UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Trading with Carbon: Technological Trends in Swedish Industries from a Climate Perspective

Tomas Hagberg and Susanna Roth

Graduate School
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Economics
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Supervisor: Åsa Löfgren

Abstract

As means for meeting the goals of the Kyoto protocol the European Union launched the Emission Trading Scheme (ETS) for tradable permits on carbon dioxide in 2005. One of the purposes of ETS is to create incentives for firms to invest in carbon abatement technology. Therefore an important measure of the success of the environmental policy is to see whether diffusion of new technologies regarding carbon dioxide emissions has changed. We look at the determinants for carbon abatement technology in Sweden during 2002-2008 in five industrial sectors and the energy sector. Using panel data at firm level our empirical results show that since the start of emission trading, carbon abatement investments have increased. By controlling for other factors we find it likely that this depends on the ETS. Our results also point at the importance of less grandfathering to further increase diffusion. Another finding is that there is internal learning by doing, for instance green research and development and earlier environmental protection investments increase the probability of adopting carbon abatement technology.

Keywords: EU ETS, European Union's Emission Trading Scheme, Sweden, environmental policy, tradable permits, adoption, diffusion, carbon abatement technology, green technology, environmental protection investments.

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Contents

1. Introduction

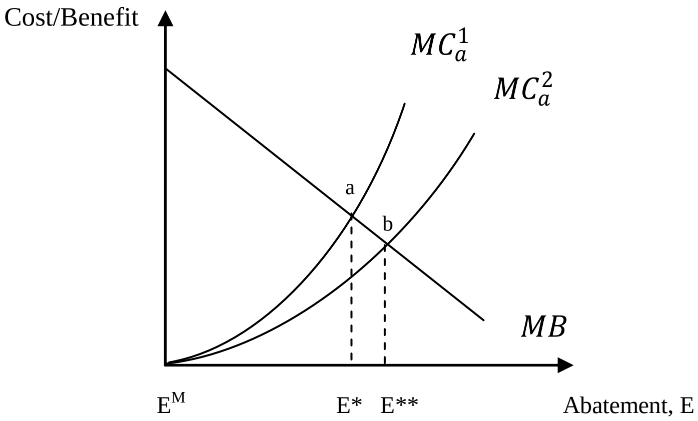
The purpose of this paper is to evaluate the effect of the European Union's Emission Trading Scheme (EU ETS) on Swedish firms' Climate Protection Investments (CPI) and to contribute to the knowledge about adoption of abatement technology regarding carbon dioxide (CO_2) emissions in general. We do this by using a unique data set for six Swedish industrial sectors between 2002 and 2008. Though the EU ETS is the world's largest trading scheme and covers around 45 % of the total CO_2 emissions in the EU, its effect on technological adoption has not, to our knowledge, been thoroughly examined. The scheme has only finished its first trial phase, 2005-2007, and is now in the middle of its second phase, 2008-2012. Continuous evaluation will be vital for the scheme to be successful in achieving its current goal of reducing CO_2 emissions by five percent by 2012, as stated by the Kyoto Protocol, as well as to provide adjustments for future phases such as the total cap of emissions and the allocation of allowances. Hence, this paper provides an important early assessment of how the EU ETS has affected Swedish firms' incentives to invest in more environmentally friendly technology.

We define our dependent variable CPI as investments in environmental protection directed at carbon abatement. Environmental protection investments are either clean technology investments, which are directed towards the production process to make it more efficient and thereby reduce emissions, or end-of-pipe solutions that capture the emissions just before they are emitted and then neutralize them. Carbon capture and storage, which is the end-of-pipe solution when it comes to CO_2 emissions is still under development and has not yet been introduced in Sweden. Since the focus of our analysis is CO_2 emissions, we concentrate on clean technology.

Technological change is usually described in the literature as a process with several steps (see e.g. Milliman and Prince 1989; Jaffe and Stavins 1995; Jaffe et al. 2002, 2004; Snyder et al. 2003; Newell et al., 2006; Gillingham et al. 2008). Schumpeter (1942) first described technological change in three steps. In the first step, an invention is created, usually after investments in research and development (R&D). The invention cannot be used commercially but might have the potential to develop. In the second step, the idea develops into something that can be commercialized, and this is the innovation of the technology. The last step is diffusion of the technology, where the innovation acquires a share of the market. Diffusion is the step where adoption of new technology occurs, hence the focus of our analysis and what we measure with CPI. Milliman and Prince (1989) include a fourth step where the policy maker responds to the new technology, i.e. in a tradable permit system reducing the cap, which is crucial for the reduction of pollution. Hence, two steps are important for our analysis: diffusion of technology and response from the policy maker.

If a firm invests in new technology it is possible to produce a given level of emissions at a lower cost. Aggregate marginal benefit for society (*MB)* and aggregate marginal abatement cost for the firms (MC_a) depend on the aggregate abatement level, E. The efficient level of emissions is defined as the level where marginal benefit is equal to marginal abatement cost. Figure 1 illustrates how adoption of new technology shifts the marginal abatement cost curve downwards from MC_a^1 to MC_a^2. As a result, the efficient level of emissions decreases without affecting output. The policy maker responds by reducing the cap of emissions from E* to E**. The social gain to society equals the area E^Mab, where E^M is the maximal amount of emissions. The firms' other possible way to reduce pollution is simply to limit production. In general that approach has little political appeal and therefore technological improvements that increase energy efficiency have been of major interest for combating climate change (Newell et al., 2006).

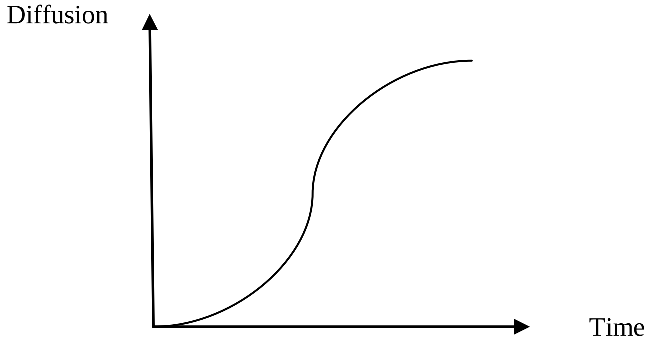
Figure 1. Adoption of new technology results in a shift in the marginal abatement cost curve.



Technological adoption is a gradual process described by e.g. Jaffe et al. (2002). Figure 2 describes this process that takes the shape of an S, a sigmoid function of time. The slow start of diffusion depends partly on firms' heterogeneity since they have different costs and benefits from the new technology. Adoption of new technology is also risky since the effects of the technology on profits are uncertain. After a while diffusion goes faster. One way of explaining this is that the new technology is being developed continuously and a positive externality is that it becomes cheaper and better, making it more attractive. This enhances the diffusion until it fades off as potential adopters become fewer. Another way to explain the increased adoption rate is that as the technology acquires a larger market share more firms are exposed to it, and therefore it spreads. The costs and benefits of the technology make it spread slower or faster. Hence, both of these explanations let the diffusion depend on the economic value of the technology.

Since there are positive spillover effects from diffusion, one firm’s adoption makes adoption cheaper for another firm. This implies that the early adopters would not be fully compensated for their investment, which reduces the incentives for adoption in the first place. Hence, policies at the stage where the product is getting commercialized on the market are of great importance and this opens up opportunities for policy to induce diffusion by making it more economically beneficial (Newell, 2010). A relevant parallel to this is the possible underinvestment in R&D due to similar negative spillover effects where private R&D for new technology might not generate the return that is expected. Hence, government-financed R&D is of great importance for the development of new technologies. (Popp, 2006)

Figure 2. Diffusion of technology.



Adoption of new technology is crucial for reducing emissions. The impact of different policies on firms’ incentives to invest in new technology have been widely discussed and examined in the literature (see e.g. Downing and White, 1986; Milliman and Prince, 1988; Jaffe and Stavins, 1995; Requate, 2005). On the whole, the literature concludes that market based instruments, like the EU ETS, perform better regarding adoption of abatement technology than command-and-control instruments, like technology or emission standards. A market based instrument provides incentives to reduce emissions through prices and firms themselves decide whether to emit or abate, i.e. whether to buy permits or invest in abatement technology. Compared to a command-and-control policy, a tradable permit scheme is not only efficient now but will also increase future efficiency since it gives incentives to invest in R&D and to adopt new technologies that will be beneficial for the firm in the future. (Sterner, 2002) Under competitive conditions a market-based instrument will lead to an equalization of marginal abatement cost across firms while abatement must take place regardless of the cost under a command-and-control measure. Hence, in theory, a tradable permit system minimizes the aggregate abatement costs.

There have been a couple of examples during history where tradable permits have been used to curb air emissions. One of them is the phase out of lead in the U.S. where tradable permits were alternated with performance standards. Kerr and Newell (2003) investigate these different policies' effects on firms' technological adoption decisions. They use a panel of refineries in the U.S. during 1971-1995 and find that firms had a higher probability of adopting abatement technology during the periods with tradable permit systems than during the periods with performance standards. This result is consistent with the theoretical conclusions that market based instruments like a tradable permit system creates more efficient incentives for technology adoption decision than command-and-control measures do.

The sulphur dioxide emission trading in the U.S. is another example of a tradable permit system on air emissions. The program was evaluated extensively in the late nineties (Stavins 1998; Schmalensee et al. 1998; Joskow et al. 1998) when the program was still unfinished. Sulphur dioxide is emitted when dirty fuels are burned and contributes to acid rain which is harmful for the environment. The tradable permit system was very successful and emissions were abated at low cost compared to the estimated costs of a command-and-control policy (Stavins, 1998). Jaffe et al. (2002) refer to research that shows that the tradable permit system provided greater incentives for technology adoption than the previous direct regulation. Schmalensee et al. (1998) describe the system as an example showing that tradable permits can work almost as efficiently as suggested by theory due to a well functioning market. But there are important differences between sulphur and carbon dioxide. In the U.S. sulphur intense coal could be substituted with cleaner coal at lower cost and faster rate than one would expect renewable energy sources to replace fossil fuels. Also acid rain is a fairly local pollutant while Green House Gases (GHGs) are global in their nature which presents additional complications regarding legislation, administration and carbon leakage[1], another determinant of a policy's efficiency.

The drivers for technological change for Swedish firms have been examined empirically by Hammar and Löfgren (2010). Their study covers three sectors in the Swedish manufacturing industry and the energy and heating sector during 2000-2003. They find evidence for a learning-by-doing effect of R&D on adoption of new technology. Hence, firms with R&D

[1] Carbon leakage occurs when emissions of CO_2 increases in countries with weak environmental regulation since production is moved there from countries with strong environmental regulation.

investments directed at environmental protection also have a higher probability of adopting new green technology. Following Hammar and Löfgren we investigate Swedish firms' investments in abatement technology, but use a more recent time period and limit the analysis to CO_2 emissions. Frondel et al. (2004) also look for the determinants for firms' investments in abatement technology in a study including seven OECD countries in 2003. They find that future cost savings, earlier R&D and technological capabilities tend to stimulate clean production investments.

