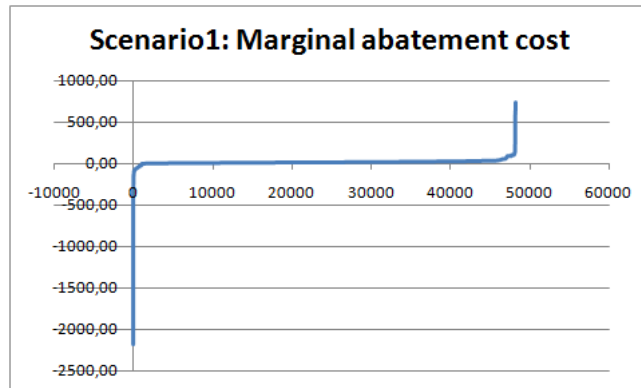
In this part of the analysis we will see what the aggregate marginal abatement cost curve would have looked like when only some of the initiatives are followed through, and there are more of each type of these projects. I use the costs from the actual investments and look at what would have happened if only some of them were funded, and what the marginal abatement cost curve would have looked like. The motivation behind this analysis is to apply some assumptions to see whether it is possible to reduce the emissions of NOx by the same amount as today, but at a lower price. I also use the same method as 5.5.2 to find the total cost of the NOx reduction in these hypothetical scenarios.

5.6.1 Scenario 1

Previously we have seen that SCR, gas and motor technical rebuilding are the three measures that reduce NOx emissions the most. They also represent 62% of the projects. I assume that there are twice as many of these projects, and look what happens to the aggregate marginal abatement cost function. This is the same assumption as saying, instead of there being 305 projects of these initiatives today, assume that we have twice as many, 610 projects in total. As the total trade fleet consists of around 1500 boats, I see this as a realistic assumption as this means that the three measures could be installed at around 40% of the Norwegian trade

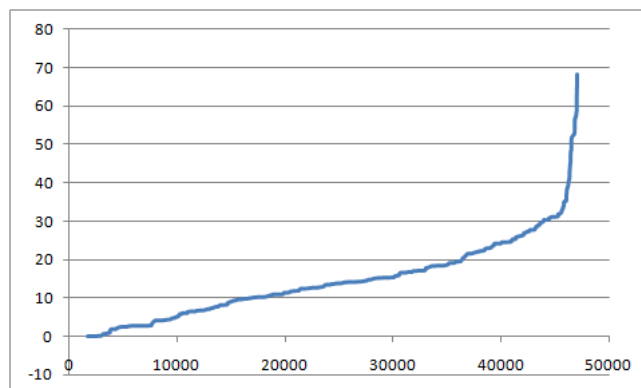
fleet, compared to 20% today. In this scenario we see that the total NOx-reductions

Graph 5.11: Scenario 1, measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis.



would be 48 208 tons of NOx, compared to today's 26 078 tons. As we have seen earlier there is a big difference between the cost efficiency of the projects, if one only carries out the most cost efficient projects this will lead to more abatement at a lower price. To get a clearer view of the picture in this scenario, we zoom in at the graph. Graph 5.12 shows that a reduction of NOx of 26 000 tons could be

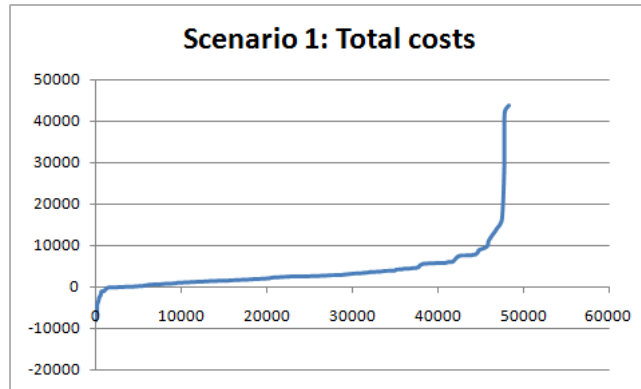
Graph 5.12: Scenario 1, zoomed. Marginal cost measured in NOK/kg NOx reduction. Accumulated NOx reduction measured in tons on the x-axis.



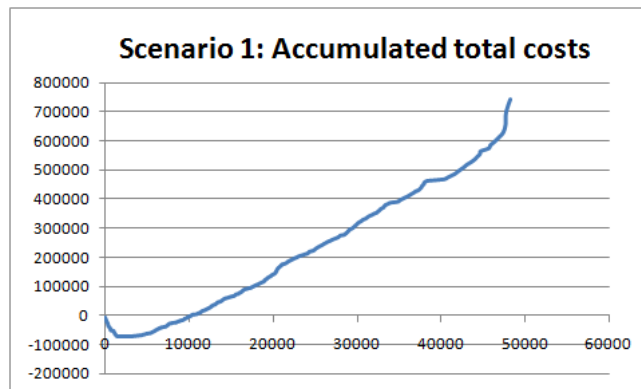
reached at a cost of 14.2 NOK/kg NOx reduction, which is clearly below today's cost of 73.4 NOK/kg NOx reduction. However, as the average abatement cost of all the projects are 23.8 NOK/kg NOx reduction, the least cost efficient one with an

average cost of 734 NOK/kg NOx reduction is rather an exemption.²⁶ Thereafter we find the total costs using the same method as previously. In this scenario it is

Graph 5.13: Scenario 1: Total costs measured in 1000 NOK. Accumulated NOx reduction measured in tons on the x-axis.



Graph 5.14: Scenario 1: Accumulated total costs measured in 1000 NOK. Accumulated NOx reduction measured in tons on the x-axis.



possible to reach a level of abatement at 26 032 at a total cost of 244 million NOK. This is 155 million NOK cheaper than what it is reached at today, corresponding to a 39% reduction of the total costs.²⁷

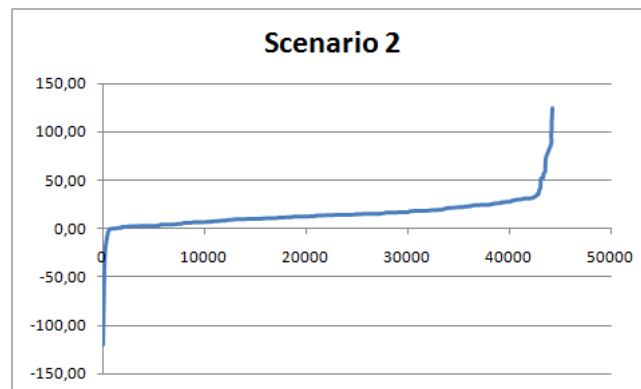
²⁶There are many rational explanations for this average cost being so high, if this ship only has been operating in foreign countries there will be no NOx reductions to report to Norway and the NOx fund.

²⁷399mill - 244million = 155 million

5.6.2 Scenario 2

In contrast to scenario 1, this scenario looks at what the aggregate marginal abatement cost curve would look like if only SCR, gas and motortech rebuilding were performed and there were twice as many projects as these three categories represent today. Graph 4.15 suggest that we could reach the same level of abatement as today

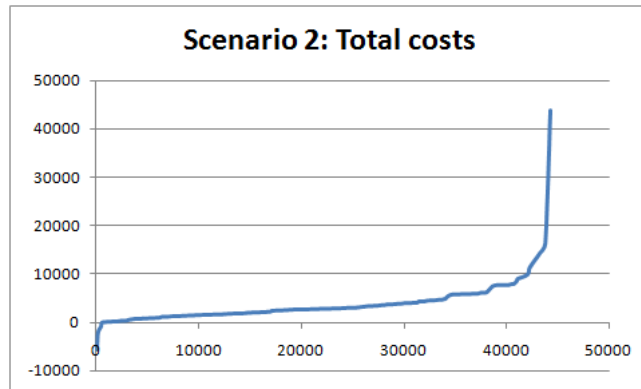
Graph 5.15: Scenario 2, measured in NOK/kg NO_x reduction. Accumulated NO_x reduction measured in tons on the x-axis.



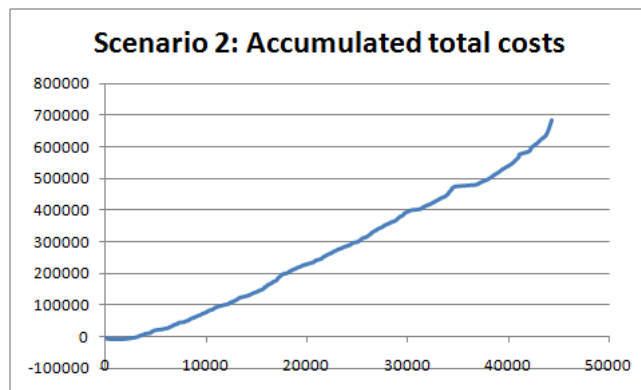
at a average cost of 15 NOK/kg NO_x reduction, compared to todays average cost of 734 NOK. This corresponds to what SFT found, they assumed that an emission reduction of around 30 000 tons of NO_x could be realized with an average cost of around 15 NOK/kg NO_x reduction. Also, we can compare graph 4.11 to graph 1.2 and we see that scenario 2 draws the same picture as the analysis of SFT. When looking at the total costs of NO_x reduction in scenario 2, we see that we can reach a NO_x reduction of 26 134 tons to a total cost of 321 million NOK. This is 78 million cheaper than what is spent today, which is 20% cheaper.²⁸ The costs here are higher because we have not taken into account the projects with a negative average cost, as we have in the previous section. Therefore, to make the scenarios comparable I assume that the project with a negative average cost would have been performed anyways, which correspond to 1 673 tons NO_x reduction, according to the assumptions made in scenario 1. The total costs would then be 295 million NOK, which is 26% lower than what is spent today. SFT found that 43 000 tons of NO_x reduction

²⁸399 million NOK - 321 million NOK = 78 million NOK

Graph 5.16: Scenario 2: Total costs measured in 1000 NOK. Accumulated NOx reduction measured in tons on the x-axis.



Graph 5.17: Scenario 2: Accumulated total costs, measured in 1000 NOK. Accumulated NOx reduction measured in tons on the x-axis.



could be reached for total costs 320 million NOK. What I have found is somewhat higher than what SFT found. This might be because I have used the average costs from all the projects, which is higher than what SFT predicted.