The performance of the EU ETS has been empirically examined by Widerberg and Wråke (2009). They look at whether the EU Emission Allowance (EUA) price has caused a reduction in the Swedish electricity sector's CO_2 intensity, for the period 2004-2008, but find no significant effect. However, Widerberg and Wråke believe that the EU ETS will reduce the CO_2 intensity in the Swedish energy sector over a longer time horizon. Hoffmann (2007), too, examines the effect of the EU ETS on the electricity sector, but he looks at German abatement investment decisions regarding CO_2 by a case study with five German electricity producers. Overall these companies were accountable for approximately a third of Germany's total CO_2 emissions. The case studies were carried out during the middle of phase I of the ETS. One of the main findings by Hoffmann is that EUA prices are integrated in the decision-making of the electricity producers but does not radically change the use of technology. Moreover, the industry does make investments with low risk aimed at short term investments that raise efficiency and long-term investments aimed at R&D. However, for large-scale low carbon investments, the uncertainty associated with the EU ETS reduced the incentives for abatement investments.

In this paper we use firm level data that include six sectors: the energy sector, the metal industry, the mineral industry, the refinery and coke oven industry, the chemical industry and the pulp and paper industry. The chemical industry is only partly included in the EU ETS. The total share of all Swedish CO_2 emissions that these sectors emitted, excluding the chemical sector, were 35 % in year 2007 (Statistics Sweden, 2009). In comparison, the total emissions from transport in Sweden in 2008 were 32 % and emissions from the agriculture sector were 13 % (The Swedish Environmental Protection Agency, 2009a). Hence, this study examines the effect of the ETS in Sweden comprehensively and the results also have importance in relation to total Swedish emissions.

We find strong indications that the EU ETS has changed firms' investments behaviour. More firms have invested in phase I and in the beginning of phase II than did so before the introduction of the tradable permit system. In our econometrical analysis we find that during phase I, the probability of investing in CO_2 abatement is 13 % higher than before the EU ETS. The start of phase II (year 2008) shows a similar result, the probability of investment is 16 % higher compared to the time before the ETS introduction. We also find support for the proposition that these results are not driven by other factors by controlling for other policies which might have affected the outcome and for investment patterns for firms which are outside the ETS

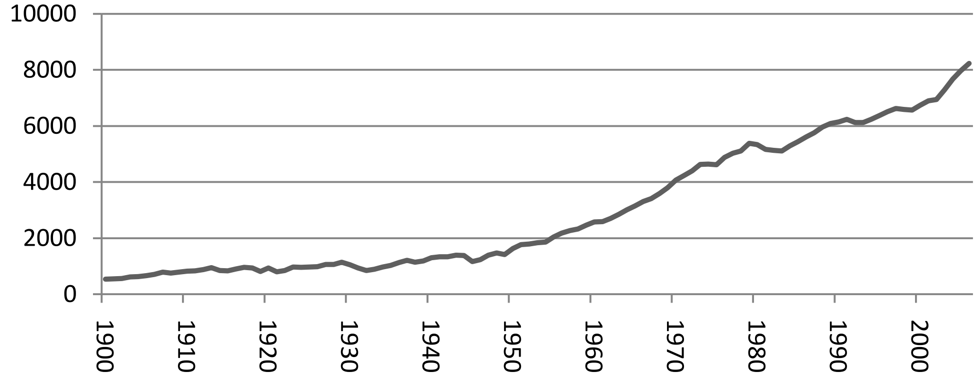
The next section (section 2) contains a background to climate change and the theory of tradable permits, and gives a more detailed description of the EU ETS progress in EU and Sweden. It is followed by a theoretical discussion of the model estimated and the variables used in section 3. After that we discuss the data and present the result of the econometrical analysis in section 4. This section also includes a robustness analysis of our empirical results. The paper ends with a conclusion (section 5).

2. Background

2.1 Climate change

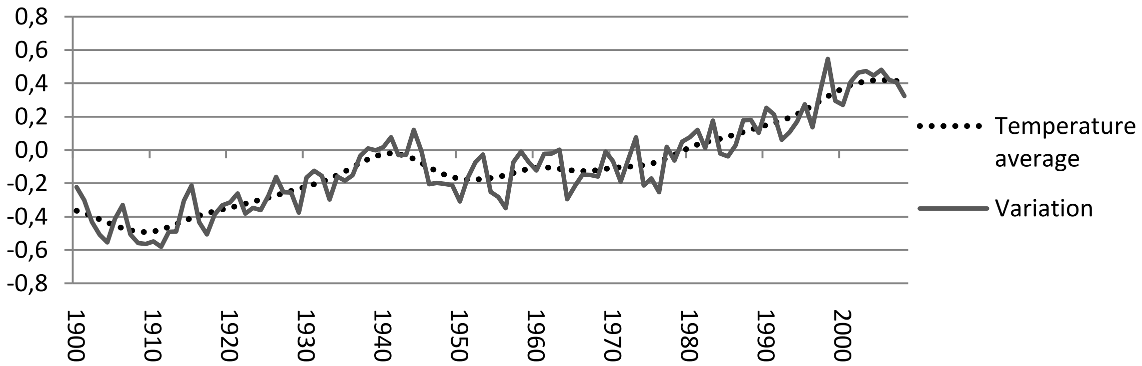
There is widespread agreement regarding the basic physics behind climate change and about the negative effects that the emissions of GHGs has on the planet's ecosystem. During the industrial era, combustion of fossil fuels and deforestation has increased the amount of carbon dioxide in the atmosphere by about 35 % (Le Treut et al., 2007). Figure 3 describes how the total emissions of CO_2 in the world have steadily increased during the last century from fossil fuel consumption while figure 4 illustrates how the average temperature in the world has changed during the same time period. The global temperature has had an increasing trend during the whole time period and is now around +0.4°C, compared to -0.4°C in the beginning of the 20th century. Hence, the average global temperature has increased almost one degree during the last hundred years. Rosenzweig et al. (2007) goes through the already evident and potential future effects of global warming. Already we can see receding shorelines, melting arctic ice and reducing snow cover in the northern hemisphere. Coral reefs are threatened and coastal vegetation is changing in different parts of the world. The disease environment for people living in temperate areas might get worse and more floods and disasters can have unpredictable and possibly devastating effects on human life.

Figure 3. Global annual carbon dioxide emissions (million tonnes) from fossil fuel consumption, during 1900-2006.



Source: Carbon Dioxide Information Analysis Center, 2009a

Figure 4. Global temperature 1900-2008. The average temperature corresponds to approximately a 10 year average.

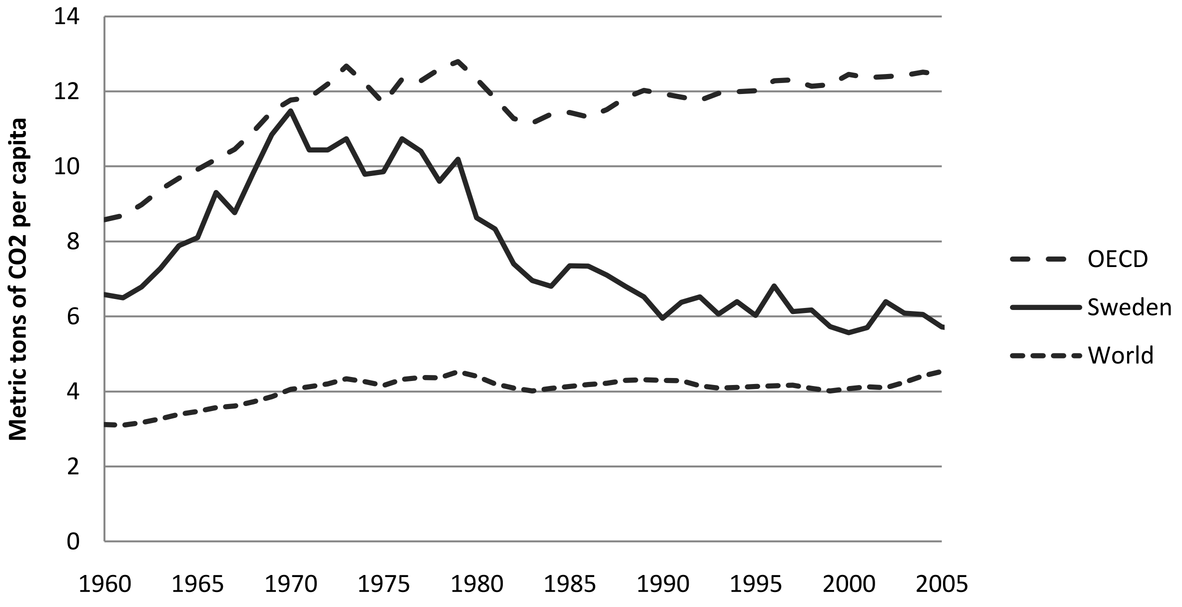


Source: Climate Research Institute, 2010

There is broad international agreement that action must be taken to prevent global warming. The Stern Review (Stern, 2008) contends that it will be cheaper for the world to act now than to wait. To tackle the challenges imposed by climate change many countries have ratified the optional protocol to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, with binding emission targets for 37 industrialized countries, of which many are EU members. The Kyoto protocol concerns the period 2008-2012 during which the industrialized countries have agreed to reduce their collective GHG emissions by five percent compared to 1990 levels. Every country has its own emission target. As part of the Kyoto Protocol three flexible mechanisms were introduced to help countries reach their emission targets and reduce GHG emissions to the atmosphere in the most cost-effective way. The Clean Development Mechanism (CDM) and Joint Implementation (JI) allow the countries to invest in emission-reducing projects in developing countries, and in other industrialized countries, respectively. The third flexible mechanism, Emission Trading, allows countries with a surplus of allocated emissions to sell their excess capacity. Countries with a deficit of permits can in the same way buy allowances on the market. As an Emission Trading mechanism, the EU launched its tradable permit system for carbon dioxide, the ETS, for member states to achieve their commitments under the Kyoto protocol. (Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1998) The EU ETS is also an important policy instrument for the EU to achieve its goal of a 20 % reduction of CO_2, compared to the 1990 emission level, until 2020.

Figure 5 shows how the yearly average per capita emissions of CO_2 have increased globally and in Sweden since the 1960s and forward. In Sweden, the per capita emissions rose until the 1970s, but have decreased since then partly due to large investments in hydro- and nuclear power. Global per capita CO_2 emissions have had a stable increase during the period but have been dampened by the great population increase in the world. Sweden's per capita emissions of CO_2 is higher than the world average. The Swedish Environmental Protection Agency estimates that it is equivalent to 5.4 tonnes per person per year while global CO_2 emissions are around 4 tonnes per person per year. Still, the Swedish emission level of CO_2 is rather low compared to other OECD countries. For example, German emissions of CO_2 in 2007 were almost 10 tonnes per person per year and in the U.S. this figure was 19 tonnes per person per year (Carbon Dioxide Information Analysis Center, 2010).