6 Adverse Selection

In this chapter I set up a model with asymmetry in information, as this characterizes the relationship between the NOx-fund and different firms, as the firms have private information about their own costs. This is because before the new investment takes place, the firms have private information about how efficient they are. Thus, we have a principal agent relationship where the NOx-fund is the principal and the participants of the NOx fund, the firms, are the agents, and we look at the production of abatement. The precise technology used is private information for the agent, and this is what we call adverse selection. This could for instance be private information on specific characteristics about the ship, how big it is and how many are working on there.

I assume here that the marginal abatement cost is exogenously given, either you are efficient or an inefficient firm. This is of course a simplifying assumption. One can do changes on a ship, hire more/less workers etc. to become more efficient, and this could for instance depend on the firms willingness to exert effort. However, because these ships are very big in size and also expensive, I ignore the aspect of effort and hence assume that what makes up for the difference between an efficient and inefficient firm is given by an exogenously given parameter. For instance a ship specific parameter unknown to the NOx-fund. Since I ignore the aspect of effort and only look at an exogenously given efficiency parameter, I choose to use an adverse selection model and not a moral hazard model.

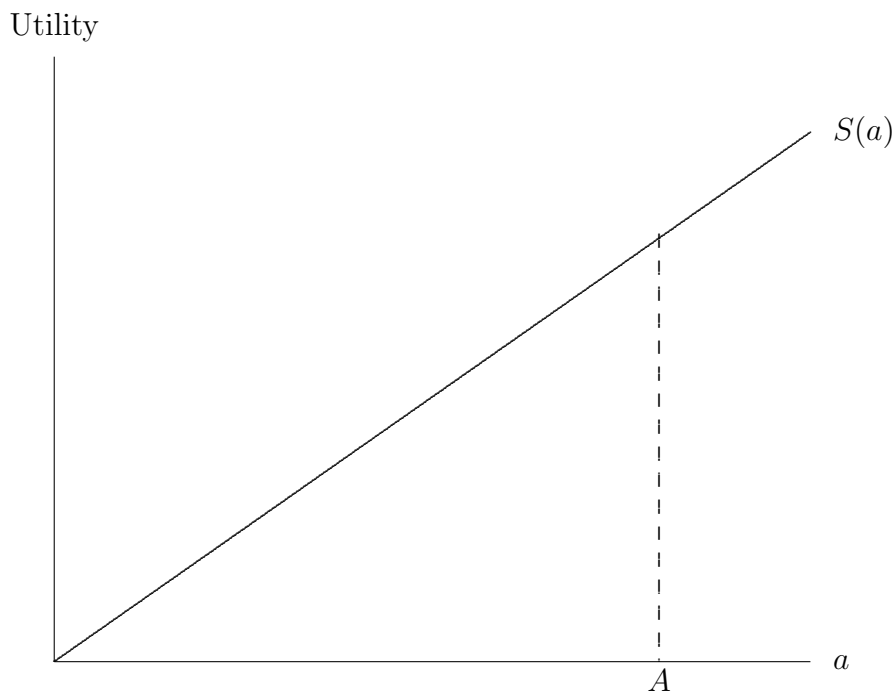
The NOx fund does not have complete information about the technology of the firms, and this is the source of the information gap between the principal and the agent. In order to reach an efficient use of economic resources, the contract between the two parts must reveal the agents private information. This can be done by giving up some information rent to the privately informed agent. This information cost just adds up to the standard technological cost of performing the task and justifies distortions in the volume of abatement achieved under asymmetric information. When designing a second-best contract there is a trade off between efficiency and information rent. In this case we look at a one-shot relationship between the agent

and the principal. The main result is that the optimal second-best contract calls for a distortion in the volume of abatement away from the first-best. This model is based on Laffont and Martimort (2002) "The Theory of Incentives: The Principal-Agent Model".

6.1 The Basic Model

Consider a firm, the NOx fund (the principal), who want to delegate the production of a units to an agent, where a is production of NOx abatement. The NOx-fund has received a target for emission reductions of magnitude A from the government. I assume that the utility function of the fund is linear and increasing up to the value A , $S(a) = \alpha + \beta a$ where $\alpha = 0$. The fund still has an increasing utility above this level because of positive publicity in media and also get positive credit from the government to have reached emissions above the target A , so the remaining part of the curve has the same slope as before. The utility function of the fund is sketched in figure 6.1, the total value of abatement (the benefit function for the principal), is a linear and increasing function, and the marginal value is constant and equal to β .

Figure 6.1: Utility function for the NOx-Fund



The abatement cost is unobservable to the fund, and we assume that there is no fixed cost. The fixed cost could for instance be a fixed cost of planning the abatement project or sending in an application for funding to the NOx-fund, but as this adds nothing to the analysis we assume that the fixed costs are zero. The marginal abatement cost θ belongs to the set $\theta = \{\underline{\theta}, \bar{\theta}\}$. The agent could be either efficient, $\underline{\theta}$, and have a low marginal abatement cost, or inefficient, $\bar{\theta}$, and have a high marginal abatement cost. It is assumed that the value of the two efficiency parameters are known to both the firm and the NOx-fund, but the fund is not capable of attaching the different values of θ to each firm. Relating this model to the theoretical model in chapter 3, we have now specified the cost function of each firm. In chapter 3 we only operated with a general cost function, whereas in this extension we have two possible specifications of the cost function, and which of the two that belongs to each firm is unknown to the fund. Here the marginal cost of the agent can take only two possible values, of course it would have been more realistic to assume a continuum type of marginal abatement cost, but the same type of result would follow, so therefore I simplify by using only two possible values. We have an efficient type with probability $v = [0, 1]$ and the inefficient type with probability $(1 - v)$.

Efficient agent:

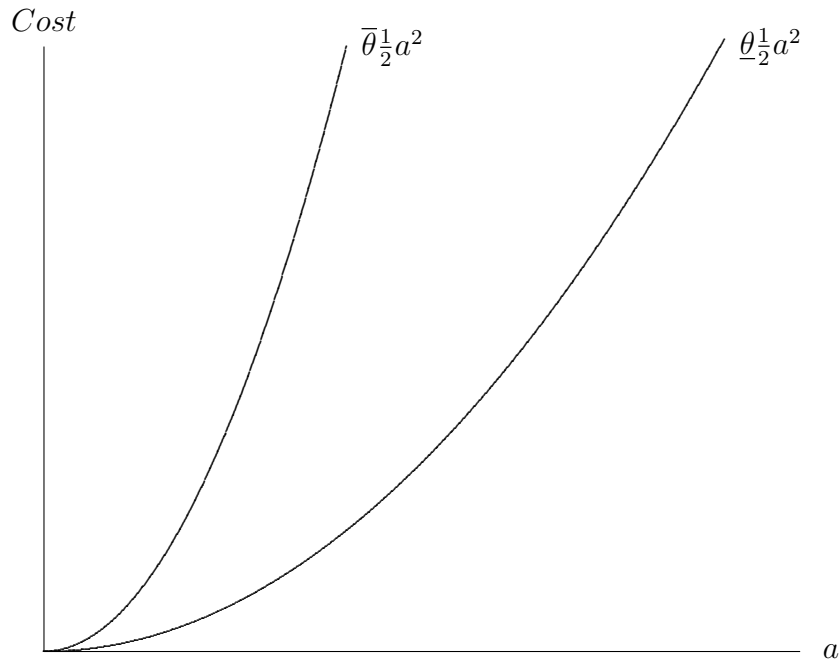
$$c(a, \underline{\theta}) = \underline{\theta} \frac{1}{2} a^2 \text{ with probability } v \quad (8)$$

Inefficient agent:

$$c(a, \bar{\theta}) = \bar{\theta} \frac{1}{2} a^2 \text{ with probability } (1 - v) \quad (9)$$

$\Delta\theta = \bar{\theta} - \underline{\theta} > 0$ is the spread of uncertainty on the agents marginal cost. When taking the abatement production decision, the agent knows his own type and his type is exogenously given by assumption. Although we look at the agent as a firm, I assume that each firm has several projects and we look at one specific project of a given firm. This could be justified by assuming that we look at the cost function for the firms represented by two different projects that only differ according to their

Figure 6.2: Cost function for the firms



efficiency. An example here is rebuilding of the engine at two different ships, where they differ in how efficient they are at taking the new capital equipment into use.

6.2 The Complete Information Optimal Contract

6.2.1 First-Best Production of Abatement

First we assume that there is no asymmetry of information between the principal and the agent. The fund will maximize his utility subject to the two cost functions with respect to a . The efficient production of abatement is obtained by equating the principal's marginal value of abatement and the agents marginal cost of abatement, where $c'_a(a, \theta) = \theta a$, so that $S'(\underline{a}) = c'_a(a, \theta)$ and $S'(\bar{a}) = c'_a(\bar{a}, \bar{\theta})$.

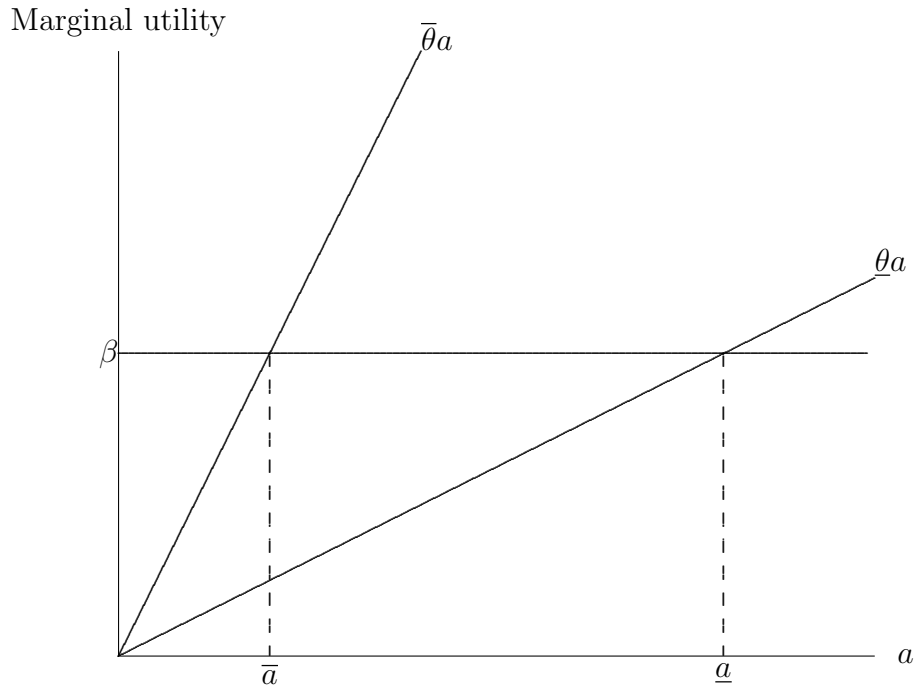
The first-order conditions for first-best production of abatement is the following:

$$\beta = \underline{\theta} \underline{a} \tag{10}$$

$$\beta = \bar{\theta} \bar{a} \tag{11}$$

\bar{a} and \underline{a} should be carried out if their social values are non-negative, $\underline{W} =$

Figure 6.3: Optimal First-Best solution

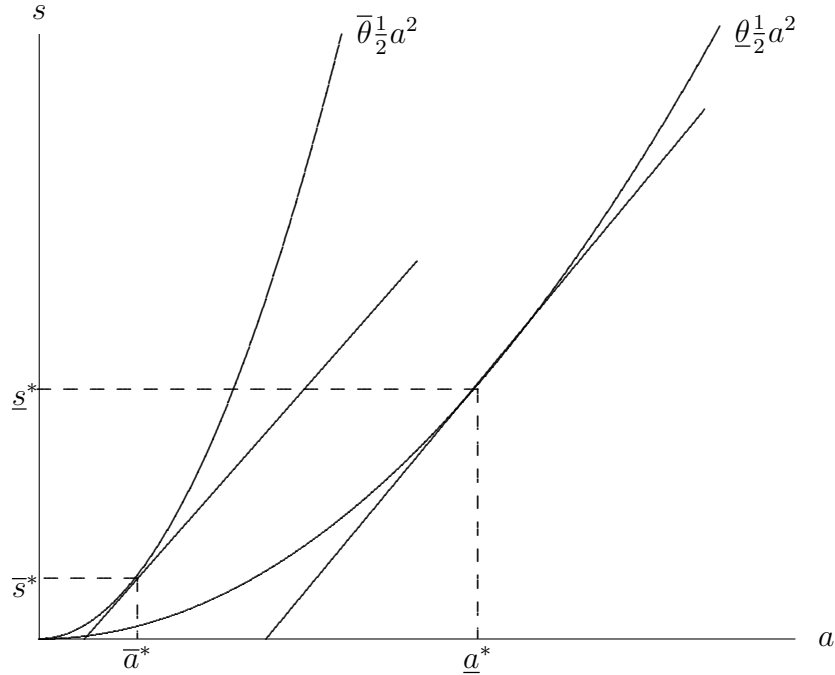


$S(\underline{a}) - \underline{\theta}\frac{1}{2}\underline{a}$, $\bar{W} = S(\bar{a}) - \bar{\theta}\frac{1}{2}\bar{a}$. $\underline{W} > \bar{W}$, the social value of production of abatement is greater when the agent is efficient, compared to when the agent is inefficient. Since the principal's marginal value of abatement is constant, the optimal production of an efficient agent is greater than that of an inefficient agent, $\underline{a} > \bar{a}$.

6.2.2 Implementation of First-Best

The principal must offer the agent a utility level that is at least as high as the utility level that the agent obtains outside the relationship. These constraints are called the agent's participation constraints, and reflects the firm's alternative choice of behavior. We define U^T as the utility of the firm if he is not a member of the NOx-fund and has to pay a tax (17NOK/kg NOx emission) to the government, U^M is the utility of the firm if he is a member of the NOx-fund, but does not apply for funding for new investments. U^I is the utility of the firm if he is a member of the NOx-fund and gets a subsidy for new investments. I assume that for both firms we have $U^T < U^M < U^I$, the utility of the firm is lower when it has to pay a tax than when he is member of the fund, which is lower than when he is member of the fund and receives funding. Hence, when considering whether the firm will participate

Figure 6.4: Optimal First-Best solution. Optimal level of abatement and corresponding optimal subsidy.



in the relationship we use U^M as the outside option. The outside option does not depend on the type, and I assume in general that we don't have type dependent participation constraints.

Starting out with the assumption that the outside option is U^M we have the following participation constraints.

$$\underline{s} - \underline{\theta} \frac{1}{2} a^2 \geq U^M \quad (12)$$

$$\bar{s} - \bar{\theta} \frac{1}{2} \bar{a}^2 \geq U^M \quad (13)$$

To implement the first-best production of abatement, the principal makes a take-it-or-leave-it offer to the agents. If $\theta = \bar{\theta}$, the principal offers the transfer \bar{s}^* for the production level \bar{a}^* , with $\bar{s}^* = U^M + \bar{\theta} \frac{1}{2} \bar{a}^{*2}$, and vice versa for the efficient type. The optimal First-Best solution is shown in figure 6.4. Both the efficient and the inefficient firm will make zero extra profit over U^M , and accept the offer. These are the complete information optimal contracts where the efficient firm gets a higher transfer and produces more abatement than the inefficient firm, because we have

assumed that U^M is equal for both types and $\underline{a} > \bar{a}$. They are thus indifferent between the two choices: being member of the fund and applying for funding and being member and not apply for funding. None of them receive information rent, because there is complete information.