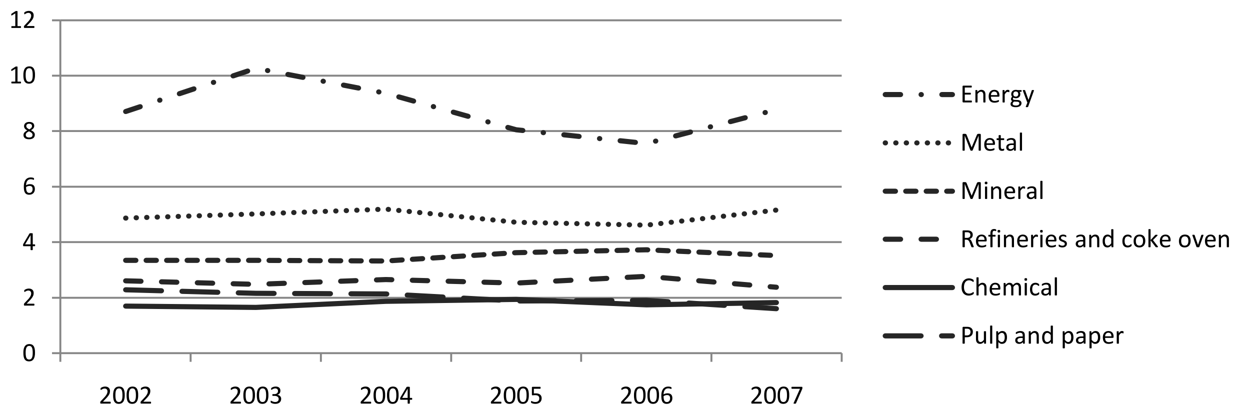
Figure 5. Per capita carbon dioxide emissions for Sweden and the world, yearly average during 1960-2005.



Source: Carbon Dioxide Information Analysis Center, 2009b

This study will include six Swedish industrial sectors. Figure 6 shows how the emissions of carbon dioxide to air in these sectors have changed during 2002-2007. During the time period, the energy sector, metal industry, mineral industry and the chemical industry have decreased their emissions of CO_2 while the refinery and coke oven industry and the pulp and paper industry have increased their emission levels. The energy sector clearly has the highest emission level compared to the other sectors. It emits around 38 % of the total emissions from the sectors covered in this analysis. The energy sector is also the sector with the largest variation in emission level. Carbon dioxide emissions had a decreasing trend during 2003-2006 but the level increased again between 2006 and 2007. The CO_2 emissions in the other sectors have been rather stable during the investigated time period.

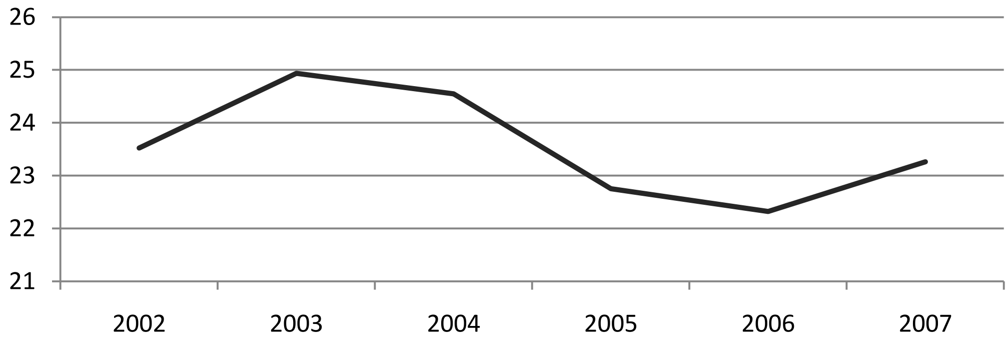
Figure 6. Change in emission level of CO_2 (million tonnes) in the Swedish sectors included in this study, during 2002-2007.



Source: Statistics Sweden, 2009

Figure 7 below presents all carbon dioxide emissions from the sectors included in our survey are presented. Just as for the energy sector, emissions peaked in 2003 with almost 25 million tonnes of CO_2 emitted. After that emissions have decreased. The lowest emission level was observed in 2006 with around 22 million tonnes. It increased slightly to just above 23 million tonnes in 2007. The emission levels for all sectors were higher before the start of the ETS than after its introduction.

Figure 7. Change in emissions level of CO_2 (million tonnes) for all sectors included in the survey, during 2002-2007.



Source: Statistics Sweden, 2009

2.2. Tradable permit theory

In a tradable permit scheme with a cap and trade system the regulator decides the, preferably socially optimal, level of aggregate emission that is allowed within the system. Thereafter, allowances are allocated to firms either for free based on historical emissions, known as grandfathering, or auctioned. Hence the total amount of pollution is known, but the price of the permits is not. Every firm *i* receives initially e_{io} allowances and have accordingly the right to emit exactly e_{io}. The firm can thereafter choose to emit exactly the amount of received permits, emit more than the initially awarded level after it bought additional permits on the market or emit less than the amount of permits initially received and thereby sell the excess permits. A single market for permits with the same price for both buyers and sellers is created.

The individual firm maximizes its profit π, given the regulator's initial allocation of permits:

$$\max\ \pi = Pq_i - c(q_i, a_i) + p[e_{i0} - e_i(q_i, a_i)] \qquad (1)$$

where P is product price, q is output, c is the cost function, a is abatement, p is the price of permits and e_i is the emission function. The first order conditions are:

$$P = mc_q + p \cdot me_q \qquad (2)$$

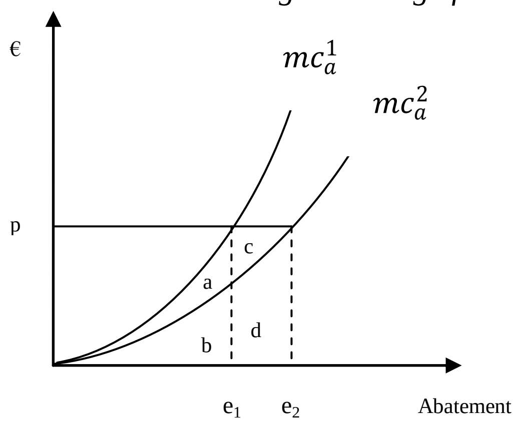
$$mc_a = -p \cdot me_a \qquad (3)$$

where *mc* and *me* are derivatives of the cost and emissions factors. The subscripts indicate derivatives with respect to output q and abatement a. The first necessary condition in equation (2) shows that product price equals marginal cost of production plus the marginal cost of buying extra permits. Hence, the damage that pollution causes is incorporated in the cost of production through the price of the permits. The second first order condition in equation (3) shows that marginal cost of abatement equals the benefit of reducing emissions by one unit of abatement. Hence, in equilibrium there is an economically efficient amount of emissions. If the level of emissions is lower than in equilibrium, society could benefit from producing more. Equivalently, if the emission level is higher than in equilibrium benefits could be gained from producing less. The first first order condition in equation (2) demonstrates that a tradable permits system fulfils the requirements for economic efficiency since price equals marginal costs and cost of permits. The second first order condition in equation (3) shows that cost of abatement equals the cost of permits for abated emissions so that marginal abatement costs are equalized among firms. If p is equal to the Pigouvian tax, meaning that the tax is equal to the externality, the permit system theoretically gives the same optimal reduction in emissions as a Pigouvian tax.

From an economic theory point of view Jaffe & Stavin (1995) argue that market-based and command-and-control policies differ mainly in two ways. Firstly, market based instruments lead to a cost-effective allocation for the burden of achieving given levels of emissions among firms. Firms experiencing high costs from investments in abatement technology can buy permits instead of being forced to invest in expensive emission reductions, while firms with low costs from investing in abatement technology can invest and sell their excess permits. Thus, the tradable permit system provides more efficient adoption and abatement where it is cheapest to abate. Secondly, market based instruments are understood to continuously provide incentives for adoption of new superior technologies to find cheaper ways of controlling pollution, compared to direct regulation that only once per update results in abatement adoption. In contrast to a tradable permits system, a technology standard does not provide any incentives to provide cleaner technology than the standard.

Figure 8 describes how a tradable permit system improves efficiency and stimulates abatement investments. Initially, the firm's marginal abatement cost function is mc_a^1 and adoption of new technology shifts this curve downwards to mc_a^2. Hence, the new technology can reduce the pollution level at a lower marginal cost than the earlier technology. We let e_1 be the amount of emissions that would be allowed under a command-and-control measure. If the firm adopted the new technology to reduce its emission level to the standard, it would reduce its compliance cost, i.e. the cost for the firm to meet the government's requirements, with the area a. In the same situation under a tradable permit system, the firm initially holds e_1 permits and its emission level is therefore e_1. The firm will again adopt new technology, but now earn an additional profit equal to c since it can sell its excess permits $(e_1 - e_2)$. The total gains for the firm from investing in technological change is equal to total initial abatement cost minus the new total abatement cost, plus the revenue from selling excess permits. In figure 8 this corresponds to the area $(a+b)-(d+b)+(c+d)=(a+c)$. The greater savings under the tradable permit system, as compared to the command-and-control measure, implies that adoption is more likely under a tradable permits scheme.

Figure 8. A tradable permit scheme and technological change for a net seller of permits.



Malueg (1987) illustrates that this conclusion assumes the firm to be a seller of permits, which is not always the case. If adoption of new technology is associated with too high costs, the firm would prefer to buy permits instead of adopting the new technology. As a consequence, firms' incentive to invest in abatement technology will not necessarily increase under a tradable permit system, but depend on the firm's position in the permit market. This also means that the aggregate abatement cost will be minimized under a tradable permit system, since abatement takes place where it is cheapest.

Adoption of new technology is also associated with a fixed cost, *f*. Hence, the firm's adoption decision depends on how big this cost is. Below, we again assume that the firm is small and cannot influence the permit price. The firm minimizes its costs until marginal cost of abatement equals the price of the emission, i.e. the price of the permit, for both technologies,

$$-mc_a^1(e_1)=p$$

$$-mc_a^2(e_2)=p,$$

which yields the emission levels e_1 and e_2 ($e_2 < e_1$). The single firm decides to adopt the new technology if:

$$c_a^1+pe_1-c_a^2-pe_2-f>0\ ,$$

where c_a^1 is the firm's abatement cost curve with the old technology and c_a^2 is the firm's abatement cost curve with the new technology. The firm's abatement cost function represents the costs of reducing emissions to a lower level. Hence, the firm chooses to adopt new technology if the cost associated with the new technology, including the fixed cost of adoption, is less than the costs of using old technology.

Above, we have assumed that the price of the permits does not change as firms invest in abatement technology. However, Requate (2005) shows that in order to analyze how different policy instruments differ one must also look at firms' incentives to invest in equilibrium. Hence, the number of firms that adopt the new technology is determined endogenously. Under a permit system, the price of the permits falls when more firms adopt the new technology, on condition that the regulator does not change the total number of permits. An individual firm can subsequently free-ride on the price decrease effect from other firms' adoption of new technology. Accordingly, the benefits from an investment decreases when the price of the permits falls. Requate therefore concludes that under a myopic rule, taxes may provide stronger incentives to invest in new technology compared to tradable permits. If the policymaker is able to react optimally to the newly available technology by setting a new optimal quantity of permits, taxes and permits will give firms the same incentives to adopt new technology.

There are also uncertainties associated with a tradable permit system, since the future control cost, i.e. the cost of reducing emissions, is not known. Regarding emissions of GHG, other uncertainties come from the fact that there is little experience of making large cuts in GHG emissions and it is not known what potential the future technology will have. Within a tradable permit system, incentives to invest may be reduced since the price of the permits is uncertain while an investment in new technology is irreversible. A command-and-control measure or other market based instruments like a tax, are not in the same way linked to uncertainty. Hence, there is a risk that the cost uncertainty associated with a tradable permits system reduces the investment incentives compared to other policies. (Zhao, 2003). Pizer (2002) looks at this issue with a simulation model, where there is uncertainty over the future control cost. He finds that the variation of control costs is much higher under a tradable permit system than a tax, which can lead to large efficiency differences between the two policies. However, one advantage with a tradable permit system regarding certainty is the level of emissions, which is always definite.

The cost-effectiveness and the incentives to invest in abatement technology from a permit system depend on the rules of allocation. E.g. Malueg (1989), Milliman and Prince (1989) and Wråke (2009) point out that grandfathering leads to lower incentives to invest in innovation than auctioning since there are rents to be collected from permits that are allocated freely. These rents will be higher the less abatement technology exists. But Requate (2005) objects, as the price of the permits will be driven downwards by innovation irrespective of how the permits are initially allocated. Hence, firms will buy permits and end up with the same quantity of allowances if they are grandfathered as if they are auctioned. After an innovation the innovating firm will be a seller of permits and therefore have the same incentives to invest regardless of how the permits were initially allocated. Cramton and Kerr (2002) discuss advantages from auctioning permits. With an auctioned system, permits are allocated to those who need them the most and the government gets the scarcity rents instead of the firms. Moreover, if permits are auctioned, the revenues can be further used to reduce emissions through research or other investments, or reduce distortionary taxes in the economy. This is called the double dividend argument.

If the permits are grandfathered, the number of allowances could either be permanent or updated. If they are set permanently, firms could benefit from emission reduction activities in the beginning of the period and be awarded the rest of the period. If the allocation is rolling and based on recent emissions, there is a risk for rent-seeking behaviour. Hence, with a rolling allocation firms are aware of that their future free allocation depends on their current behavior and may therefore act differently than they would have done otherwise. This is investigated by Sterner and Muller (2008). They develop a model where they show that readjustment of allowances results in less abatement activity.

A tradable permit scheme may also be associated with large administrative costs which can make them politically infeasible. Stavins (1995) identified three sources of transaction costs that can arise in a tradable permits system. Firstly, there are search and information costs in a tradable permits system since a buyer and a seller must identify each other for trade to take place. The search and information costs will be higher the more heterogeneous the market is. Secondly, there are bargaining and decision making costs stemming from the fact that the buyer and the seller negotiate to agree on a price for the permits. Thirdly, a permit system is associated with monitoring and enforcement costs which affect the regulating agency. In the worst case scenario, the efficiency of the tradable permits system fails due to high transaction costs. For that reason a less complex system may be preferable to a more complicated system.

2.3. The EU ETS

The EU ETS comprises about 12,000 installations covering around 45 % of the total EU emissions of carbon dioxide and is the largest tradable permit system in the world as well as the largest attempt to reduce carbon emissions. The EU ETS Directive (2003) states which industries that are covered by the tradable permit system:

- All energy combustion units with a rated thermal input exceeding 20 MW
- Refineries and coke ovens
- Production and processing of ferrous metals
- The mineral industry
- The pulp and paper industry

The EU ETS was rather unthinkable only fifteen years ago. EU-wide taxes were discussed as a strategy to decrease GHG emissions but were politically problematic, partly because many member states were not willing to give away their national tax sovereignty. But the flexible mechanism, Emission Trading, within the Kyoto Protocol made tradable permits more popular in the EU. The European Commission proposed its directive for the ETS in 2003 and the program was launched in 2005. When the ETS was formalized, the National Allocation Plans (NAP) gave each member country an opportunity to assign permits for free. The European Commission decides the number of permits available to each country as well as the cap of the whole system. More than 95 % of the permits were grandfathered during phase I and more than 90 % were grandfathered during phase II. The high degree of grandfathering was driven through by the European Council, though the European Parliament preferred auctioning of the permits. The decision on grandfathering was a way to appease the industry where firms argued that with too high costs they would be forced to shut down, move abroad or move outside of the EU (Wråke, 2009). In phase II, companies will be able to save unused allowances to meet their obligation in subsequent trading periods, something that was not possible in phase I. (EU ETS Directive, 2008) Another big difference is that for phase II the scheme’s allocation time is five years compared to only three years in phase I.

To limit windfall profits, the EU ETS has an official policy of not updating the amount of distributed permits. In reality allocations are updated when the National Allocation Plans are updated. There are many risks associated with continuously updating the number of allowances. If industries are successful in lobbying for allowances, there may be over allocation of permits which will hinder the fulfillment of the Kyoto targets. There are special free allowances saved for new firms and closing installations' allowances are usually withdrawn or moved to other installations. The number of allowances saved for new entries varies between countries. (Wråke, 2009) If individual companies do not have emission allowances corresponding to their actual emissions, they must pay a penalty of 100 euro per excess tonne of CO_2 (EU ETS Directive, 2008).

A common view is that the cap was set too high during the first trial phase. Figure 9 illustrates the EUA price from the start of phase I to the end of year 2008. The sudden price drop in April 2006 is a result of the disclosure of 2005 verified emissions and the understanding that the cap was set too generously. Release of installation data with verified emissions for the first two years of phase I revealed, according to Ellerman and Buchner (2008), that CO_2 emissions were 3 % lower than the number of allowances available. In April 2007, verified emissions were again below 2006 allocations and the price reacted by moving towards zero in the end of the first phase (Alberola et al., 2007). At the same time the European Commission announced a more stringent cap for phase II. The Commission also limited many of the proposed NAPs for phase II. Additionally, the EU adjusted the definition of combustion installation which has resulted in more installations being included in the EU ETS for phase II. So far these strategies have resulted in a higher carbon price in phase II than in phase I. Figure 9 shows that the EUA price for 2008 increased to around 20 €/t until the beginning of phase II. The low price during the first phase is problematic in view of the fact that such a low price on carbon does not provide incentives for firms to invest in abatement technology. The gains from selling excess permits after adoption will tend to zero with the price. During 2008 the price increased in the beginning of the year but then decreased to around 15 €/t. There have been early reports indicating that the cap for phase II is not stringent enough to achieve the goals of the Kyoto protocol (see e.g. Betz et al., 2006).

Figure 9. EUA prices from December 2004 to December 2008. Dec 2007 and 2008 indicates the expiry date for the EUA.

Source: Point carbon, 2010

The number of auctioned permits will increase for phase III, 2013-2020, and an even more stringent allocation will be introduced. Free allocation will mostly be phased out towards 2020 (Swedish Environmental Protection Agency, 2006). A stringent policy is necessary for the functioning of the CO_2 market and phasing out free allowances after 2012 could circumvent many distortions regarding rent-seeking behaviour that the system is experiencing today (Neuhoff et al., 2006). From 2012 parts of the aviation sector will also be covered by the EU ETS. The time-period is also longer for phase III, 8 years compared to 5 years for phase II. For phase III, the national allocation plans will be replaced by a common allocation principle in the EU. Hence phase III would be surrounded by less uncertainty compared to earlier phases, which may provide more incentives for firms to invest in abatement technology.

Decisions on how the allowances are distributed in Sweden are taken by the Environmental Protection Agency after discussion with the Swedish Agency for Economic and Regional Growth and the Swedish Energy Agency. For phase I, the allowances are distributed for free to the companies based on historical emissions from the period 1998-2001. The same principle is used for phase II except in the energy sector where no free allocation are made to existing firms. New entrants in the energy sector are still given permits for free. Roughly 750 installations are covered by the EU ETS in Sweden today.

Outcomes regarding verified emissions and annual allocation of allowances during phase I for Sweden and the EU are presented in table 1. In the EU, emissions of CO_2 increased by 1.9 % during the period. Sweden reduced its emission by 1.8 % during phase I. Almost all countries had on average an over-allocation of allowances during the first period, including Sweden. Hence, to a large extent installations were given more allowances than their historical emissions.

Table 1. Verified emissions of CO_2 (million tonnes), for EU and Sweden during phase I.

	Emissions 2005	Emissions 2006	Emissions 2007	Change	Annual allocation
Sweden	19.38	19.88	19.04	-1.8 %	23.20
Total EU	2,012	2,034	2,050	1.9 %	2,152

Source: EUROPA, Press Release RAPID, 2007 and
Swedish Environmental Protection Agency, 2008.

The allocated permits for phase II cover about 20.8 million tonnes of CO_2 emissions in Sweden. Swedish CO_2 emissions in the trading sector were 20.1 million tonnes during 2008. In comparison with 2007, the emissions from the firms in the ETS increased by 1.06 tonnes for the second trading period. This increase can be explained by the fact that new emission sources at installations have been added as a result of the expanded definition of combustion installations. The broadened definition can be attributed to an increase of 1.2 million tonnes. Thus, emissions between 2007 and 2008 actually decreased. (Swedish Environmental Protection Agency, 2009b)

The different sectors' emissions and allocations of allowances during the first trading period and 2008 are presented in table 2. The sectors are divided by the Swedish Environmental Protection Agency and include an additional sector which is not a separate sector in our analysis, namely ore-based production. Following definitions from Statistics Sweden this sector is included in the mineral industry, but is presented as a separate sector in table 2. Emissions increased in all sectors except for the pulp and paper sector, when comparing emissions in year 2008 with the average emissions during phase I. In the energy sector no free allocations are given to existing installations for phase II. The energy sector accounted for approximately 60 % of total emissions in the energy and combustion units sector in 2008. Hence, only new installations are given allowances while existing installations in these industries have to rely on the market to buy permits equal to their emissions. This downscaling is consistent with the judgment of the potential in these sectors to achieve reductions in emissions of greenhouse gases (Ministry of Sustainable Development, 2006).

The emissions in the energy sector decreased by 430 000 tonnes between 2007 and 2008, particularly due to increased use of bio fuels and the mild winter in 2008. The total emissions in the energy and combustion units sector did increase but the sector has a deficit of grandfathered allowances. (The Swedish Environmental Protection Agency, 2009b)

The metal sector is the sector that is most affected by the broadened definition of combustion installations. Hence, the observed emission increase in table 2 is not due to increased production. The increase in emissions due to the broadened definition has not been as big as expected. There is a large surplus of free allowances in this sector, which indicates a generous allocation. In contrast to the metal sector, the increased emission level in ore-based production is only due to increased production and one expanded installation. The ore-based production sector had a deficit of allowances during 2008. The pulp and paper sector has decreased its emissions when comparing the average for phase I and 2008. This has resulted in a large surplus of free allowances. The decrease in emissions is mainly due to an increased use of bio fuels. The mineral sector encompasses production of cement, glass, lime and ceramics. The sector had a total increase in emissions and had a relatively big surplus of allocated allowances. The increase in emissions can be explained with increased production in the cement industry due to strong demand in 2008. Another sector with high increase in emissions is the refining sector. The increase is explained with major shutdowns in 2007 to carry out maintenance repairs and inspections. Even though emissions increased, the sector had a surplus of free allowances in 2008. The overall decrease in emissions in all sectors can be explained by installations' increased switch to bio fuels, the mild weather during 2008 and the weakened economic situation during the second half of 2008. (Swedish Environmental Protection Agency, 2009b)

Table 2. Emissions and allocated allowances, comparing the average for the first period and year 2008.

Sector	Emissions[1] 2005-2007	Allocation[1] 2005-2007	Surplus of permits[1] 2005-2007	Emissions 2008	Allocation 2008	Surplus of permits 2008
Energy sector and energy combustion units sector [2]	4,799,655	5,364,204	564,549	5,160,927	3,360,758	-1,800,169
Metal industry	6,355,364	7,240,641	885,277	6,621,514	7,780,104	1,158,590
Pulp and paper industry	1,842,605	2,655,404	812,799	1,434,172	2,289,738	855,566
Mineral industry	3,271,069	3,527,096	256,027	3,289,797	3,677,447	387,650
Refinery and coke oven industry	2,710,005	3,024,274	314,269	3,018,116	3,186,180	168,064
Ore-based production[3]	463,118	450,075	-13,043	572,595	537,248	-35,347
Total	19,441,817	22,359,673	2,917,856	20,097,121	20,831,475	734,354

[1] Yearly averages.
[2] As part of these emissions are emissions from the chemical industry's combustion units. Approximately 25 % of the chemical industry's emission is covered by the ETS.
[3] Ore based production is included in the mineral industry sector.