6.3 Hidden Information

6.3.1 Incentive Compatibility and Participation

Now we assume that the marginal abatement cost, θ , is the agent's private information. Both the efficient and the inefficient agent will prefer the contract intended for the least efficient type. The efficient agent will prefer the contract of the inefficient agent because this gives him a profit above U^M , as he has lower costs than the inefficient agent. Thus, offering the two contracts that were optimal under full information will in this case not make the agent's reveal their type. The principal want to make contracts that make the agent's self select, but this will not be implemented under asymmetric information.²⁹ In order to make the two agents self select we have the following incentive compatibility constraints:

$$\underline{s} - \theta \frac{1}{2} \underline{a}^2 \geq \bar{s} - \theta \frac{1}{2} \bar{a}^2 \quad (14)$$

$$\bar{s} - \bar{\theta} \frac{1}{2} \bar{a}^2 \geq \underline{s} - \bar{\theta} \frac{1}{2} \underline{a}^2 \quad (15)$$

When the two incentive compatibility constraints are satisfied it means that the agents prefer the contract intended for himself over the contract intended for the other type, given his efficiency parameter θ . We now have two participation constraints and two incentive constraints, that together fully characterize the set of incentive feasible menus of contracts.

²⁹Self select means choosing the contract intended for his own type.

6.3.2 Optimization Program of the NOx-Fund

The NOx-fund must offer a menu of contracts before knowing which type of the firm they are facing. Because of this, the fund computes the benefit in expected terms.

$$\text{Max } v[S(\underline{a}) - \underline{s}] + (1 - v)[S(\bar{a}) - \bar{s}] \quad (16)$$

subject to

$$\underline{s} - \underline{\theta} \frac{1}{2} \underline{a}^2 \geq \bar{s} - \underline{\theta} \frac{1}{2} \bar{a}^2 \quad (17)$$

$$\bar{s} - \bar{\theta} \frac{1}{2} \bar{a}^2 \geq U^M \quad (18)$$

We use $\underline{U} = \underline{s} - \underline{\theta} \frac{1}{2} \underline{a}^2$ and $\bar{U} = \bar{s} - \bar{\theta} \frac{1}{2} \bar{a}^2$ to denote the respective information rent of each type. Under complete information, the NOx-fund, who by assumption has all bargaining power, is able to maintain the two types at their outside option utility level U^M .

$$\underline{U}^* = \underline{s}^* - \underline{\theta} \frac{1}{2} \underline{a}^{*2} = U^M \quad (19)$$

$$\bar{U}^* = \bar{s}^* - \bar{\theta} \frac{1}{2} \bar{a}^{*2} = U^M \quad (20)$$

Generally, this is not possible anymore, at least not when both the firms produce a positive amount of abatement. When there is asymmetric information about the marginal abatement cost for each firm, the utility level that a $\underline{\theta}$ -firm would get by mimicking a $\bar{\theta}$ -firm is higher than when choosing the contract intended for himself. This is because the efficient firm benefits from his ability to possibly mimic the less efficient type.

$$\bar{s} - \underline{\theta} \frac{1}{2} \bar{a}^2 = \bar{s} - (\bar{\theta} - \Delta\theta) \frac{1}{2} \bar{a}^2 = \bar{s} - \bar{\theta} \frac{1}{2} \bar{a}^2 + \Delta\theta \frac{1}{2} \bar{a}^2 = \bar{U} + \Delta\theta \frac{1}{2} \bar{a}^2 \quad (21)$$

As long as the fund wants both firms to produce abatement, the fund must give up a positive rent to the most efficient firm, represented by the last term above. This information rent is generated by the information advantage of the firm over the fund. The fund's problem is thus to determine the smartest way to give up the rent and at the same time make the firm produce the wanted amount of abatement. Now we are interested in the variables information rent and production of abatement. We insert for \underline{U} and \bar{U} and get:

$$\begin{aligned} \text{Max } & \overbrace{v[S(\underline{a}) - \frac{\theta}{2}\underline{a}^2] + (1-v)[S(\bar{a}) - \frac{\bar{\theta}}{2}\bar{a}^2]}^{\text{expected allocative efficiency}} \\ & - \underbrace{[v\underline{U} + (1-v)\bar{U}]}_{\text{expected information rent}} \end{aligned} \quad (22)$$

subject to the incentive compatibility constraints and the two participation constraints

$$\underline{U} \geq \bar{U} + \Delta\theta\frac{1}{2}\bar{a}^2 \quad (23)$$

$$\bar{U} \geq \underline{U} - \Delta\theta\frac{1}{2}\underline{a}^2 \quad (24)$$

$$\underline{U} \geq U^M \quad (25)$$

$$\bar{U} \geq U^M \quad (26)$$

6.4 Rent Extraction-Efficiency Trade-Off

6.4.1 The Optimal Contract under Asymmetric Information

(23) and (26) are the two binding constraints, and (24) and (25) will also be satisfied.³⁰ We insert these two into the funds maximization problem, which becomes the following:

$$\text{Max } v[S(\underline{a}) - \frac{\theta}{2}\underline{a}^2] + (1-v)[S(\bar{a}) - \frac{\bar{\theta}}{2}\bar{a}^2] - [v(\bar{U} + \Delta\theta\frac{1}{2}\bar{a}^2 + (1-v)U^M)] \quad (27)$$

³⁰See Laffont and Martimort (2002).