Source: Swedish Environmental Protection Agency, 2009b.

The present paper covers six industrial sectors in Sweden, among which five are fully covered by the ETS and one partly covered, see table 3. The relevance of this study depends both on how many of the ETS sectors we cover and how much CO_2 emissions these sectors emit. The total share of all Swedish CO_2 emissions that these sectors stood for (i.e. the chemical industry excluded) was 35 % in year 2007 according to Statistics Sweden. The corresponding figure for the coverage of the ETS in Sweden from the Swedish Environmental Protection Agency is 32 %. Table 3 also presents the sectors total emission of CO_2. For different reasons the emission levels from the Swedish Environmental Protection Agency presented in table 2 do not fully correspond to the emissions level for sectors from Statistics Sweden used in our survey and presented in table 3. The main reason for this is that the sectors have different definitions. But even though these definitions somewhat differ, they cover in total corresponding amounts of emissions and the same firms, which is the important assumption for our investigation. According to the definitions of which industries are included in the EU ETS, as stated by the EU ETS directive (2003), all sectors in this study are included except for the chemical industry which is only partly covered.

Table 3. The different sectors within the study, their ETS coverage, share of total Swedish emissions of CO_2 and total emissions of CO_2 (tonnes) for year 2007.

Sector	Covered by the ETS	Share of Swedish CO_2 emissions (2007)	Total emissions of CO_2 (2007)
Energy sector	Yes	14.3 %	8,777,731
Metal industry	Yes	8.4 %	5,155,315
Mineral industry	Yes	5.7 %	3,519,244
Refinery and coke oven industry	Yes	3.9 %	2,376,733
Chemical industry	Partly	3.0 %	1,822,298
Pulp and paper industry	Yes	2.6 %	1,609,679
Total emissions from above sectors		38 %	23,261,000
Total Swedish emissions		100 %	61,268,933

Source: The EU ETS Directive (2003) and Statistics Sweden, 2009.

3. Theoretical Analysis

3.1. Model of Technological Adoption Decision

We follow modelling from Jaffe and Stavins (1995), Kerr and Newell (2003) and Hammar and Löfgren (2010), and assume that a firm will adopt the new technology if the cost-savings associated with the adoption are greater than the adoption costs. Hence, each firm maximizes its own profit, decides whether or not to adopt and the time for adoption. The technology is available to each firm *i* at time *t* and the decision to adopt is treated as a discrete choice variable. Moreover, the decision to adopt is a function of learning by doing, input prices, firm characteristics, cost of investment and policy. A firm's net profit at time *t* is written as $\pi_{it} = f(L_{it}, I_{it}, Z_{it}, C_{it}, E_{it})$, where L_{it} is the firm's environmental learning by doing, I_{it} is an input vector, Z_{it} is a vector of firm characteristics, C_{it} is the cost of the investment[2] and E_{it} is the policy effect, i.e. whether the firm *i* at a given time *t* is a part of the EU ETS. For adoption to take place the adoption must be profitable, hence investments in new technology occur when net profits are positive. However, in reality net profits are not observed and therefore an indicator variable for climate protection investments CPI_{it} is created:

$$CPI_{it} = \begin{cases} 1 \text{ if } \pi_{it} > 0 \\ 0 \ \text{ otherwise} \end{cases}$$

[2] Cost of investment will not be included in the empirical analysis because of perfect collinearity.

3.2. Variables

Learning by doing

Hammar and Löfgren (2010) examine the relevance of learning by doing for abatement technology adoption. They use green R&D as a measure of the environmentally related internal knowledge within the firm since the firm engages in private R&D to develop capabilities of assimilating new technologies. New technology can be complicated and firms need deeper technological knowledge not only to innovate but also to adopt new technology. Hammar and Löfgren find that green R&D has a statistically significant impact on adoption decisions of clean technology for abating air pollution and the result is economically significant as well. Frondel et al. (2004) also test this hypothesis for air polluting firms and find that green R&D does improve adoption of clean technology. Cole et al. (2005) examine industrial emissions to air in the U.K. manufacturing sector during 1990-1998. They find that R&D investments negatively influence the emitted amounts of CO_2, which indicates that the firms have been successful in adopting abatement technology. We hypothesize that a firm's ability to adopt new technology depends on the broader technological knowledge within the firm. The level of R&D towards green technology should therefore be correlated with the level of CPI.

Hammar and Löfgren (2010) also use earlier investments as a complement for measuring learning by doing. They find that having made earlier environmental investments increases the firm's probability to invest in new technology that decreases emissions of carbon dioxide. We believe that the more investments the firm has done in an earlier time period the higher capacity it has of investing in abatement technology and the probability that the firm invests in CO_2 reducing technology is higher.

Inputs

A firm with high energy use is more affected by policies changing energy costs, which is an indirect effect of carbon trading. Maynard and Shortle (2001) look for determinants for adoption of abatement technology in bleach kraft pulp production and include firms' chlorine releases per tonne of capacity. They find that this variable has a positive and significant impact on abatement investments. Hence, a firm with high energy intensity will have strong incentives to reduce its energy dependency and may therefore have a higher probability of investing in abatement technology. We include fuel intensity as a possible determinant for CPI. The likelihood of adopting abatement technology is predicted to increase with fuel intensity since firms with high fuel intensity would benefit more from climate protection investments.

Hammar and Löfgren (2010) find that higher wages lead to higher adoption rates of clean technology. With a higher wage level it is possible that a firm has a higher ability to make environmental investments since it might mean more skilled personnel. Also, the higher input prices a company can endure, the more they might be able to spend on abatement technology. High wages could also have a negative relationship with CPI since they might crowd out other expenses, such as environmental investments.

Firm Characteristics

The size of firms might be important for whether or not they decide to adopt new technology. Larger firms may have more access to knowledge and capital and therefore have higher probability of adopting technology. However, larger firms may face more barriers than smaller firms when it comes to decisions about technology adoption. Hammar and Löfgren (2010) use revenues as a measure of firm size and find that it does not matter for clean technology investments. Frondel et al. (2004) also use revenues as a measure for size and find no effect on adoption of new technology. They also apply number of employees as a measure of firm size and find that a firm with more employees on average has a higher rate of clean technology adoption. Cole et al. (2005) find no effect of size measured as value added per firm on carbon dioxide emissions in their main regressions. Kerr and Newell (2003) find that refinery size increases technology adoption but that company size decreases it. Furthermore, a more complex refinery has a larger probability of adoption. Based on these arguments we predict that a larger firm will have a higher rate of adoption of new technology.

Frondel et al. (2004) argue that if a firm has a person dedicated to environmental protection activities that might have an effect on adoption of technology. They find that having this kind of officer increases the level of adoption of clean technology significantly. In our regression we predict that having an environmental prioritization within the firm will increase the level of adoption.

Environmental Policy

Using case studies of the German electricity sector Hoffmann (2007) finds that retrofit activities are substantially affected by the ETS. However, the first period of the first phase of the ETS had in itself a small impact on firms' decisions while the general discussion about climate policy was a larger determinant. Frondel et al. (2004) measure the effects of different types of policy, such as market based instruments and direct regulations, on Environmental Protection Investments (EPI). They find that neither of these policies influence adoption of clean technology and that the policy stringency is insignificant as well. Cole et al. (2005) find that higher pollution prosecution incidence in a region leads to lower carbon dioxide emissions. Widerberg and Wråke (2009) examine whether the CO_2 intensity for electricity firms in Sweden has changed after the introduction of the ETS. They find that the EUA price has not affected carbon dioxide intensity.

Kerr and Newell (2003) examine the lead phase down in the US 1971-1995 and find that a more stringent policy has achieved a higher adoption rate among firms and that a tradable permit system provides stronger incentives for investments in new technology than an emission standard does. To investigate this they use a dummy variable for the time periods when the companies were subject to tradable permits. Also, the tradable permit system for sulphur dioxide emissions in the U.S. was found to provide greater incentives for technology adoption than previous direct regulation (Jaffe, 2002).

Sectors

We will also investigate whether there is any difference regarding investments in carbon abatement technology between the six sectors included in the survey. We hypothesize that being in the electricity sector increases the probability of investing in carbon abatement, since there was no free allocation of permits to this sector year 2008. We further believe that this has influenced the investments, not only 2008, but also earlier years since firms probably make the investments before the reduction in the cap to avoid being economically affected. Moreover, we believe that the EU ETS' effect on the pulp and paper sector will be bigger relative to the other sectors, given that this sector decreased its emissions when comparing phase I with year 2008 due to increased use of bio fuels. The metal sector had a major surplus of allocated allowances in 2008, which indicates that being in this sector will not have a positive effect on the number of carbon abatement investments. Regarding the refinery and coke oven industry we believe that it will be difficult to see an effect since the numbers of observations are small. During the investigated time period we have observed a slight reduction of CO_2 emissions in the mineral and chemical sector but we do not expect to find any significant effect in these sectors. Since the chemical sector is not fully part of the EU ETS we will investigate further in section 4.3 how its CPIs have changed during the time period, relative to the other sectors.

4. Empirical Analysis

4.1. Data Description

All data on environmental protection investments is provided by Statistics Sweden from a yearly collection of data. Statistics Sweden has collected environmental protection data to report to Eurostat since Sweden's entrance into the European Union. Since 2001 this has been a compulsory response on the survey. Before 2005, the collection of data included firms with more than 20 employees, but has since 2005 consisted of firms with more than 50 employees. Hence, before 2005 a sample of roughly 1000 firms were drawn from a population of about 4400 firms. Since 2005, approximately 900 firms have been drawn from a sample of around 2000 firms. This change is not estimated to affect the quality of the survey according to Statistics Sweden (2008). Neither will it affect the outcome of our survey, given the fact that we only have two observations where the firms have less than 50 employees. The total response rate of the survey is high. It varied from 84 % to 93 % during the period. Moreover, the attrition is regarded as random. (Statistics Sweden, 2008)

On the whole we can conclude that the dataset used in our survey provides a detailed and high quality description of environmental protection investment and contains low risks of sample selection problems.

The environmental protection investments in the survey are separated into four categories; air, water, waste and remaining. Moreover the firms have reported whether the investments are clean technology investment or end of pipe solutions. Our focus is firms' investments aimed at reducing carbon pollution. The firms have also made a short description of the investment and based on that description we decide whether it is an investment aimed at reducing CO_2 emissions or not. Included in carbon abatement investments are investments aimed at more efficient processes, i.e. more efficient boilers, burners, engines, turbines or other processes, switch to greener fuels, long distance heating or cooling, geothermal heating and less transportation. Out of them, more energy efficient processes, greener fuels and long distance heating or cooling dominate. See Appendix 1 for a full review of how the different descriptions are categorized. Green R&D and environmental administration also originate from this survey. Revenues, number of employees, wages and fuel intensity are collected by Statistics Sweden.

The empirical analysis is based on an unbalanced panel data set consisting of 159 firms and 6 sectors, with a total of 539 observations. Table 4 describes the number of CPI and API (Air

Protection Investments) made each year for all firms included in the analysis. The proportion of CPI investors was lowest in 2002 and has since then increased. The large proportion in 2003 is largely driven by the energy sector. A possible explanation for this is the introduction of electricity certificates for renewable energy that occurred in 2003. We will discuss the electricity certificates further in the analysis section. The highest proportion of CPI investors is observed in 2006 when 34 % of the firms in the survey made an investment aimed at carbon abatement. In total, 155 investments aimed at carbon abatement were made during the period which corresponds to 29 % of the observations in our sample. Table 4 also describes the number of investments made in air protection, i.e. both clean technology and end-of-pipe environmental protection investments aimed at air emissions. The proportion of API investors was highest in 2003 and 2004 and lowest in 2005 and 2006. This decrease in investments can partly be explained by legislation regarding refrigerants and its air emissions during 2004. In total, 398 air protection investments were made during the time period which corresponds to 74 % of the observations.

Table 4. Investments in CPI and API by year.

	Number of observations	Nr. of CPI investments	Proportion of CPI Investors	Nr. of API investments	Proportion of API investors
2002	79	16	20 %	57	72 %
2003	79	24	30 %	63	80 %
2004	87	21	24 %	67	77 %
2005	87	28	32 %	63	72 %
2006	81	28	34 %	62	77 %
2007	69	21	30 %	46	67 %
2008	57	17	29 %	40	70 %
Total	539	155	29 %	398	74 %

In total, 153 firms are included in the analysis. Of these 73 firms made at least one investment in carbon abatement during the period, while 80 firms did not. From the 73 firms that made an investment in carbon abatement, 20 belong to the energy sector, 11 to the metal sector, 6 to the mineral sector, 1 to the refinery and coke oven industry, 13 to the chemical sector and 22 to the pulp and paper sector. Table 5 summarizes the total investments made during 2002-2008 by sector. The energy sector has the highest proportion of CPI investments. 59 % of the observations in the energy sector in the sample are climate protection investments. The pulp and paper sector has the largest number of observations and the second highest proportion of CPI investors, 29 %. Thereafter follows the chemical sector with 26 %, the mineral sector with 19 % and lastly the metal sector and the refinery and coke oven industry, both with 18 %. The refinery and coke oven industry has the smallest number of observations and only four observed CPI investments made by the same firm during the period. Due to the small number of observations in the refinery and coke oven industry it will be difficult to interpret specifically how this sector has been affected by the EU ETS.

Table 5. Investments in CPI by sector during 2002-2008.

Sector	Number of observations	Number of CPI investments	Proportion of CPI investors
Energy sector	75	44	59 %
Metal sector	109	20	18 %
Mineral sector	70	13	19 %
Refinery and coke oven industry	22	4	18 %
Chemical sector	89	23	26 %
Pulp and paper sector	174	51	29 %
Total	539	155	29 %

Average characteristics of the firms that made an investment in CPI during 2002-2008 are presented in table 6. Investing firms generally have higher revenues than non investing firms. They also have higher expenses on green R&D and higher total investments in environmental protection. Energy use and CO_2 emissions are normalized with firms' revenues. In general investing firms have higher energy use than non investing firms, but emissions of CO_2 from non investors are higher than from investors.

Table 6. Average characteristics of investors and non investors, n=321 for investors and n=218 for non investors.

Variable	Investors	Non investors
Revenues (billion SEK)	4.1	1.5
R&D costs (1000 SEK)	836	232
Total EPI (million SEK)	23.1	6.8
Energy use/Rev (TJ/SEK)[1]	1.8	1.4
CO_2 emissions/Rev (tonne/SEK)[1]	52	60

[1]Energy use and CO_2 emission only have observations during 2002-2007, hence n=288 for investors and n=194 for non-investors.

Summary statistics of the variables used in our regression analysis is presented in table 7. All variables except for fuel intensity are observed during 2002-2008. The number of observations is 539. The dependent variable CPI is a dummy variable that is equal to one if the firm made an investment in abatement technology aimed at reducing emissions of carbon dioxide. EPI intensity is a continuous variable measured as total environmental protection investment, divided by the firms' revenues to control for firm size. The variable is used as a measure for earlier investment and is therefore lagged one time period. As an alternative to earlier investments we use a dummy variable for air protection investment, API, which is equal to one if the firm has made an investment aimed at air protection. This variable is also lagged one time period and equal to one irrespective of whether it was a clean technology investment or an end-of-pipe solution. R&D is a dummy variable that is equal to one if the firm had expenses on environmental research and development. Environmental administration is a dummy variable equal to one if the firm had expenses on environmental administration, education or information. Size is measured by the firm's revenue, in billion SEK. As a substitute to revenues we measure firm size by the firm's number of employees. The variable wages is created as the ratio between the firm's total wage costs and the number of employees and is measured in thousands of SEK per employee. Fuel intensity measures the firm's total use of energy in terajoule (TJ) normalized with revenues. Due to lack of data we only have observations of fuel intensity during 2002-2007 and therefore we have 482 observations for this variable. To control for fuel intensity in the econometric analysis for year 2008, we replace the missing data for year 2008 with the observations from year 2007.

Table 7. Summary statistics, 2002-2008.

Variable	Number of observations	Mean	Std.Dev	Min	Max
Climate Protection Investments (CPI)	539	0.29	0.45	0	1
Environmental Protection Investment (EPI) intensity[1]	539	0.013	0.027	0	0.28
Air Protection Investments (API)[1]	539	0.75	0.44	0	1
Research and Development (R&D)	539	0.42	0.49	0	1
Wages	539	0.33	0.061	0.15	0.58
Fuel intensity	482	0.0017	0.0028	2.31e-08	0.024
Revenues	539	3.04	6.41	0.0601	69
Employees	539	757	1,206	36	12,830
Environmental admininstration	539	0.90	0.30	0	1

[1] EPI intensity and API are lagged and are therefore summarized with observations during 2001-2007

4.2. Econometric model

The econometric model is based on the theoretical model in section 3.1. Learning by doing is measured by rate of earlier EPI and whether a firm has made a R&D investment during the year. Inputs are wages and fuel consumption. Revenues and whether a firm has any environmental administration costs are firm characteristics. We use year dummies alternated with a phase dummy for phase I to control for the ETS effect. Hence, our estimated model looks like:

$$CPI_{it} = \beta_o + \beta_1 \cdot EPI_{it-1} + \beta_2 \cdot Revenues_{it} + \beta_3 \cdot R\&D_{it} + \beta_4 \cdot Env\ administraion_{it} + \beta_5 \cdot Wages_{it} + \beta_6 \cdot Fuel\ Intensity_{it} + \beta_7 \cdot Time\ effect_t + \varepsilon_{it}$$

If not stated otherwise, we use random effects logistic regression with sector as panel level.

4.3. Empirical results

Since the EU ETS was launched in 2005 we want to determine whether 2005 and the following years have been different than the years prior to 2005. Table 8 shows the marginal effects at average values for our models. Model (1) and (2) include 2002-2007 while model (3) and (4) extend the period to 2008. The exclusion of 2008 is interesting because it shows the effect of phase I by itself. Moreover, model (1) and (3) contain phase I dummies while model (2) and (4) contain year dummies. We alter the dummies in order to see if phase I has been significant as well as to be able to see year specific effects. The predominant effect is that investments in carbon abatement have increased since the introduction of the ETS.

The marginal effect for phase I is significant at the 1 % significance level regardless of whether we include or exclude year 2008. On average firms have increased their probability of adopting CPI by 13 % in phase I compared to before the ETS. Looking at individual years of the first phase gives a less clear effect. The marginal effect for the 2005 dummy is positive both in model (2) and (4), but lies just above the 10 % significance level. The strict interpretation of this is that firms did not respond to the policy during 2005. However, we still have a positive marginal effect close to significance so it might be that the effect came gradually in the first year of the ETS due to inertia in firm response. If we are to evaluate the precise effect of the dummy for 2005, though the significance is low, we would state that being in year 2005 compared to the period 2002-2004 would increase the probability of a firm of investing by around 10 %. The following years show more certain effects. The dummies for 2006 and 2007 are both significant in model (2) and (4). The size of the marginal effects tells us that being in year 2006 and 2007 would increase a firm's probability of investing by 16-17 %. These results indicate that, since the introduction of the ETS, firms already began to change their investment behavior in phase I of the ETS. The positive and significant marginal effect for the year dummy of 2008 shows that the effect was still evident in the beginning of phase II. The marginal effect is slightly less significant than for 2006 and 2007 but the size is approximately the same. Being in 2008 increases the probability of a firm investing in carbon abatement by 16 % compared to the period before the ETS. It should also be noted that when controlling for possible effects in the years before the EU ETS by including dummy variables for 2002, 2003 and 2004, we find no significant effect. When comparing whether the effect of 2008 differs compared to phase I, we find no signs on increased abatement investments. Hence, we find no results indicating an increased effect for the first year of the second phase compared to the first phase.

Table 8. Marginal effects with CPI as dependent variable.

	(1)	(2)	(3)	(4)
Lagged EPI intensity	2.60***	2.65***	2.46***	2.50***
	(0.89)	(0.89)	(0.86)	(0.86)
Revenues	0.0078**	0.0079**	0.0087***	0.0088***
	(0.0033)	(0.0033)	(0.0033)	(0.0033)
R&D	0.080*	0.079	0.072	0.072
	(0.048)	(0.048)	(0.045)	(0.045)
Environmental	0.074	0.073	0.089	0.088
Administration	(0.069)	(0.070)	(0.065)	(0.065)
Wages	-1.02**	-1.07**	-0.81*	-0.85**
	(0.46)	(0.47)	(0.42)	(0.42)
Fuel intensity	13.4*	13.7*	14.9*	15.2*
	(8.07)	(8.12)	(7.92)	(7.96)
ETS Phase I dummy	0.13***		0.13***	
	(0.047)		(0.047)	
Year dummy 2005		0.11		0.10
		(0.067)		(0.067)
Year dummy 2006		0.17**		0.16**
		(0.072)		(0.072)
Year dummy 2007		0.17**		0.16**
		(0.080)		(0.079)
Year dummy 2008			0.16*	0.16*
			(0.088)	(0.088)
Prob > chi^2	0.0003	0.0012	0.0003	0.0010
Observations	482	482	539	539
Pseudo R^2	0.156	0.157	0.051	0.052

Standard errors are presented in parentheses. *= significant at 10 % level, **= significant at 5 % level and ***= significant at 1 % level. Prob > chi^2 shows the p-value for the Wald test.

These results altogether can be taken as signs that the ETS has a positive effect on the probability of a firm undertaking an investment to reduce carbon dioxide emissions. In comparison, Hoffmann (2007) finds that the ETS has only a limited effect of on German electricity investments aimed at reducing carbon emissions for the first half of phase I. Hoffmann did however conclude that the EUA prices are integrated in firms' decision making process. Widerberg and Wråke find no effect of the price of the permits on carbon intensity for Swedish firms in the electricity sector, but they do not investigate whether the price of permits have affected firms' carbon investment behavior. Both the above studies are restricted to the electricity sector, while our survey investigates all sectors that are included in the ETS, which might be an explanation to why our results differ.