We differentiate with respect to \underline{a} and \bar{a} and assume an interior solution:

$$v(S'(\underline{a}) - \theta\underline{a}) = 0 \quad (28)$$

$$(1 - v)(S'(\bar{a}) - \bar{\theta}\bar{a}) - v\Delta\theta\frac{1}{2}\bar{a}^2 = 0 \quad (29)$$

Rearranging this gives us two first order conditions, where I denote SB as the second best solution

$$S'(\underline{a}_{\text{SB}}) = \theta\underline{a}_{\text{SB}} \quad (30)$$

$$S'(\bar{a}_{\text{SB}}) = \bar{\theta}\bar{a} + \frac{v}{(1-v)}\Delta\theta\frac{1}{2}\bar{a}_{\text{SB}}^2 \quad (31)$$

The first condition shows us that $\underline{a}_{\text{SB}} = \underline{a}^*$, the level of production of abatement for the efficient firm is the same as in the first best optimum. This is because the expected rent given does not depend on the level of abatement for the efficient type. We want to look deeper into the other first order condition.

$$(1 - v)(S'(\bar{a}_{\text{SB}}) - \bar{\theta}\bar{a}_{\text{SB}}) = v\Delta\theta\frac{1}{2}\bar{a}_{\text{SB}}^2 \quad (32)$$

$$\underbrace{(1 - v)(\beta - \bar{\theta}\bar{a}_{\text{SB}})}_{\text{Expected marginal payoff by an increase in } \bar{a}} = \underbrace{v\Delta\theta\frac{1}{2}\bar{a}_{\text{SB}}^2}_{\text{Expected marginal cost by an increase in } \bar{a}} \quad (33)$$

This condition expresses the trade-off between efficiency and rent extraction that exists under asymmetric information. The Fund's expected payoff in terms of production of abatement is the left hand side of this equation. The Fund's expected marginal efficiency gain will increase by the left hand side when there is an increase in the level of abatement for the inefficient firm. At the same time the expected marginal cost in terms of increased information rent to the efficient firm will also increase as \bar{a} increases. These two must balance each other in a second best equilibrium. This is the condition that express the important trade-off between efficiency and rent extraction, which arises under asymmetric information.

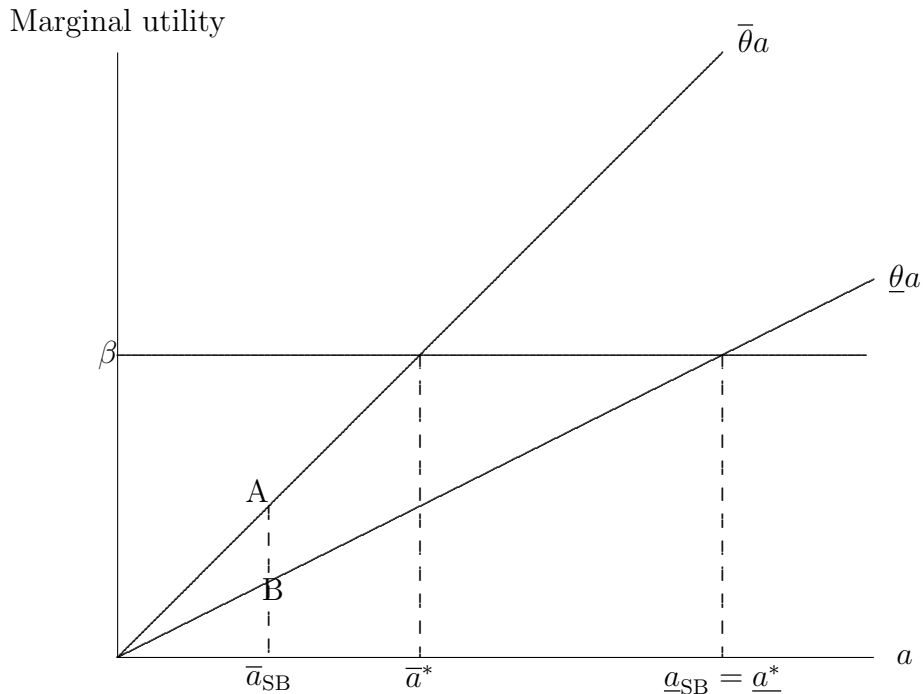
Under asymmetric information we have found that the efficient firm will produce the same amount of abatement as it did under full information and receive a positive information rent $\underline{U}^{\text{SB}} = \Delta\theta\frac{1}{2}\bar{a}_{\text{SB}}^2$, and his total transfer is thus $\underline{s}_{\text{SB}} = \theta\frac{1}{2}\bar{a}^2 + \Delta\theta\frac{1}{2}\bar{a}_{\text{SB}}^2$.