Regarding how a tradable permit system can affect abatement investments, our results follow the general theoretical conclusions. A tradable permit scheme stimulates adoption since a firm that invests in new technology can reduce its emissions and earn a profit on selling excess permits on the market, if the fixed cost associated with the investment is not too high. Accordingly, the cost of emitting carbon dioxide is incorporated in the firms' cost functions and the profit after an investment is higher than if no investment was made. Our finding that the ETS affects adoption of new technology positively is in line with empirical findings from Kerr and Newell (2003), who find that the adoption rate in the U.S. lead phase down was higher when tradable permits were used compared to an emission standard. Kerr and Newell use, as we do, dummy variables for the periods when the firms were subject to a tradable permit system. Furthermore, Jaffe et al. (2002) made the same conclusion about the sulphur dioxide emission trading in U.S.: the tradable permit system has a positive effect on investments in abatement technology.

There could be other explanations for the increased carbon abatement investments than the ETS. One pitfall would be if other policies affect the investment pattern. We will therefore investigate the carbon tax and the introduction of electricity certificates to see if they are driving the results. Another error is if the effect would be true even for firms outside of the ETS, i.e. if there has been an increasing trend in carbon abatement investments for all firms, not only in the ones that are a part of the trading scheme. In the following passage we discuss these potential problems.

Our econometrical analysis showed that since the introduction of the EU ETS, Swedish firms' climate protection investments have increased. Another possible explanation of this result could be that changes in the carbon tax affect firms' decision to invest in carbon abatement. Table 9 illustrates the carbon tax per ton of carbon dioxide emissions for every sector during 2002-2007. The carbon tax per carbon emissions for all sectors has increased between 2002 and 2004, except in the energy sector where the marginal tax was rather stable. In all sectors, the tax on the margin decreased between 2004 and 2005 and was rather stable between 2005 and 2006. During 2004-2006, i.e. before and after the year that the EU ETS was introduced, the carbon tax decreased in all sectors except for the energy sector where it increased somewhat. The tax in the energy sector did though decrease until 2007. We have observed an increase in CPI since 2005 and given that we have not observed an increase in the carbon tax during this time period we have strong indications that the carbon tax did not drive our regression result.

Table 9. Carbon tax per ton of carbon dioxide emissions (SEK/tonne CO_2), -for sector and year during 2002-2007.

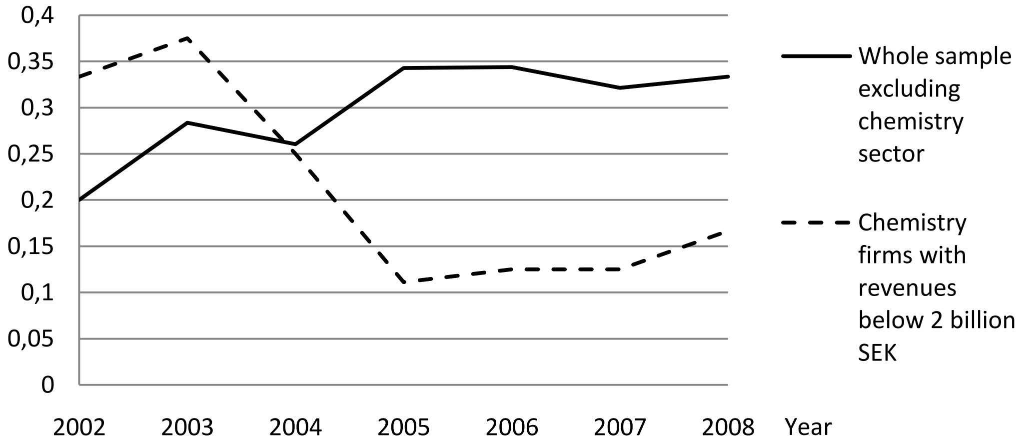
Sector	2002	2003	2004	2005	2006	2007
Pulp and paper industry	150	189	224	198	191	202
Refinery and coke oven industry	10	12	22	20	18	37
Chemical industry	72	88	99	68	68	69
Mineral industry	54	53	66	55	57	63
Metal industry	51	52	56	50	49	48
Energy and heating	129	126	128	116	135	107
Average for all above sectors	87	93	99	84	89	84

Source: Statistics Sweden, 2010

Since 2003, energy producers can receive electricity certificates if they produce electricity from renewable sources. These certificates only concern the energy sectors. Basically, the firms who increase their production of green electricity can apply for a certificate which they can sell forward on a market and thereby be compensated for its investment expenses. (The Swedish Energy Agency, 2009) If only the energy sector is driving our results, the increase in carbon investments might be due to electricity certificates and not because of the ETS. To control for this we run a regression where the energy sector is excluded. The regression is presented in table 10 as model (6). Excluding the energy sector does not change our result regarding the ETS. Being in phase I is still associated with a significant increased probability of investing in carbon abatement. The marginal effect for the dummy variable for 2008 is also still positive but just above the 10 % significance level. If our results were only driven by the green electricity certificates, the ETS effect would disappear when the energy sector is excluded.

We can control our result for firms outside the ETS since we have included the chemical sector which is only partly covered by the ETS. Since the chemical sector is not specifically part of the trading system, only the largest firms with a rated thermal input exceeding 20 MW are included. Hence, we can empirically examine whether these are the firms that made most of the CPI investments. We make the distinction that firms with revenues of less than 2 billion SEK are small firms and unlikely to be included in the ETS. The firms below this level represent 56 % of the chemical firms. Figure 10 presents the share of these firms that have invested in CPI compared to the other firms in our sample, excluding the chemical sector. The figure shows a clear distinction in the trend of these groups of firms' investment behavior. The larger sample shows a steady growing trend until 2005 and after that stays on a stable level while the small chemical firms have high investments before 2005 and lower investments onwards. If the sample of small chemical firms is representative of the population of firms not included in the ETS this indicates that the ETS has most likely made a difference to firms' investment behavior.

Figure 10. Share of CPI. Comparing small chemical firms with the other sectors.



Note: Number of observations for whole sample excluding chemical sector is 450.
Number of observations for chemical firms with revenues below 2 billion SEK is 50.

Based on our regression analysis and on the above discussions regarding what other factors that might have driven the regression result, we find it very likely that the increased investments in observed carbon abatement are due to the introduction of the EU ETS.

Regarding carbon dioxide emissions, there is no general solution for curbing emissions, instead there are many different abatement investments that can be made. From our carbon dioxide investment data we find that more energy efficient processes, greener fuels and long distance heating or cooling investments dominate. Hence, in our regression, we see signs of increased diffusion of these technologies. The rate of diffusion should in theory slow down after all firms have adopted the new technology. For technologies regarding carbon abatement there is a very small risk that all firms in the near future have invested in the best available technology and that diffusion will slow down. So far there are many prospects for improvements and new solutions to decrease CO_2 emissions. Hence, diffusion has significant potential to continue under the future phases of the EU trading scheme.

During the first phase of the ETS, the price of permits decreased during 2006 and reached zero in the end of 2007. In theory this would reduce firms' incentives for adopting new technology since there is no profit to be made from selling excess permits. Our results show no indications of this. A possible explanation for this may be that firms did not expect the price of allowances to remain that low. The European Commission announced that it would reduce the cap for phase II and that the cap for phase III will be even more stringent. Hence, firms are aware that the cap will be more stringent in the future and that ETS will continue for a long period of time and accordingly they can benefit from a carbon abatement investment for many years. A possible interpretation of our result may be that the ETS is not associated with as much uncertainty as a tradable permit system could be. Additionally, since it is known that grandfathering of permits will be phased out, there will be no reason for firms to keep the emission level high, because the allocation will not be based on historical emissions.

Learning by doing

The coefficients for earlier EPI are significant at the 1 % level in all regressions in table 8. This result says that if a firm has a history of investing a large share of its income in environmental protection it will have a higher probability to invest in carbon abatement. The marginal effect says that as a firm's previous year's rate of investment in EPI relative to its total revenues increases by 10 %, the probability of the firm investing in the current year increases by around 25 %.

The coefficient for green R&D is significant at the 10 % level for model (1) when 2008 is not included. Hence, if a firm devotes resources to develop new environmentally friendly technologies, it has a higher probability of adopting carbon abatement technology. If a firm invests in green R&D their probability of also investing in carbon abatement is 10 % higher than that of a similar firm that has not invested in R&D. For model (2) - (4) R&D is not significant, but the marginal effects are positive and close to significant, indicating that engaging in environmental R&D does matter for firms' adoption of new green technology.

Together, these effects show that firms are experiencing learning by doing, i.e. the more they engage in the environment, either by researching or by adopting EPI, the larger their ability to adopt carbon abatement technology becomes. These results are in line with our predictions and with Frondel et al. (2004) and Hammar and Löfgren (2010) who both find evidence for the importance of R&D for clean technology investments. It is also in line with Cole et al. (2005) who find that high R&D investments lead to lower CO_2 emissions.

Inputs

We find that the marginal effect for wages is negative. For every million SEK higher average wage level the probability of investing in carbon abatement reduces by 10 %. This result is contradictory to the result from Hammar and Löfgren (2010), who find a positive effect of wages on environmental protection investments. One interpretation of this result might be that wage expenses crowd out other costs, so that carbon abatement investments are turned down.

Fuel use is the other input variable of our analysis. The marginal effect is significant at the 10 % level for all models in table 8. An increase of 10 TJ annual fuel consumption increases the probability of adopting CPI by around 13 %. The result is in line with our predictions and the findings of Maynard and Shortle (2001) and shows that firms with higher energy use have a higher probability of investing in carbon abatement.

Firm characteristics

The size of a firm has a significant effect on carbon abatement investments. The marginal effects translate into an effect of 0.8 - 0.9 % more CPI for every billion SEK of revenues for an average firm. This is contradictory to Hammar and Löfgren (2010) and Frondel et al. (2004) who all find that revenues do not increase the probability of clean technology investments. However, our result is in line with Kerr and Newell (2003) who measure size with refinery size and Frondel at al. (2004) who use number of employees, and find that it is a determinant for higher adoption rate. We interpret this as meaning that larger firms with more resources have more access to knowledge and capital and are therefore more likely to invest in new technology.

Environmental administration is positive but found insignificant in all models presented in table 8. This means that if a firm has dedicated resources to environmental administration, in general they have no higher probability of investing in carbon abatement. This is contradictory to our predictions and the result of Frondel et al. (2004).

Sectors

In the data description section we find that the proportions of CPI differ substantially between the six sectors in the survey. For example, 59 % of all observations in the energy sector are carbon abatement investments while this figure is only 18 % for the metal sector. Hence, we empirically investigate whether the probability of investing in carbon abatement differs if the firm belongs to a specific sector. Since the number of observations is quite small for each sector, we do not run regressions where only observations from one sector are included, but use dummy variables for each sector. The regressions are based on model (3). We do not present these regressions since all dummy variables for the sectors, except the one for the energy sector, are insignificant. However, we present a regression where only the dummy for the energy sector is included.

The dummy variable for being in the energy sector is, as we predicted, positive and significant (see table 10 model (5)). We find that being in the energy sector increases the probability for a firm to invest in carbon abatement with 32 % compared to being in another sector. One possible explanation for this outcome might be that the allocation of permits to this sector has decreased substantially during the investigated time period. We have also observed a decrease in the sector's emission level of CO_2 since the start of the ETS. During the studied time period, CO_2 emissions were highest in 2003 with over 10.2 million tones of CO_2. In comparison, CO_2 emission in 2007 were around 8.8 million. Hence, the decrease has been quite substantial. The high proportion of carbon investments illustrate that diffusion of new technology regarding carbon abatement has been extensive in this sector. In addition, the policy response to decrease the number of allocated allowances may have pressured firms to make further abatement investments.