The inefficient firm will produce a lower level of abatement, $\bar{a}^{\text{SB}} < \bar{a}^*$ with $S'(\bar{a}_{\text{SB}}) = \beta = \bar{\theta}\bar{a} + \frac{v}{(1-v)}\Delta\theta\frac{1}{2}\bar{a}^2$, and receive a second best transfer, $\bar{s}_{\text{SB}} = \bar{\theta}\frac{1}{2}\bar{a}_{\text{SB}}^2$.

6.4.2 Graphical Representation of the Second-Best Outcome

This figure shows the second-best outcome, and illustrates exactly how big the information rent to the efficient type is. The information rent to the efficient firm is given by the term $\underline{U}^{\text{SB}} = \Delta\theta\frac{1}{2}\bar{a}_{\text{SB}}^2$, and represents what the efficient agent must receive in order not to mimic the inefficient type.

Figure 6.5: Optimal Second-Best solution



If the efficient firm pretends to be the inefficient one and chooses his contract he must produce the level of abatement $\underline{a}_{\text{SB}}$. For producing this level of abatement he will receive a subsidy represented by the triangle in figure 6.4, [origo, A, \bar{a}_{SB}], which exactly covers the costs of the inefficient firm, as he receives no information rent. Thus, the surplus for the efficient firm is represented by the triangle, [origo, A, B]. This in turn means that for the efficient firm not to mimic the inefficient firm, the information rent has to be at least as high as this area.

6.4.3 Findings in the adverse selection model

The main result in this model is that a first best optimum is impossible to reach when the firms have information power over the fund, and thus information rent has to be paid to the most efficient firm. In a second best solution a lower level of abatement is reached at a higher cost.

7 Conclusions

This thesis has attempted to evaluate the Norwegian NOx-fund, as an alternative method to reduce NOx emissions compared to a standard tax system. I start with a theoretical analysis using a standard tax model and compare it with a fund using an investment based funding system.

I find that if the tax level is the same in both cases, the fund system will lead to a higher level of abatement because of the subsidy given to the firms. The subsidy makes the marginal abatement cost in equilibrium higher, and thus the abatement level will be greater than in the case of a tax. However, the two taxes are not equal, and the same optimal solution could be reached in both cases. As we know that the subsidy given to the firms varies a lot, this suggests that a fund system will not provide equal marginal abatement costs between firms, and abatement will not be cost efficiently distributed. One social cost of a fund is that it does not create public revenue like a tax on emissions would have done. Therefore the fund has two types of social costs: abatement effects are not cost efficiently allocated between firms and public revenue is lost and must be collected in other ways.

I analyze the fund by looking at the marginal abatement cost curve using data both from implemented and planned abatement projects. Here I find that the marginal cost of the projects differs a lot between different initiatives, and also within categories. I find that the most cost efficient initiatives which also contribute to high abatement levels are fuel saving, SCR and motor technical rebuilding. This shows that the most efficient initiatives are also among the majority of the funded projects from the NOx-fund. Changes from existing technology to gas also contribute with high emission reductions, with an average cost somewhat above the most cost efficient initiatives. I also find that the initiative where the costs varies the most within that measure is process optimizing, which is a measure that does not contribute with more than 4% of the total emission reductions.

Finally I present reflections about what would have been the situation under different circumstances, and I find that it would have been possible to reach the same level of abatement as what is reached today at a total cost 39% lower than

today, if twice as many of the projects SCR, motor technical rebuilding and change to gas were added to the already existing projects. Instead of reaching the level of 26 078 tons of NO_x abatement at a total cost of 399 million NOK, it could have been reached at a total cost of 244 million NOK. In a more modest scenario I find that the same level of abatement could be reached at a total cost of 321 million NOK, 20 % cheaper than today, if only these three categories were carried out and none of the other categories. My estimates of the total costs are also in accordance with previous studies done by SFT; one scenario finds that they can be reached at a lower level than what SFT predicted, and the other scenario gives somewhat higher costs.

One possible explanation for why some average costs are so much higher than others is that the fund has granted funding to almost all applying projects. As new investments only are profitable when they are in dock for other maintenance purposes, this might suggest that one needs more time in order to reach a more cost efficient solution. If the fund had a longer time perspective, one would have the possibility to prioritize the most cost efficient investments over others. This also suggests that if one uses an emission tax, it is necessary to announce the tax a long time in advance in order for investments to be undertaken when it is profitable for the firm. Another reason for not reaching the first best level of abatement is lobbying from interest groups that might affect the government's preferences when maximizing welfare. This leads to environmental policy not maximizing the NO_x reduction at the lowest possible costs.

The theoretical analysis is extended by assuming that there is asymmetry in the information on the firms marginal abatement cost, between the firms and the NO_x-fund. I set up an adverse selection model and find that first best optimum is impossible to reach because of the information asymmetry. In the second best solution some information rent must be given up to the most efficient agent in order to make him not mimic the least efficient firm. The main result here is that the optimal second best contract gives a lower level of abatement at a higher cost than the first best solution.

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