Table 10. Marginal effects with CPI as dependent variable.

	(3) Original analysis	(5) Energy sector dummy	(6) Energy sector excluded	(7) Chemical sector excluded
Earlier EPI	2.46***	2.36***	1.46	2.75***
	(0.86)	(0.81)	(1.01)	(0.92)
Revenues	0.0087***	0.0089***	0.0077***	0.031***
	(0.0033)	(0.0031)	(0.0028)	(0.0086)
R&D	0.072	0.084*	0.13***	0.0066
	(0.045)	(0.043)	(0.042)	(0.048)
Env Adm	0.089	0.086	0.11*	0.054
	(0.065)	(0.065)	(0.060)	(0.074)
Wages	-0.81*	-0.74*	-0.65*	-1.20**
	(0.42)	(0.39)	(0.39)	(0.52)
Fuelintensity	14.9*	13.5*	9.05	18.6**
	(7.92)	(7.33)	(7.54)	(8.29)
Energy sector		0.32***		
		(0.069)		
Phase 1	0.13***	0.13***	0.11**	0.14***
	(0.047)	(0.046)	(0.046)	(0.055)
Year 2008	0.16*	0.16*	0.12	0.22**
	(0.088)	(0.087)	(0.085)	(0.11)
Prob > chi^2	0.0003	0.0000	0.0007	0.0000
Observations	539	539	464	450
Pseudo R^2	0.051	0.070	0.061	0.086

Standard errors are presented in parentheses. *= significant at 10 % level, **= significant at 5 % level and ***= significant at 1 % level. Prob > chi^2 shows the p-value for the Wald test.

We find no significant effects for the other sectors included in this survey. Except for the pulp and paper sector this result goes in line with our predictions. Since we observed a large reduction of emissions in the pulp and paper industry due to increased use of bio fuels we expected to find a positive effect in this sector. One explanation for why there is no observed effect might be that the sector had a large surplus of permits. Additionally, compared to the energy sector where we found a positive effect and 59 % of the observations were carbon investments, this figure for the pulp and paper sector only is 29 %.

Since the chemical industry is not fully covered by the emission trading scheme we test our results when all firms in the chemical industry are excluded. The results of this regression are presented in table 10 model (7). In general, excluding the chemical sector does not affect the outcome compared to model (3) but makes the marginal effect for phase I and the year dummy 2008 somewhat larger. Being in phase I is associated with a 14 % higher probability of adopting carbon abatement technology while being in the first year of phase II increases the probability of adoption with 22 %.

We believe that the results of this survey point at the importance of a stringent cap. No free allowances were given to the energy sector in year 2008 which implies that carbon emissions are associated with higher costs for firms in the energy sector. In the other sectors in the ETS where we found no specific sector effects of increased investments, allowances were over supplied and grandfathered. In line with the theoretical reasoning by Malueg (1989), Milliman and Prince (1989) and Wråke (2009) our result regarding the energy sector provides empirical indications that grandfathering of permits leads to lower incentives to invest in new technology, compared to auctioning of permits.

4.4. Robustness Analysis

To examine the robustness of our results we present a sensitivity analysis in table 11, where we include alternative parameters to the ones used in previous models. To capture both phase I and the first year of phase II, the analysis is based on model (3), which includes a dummy variable for phase I and a dummy variable for the year 2008.

In table 11, model (8) measures firm size with number of employees instead of revenues. If a firm increases the number of employees by 1000, the probability of CPI increases with 0.38 %. In line with Frondel et al. (2004), we find that this variable is positive and significant. Using the number of employees does not change the result regarding earlier investment, R&D, or fuel intensity. It affects neither the significance regarding phase I and year 2008 nor the amplitude of the marginal effects for phase I and year 2008 substantially. It does however affect the significance of wages which becomes insignificant.

In model (9) we use lagged air protection investments instead of lagged EPI intensity. We find that this variable is positive and significant at the 1 % level. If a firm has made an abatement investment aimed at air in the previous year the probability of making a carbon abatement investment in the current year increases by 15 %. When the variable lagged air protection investments is used, all variables from model (3), except the dummy variable for year 2008, give the same outcome regarding significance and sign. The dummy variable for year 2008 becomes insignificant, but the marginal effect remains positive.

We also use an alternative measure for energy intensity, namely energy use to value added instead of revenues. This does not change the result and the regression is not presented. The dummy variable for phase I and year 2008 are still positive and significant. In model (10) and (11) we use the firms' energy use from fossil fuel and bio fuel, respectively. Fossil fuel does not affect firms' investment in climate protection while a high intensity of bio fuel does. Hence, if bio fuel intensity increases with 1 TJ per revenue, the probability of investing in new technology aimed at carbon abatement increases with 40 %. Neither fossil fuel intensity nor bio fuel intensity change the outcome regarding significance and sign for the other variables in the analysis compared to model (3). It is interesting to see that bio fuel is the part of fuel consumption that drives the effect on CPI. It is not the firms that are highly dependent on fossil fuels that invest the most, but the firms that already have the largest bio fuel use.

We also test normalizing wage expenditure, R&D expenditure and cost of environmental administration with firms' revenues, but this does not change our results significantly. R&D measured in this alternative way is positive but not significant. Environmental administration is not significant at the 10 % level, just as when it is a dummy variable.

Overall we can conclude from the sensitivity analysis that our result for the first phase of the EU ETS is very robust. The marginal effect for phase I is stable and varies between 0.12 and 0.14. Regarding the first year of the second phase we get a significant effect in all models except for one. The marginal effect varies between 0.14 and 0.22. Generally, the result for year 2008 is not as strong as for phase I but its marginal effect is always positive and significant or close to significant at the 10 % level.

Table 11. Sensitivity analysis. CPI is dependent variable. Coefficients show marginal effects.

	(3) Original analysis	(8) Employees	(9) Earlier API	(10) Fossil fuel	(11) Bio fuel
Earlier EPI	2.46***	2.36***		2.77***	2.65***
	(0.86)	(0.86)		(0.92)	(0.85)
Earlier API			0.15***		
			(0.046)		
Revenues	0.0087***		0.0074*	0.0086*	0.0089**
	(0.0033)		(0.0031)	(0.0033)	(0.0033)
Employees		0.038**			
		(0.017)			
R&D	0.072	0.070	0.059	0.080*	0.064
	(0.045)	(0.045)	(0.044)	(0.045)	(0.046)
Env Adm	0.089	0.080	0.062	0.096	0.092
	(0.065)	(0.066)	(0.066)	(0.066)	(0.067)
Wages	-0.81*	-0.65	-0.79*	-0.73*	-0.71*
	(0.42)	(0.40)	(0.41)	(0.42)	(0.42)
Fuelintensity	14.9*	14.3*	16.7**		
	(7.92)	(7.94)	(7.87)		
Fossil fuel intensity				0.40	
				(11.1)	
Bio fuel intensity					39.6***
					(14.1)
Phase 1	0.13***	0.13***	0.12***	0.12**	0.13***
	(0.047)	(0.048)	(0.047)	(0.048)	(0.048)
Year 2008	0.16*	0.16*	0.14	0.15*	0.15*
	(0.088)	(0.087)	(0.087)	(0.087)	(0.088)
Prob > chi^2	0.0003	0.0007	0.0004	0.0013	0.0013
Observations	539	539	539	539	539
Pseudo R^2	0.051	0.047	0.051	0.046	0.060

Standard errors are presented in parentheses. *= significant at 10 % level, **= significant at 5 % level and ***= significant at 1 % level. Prob > chi^2 shows the p-value for the Wald test.

In our empirical analysis we have consistently used a logistic regression model. In table 12 we therefore present marginal effects from using probit regression and Ordinary Least Squares (OLS). In general our results do not change when using probit or OLS compared to logistic regression. Regarding phase I this dummy variable remains significant in both the probit and the OLS model. The estimated marginal effect is 0.13 with the logit model, 0.12 with the probit model and 0.10 with OLS. The year 2008 is significant at 10 % level with the probit model, the marginal effect is 0.15 compared to 0.16 with the logit model. With OLS, year 2008 loses its significance but is still positive and close to significant at 10 % level. Hence, we can conclude that the logistic regression model used for our analysis is robust.

To control our estimated model we also include a regression where firm is panel level instead of sector. This regression is presented in model (13). This model decreases the significance of phase I and makes wages and the year dummy for 2008 insignificant. Using firm as panel level is problematic, though, since 159 firms are included in the regression which means around 3 observations per firm.

In table 12 we also control for fixed effects instead of random effects. The result is presented in model (14). Using fixed effects gives similar marginal effects as random effects. Compared to model (3), R&D becomes significant at the 10 % level and regarding the dummy variable for the first year in phase II it becomes more significant and the marginal effect is larger. The marginal effect for phase I increases from 0.13 to 0.16. The marginal effects for earlier investments, revenues, wages and fuel intensity also become slightly larger but have the same significance levels.

The wald test, shown in table 8, 10, 11 and 12, rejects the null for every regression. This means that the variables for each regression are jointly significant.

Table 12. Controlling for logit, probit, OLS, firm as panel level and fixed effects. Coefficients show marginal effects.

	(3) Logit	(12) Probit	(13) OLS	(14) Firm as panel level	(15) Fixed effects
Earlier investments	2.46***	2.56***	3.49***	2.60***	2.88***
	(0.86)	(0.85)	(0.74)	(0.88)	(1.04)
Revenues	0.0087***	0.0089***	0.0091***	0.0090**	0.011***
	(0.0033)	(0.0031)	(0.0031)	(0.0039)	(0.0041)
R&D	0.072	0.075*	0.054	0.053	0.091*
	(0.045)	(0.044)	(0.040)	(0.049)	(0.054)
Environmental administration	0.089	0.087	0.082	0.072	0.12
	(0.065)	(0.066)	(0.067)	(0.065)	(0.10)
Wages	-0.81*	-0.79*	-0.42	-0.30	-1.17**
	(0.42)	(0.41)	(0.35)	(0.44)	(0.47)
Fuel intensity	14.9*	15.1*	18.6**	15.0*	19.5*
	(7.92)	(7.91)	(7.38)	(8.73)	(10.5)
Phase1	0.13***	0.12***	0.10**	0.090*	0.16***
	(0.047)	(0.046)	(0.042)	(0.046)	(0.056)
Year 2008	0.16*	0.15*	0.10	0.10	0.19**
	(0.088)	(0.083)	(0.068)	(0.089)	(0.089)
Prob > chi^2	0.0003	0.0001	0.0000	0.0029	0.0002
Observations	539	539	539	539	539
Pseudo R^2	0.051	0.053		0.039	0.053
R^2			0.054		

Standard errors are presented in parentheses. *= significant at 10 % level, **= significant at 5 % level and ***= significant at 1 % level. Prob > chi^2 shows the p-value for the Wald test.

5. Conclusions

The purpose of this paper is to evaluate whether the EU ETS has changed firms' carbon abatement investments. Looking at Swedish firms in heavy industries we find empirical evidence for increased investments after firms started to trade with carbon. This effect is evident in both phase I and the first year of phase II, which are the periods of ETS that we examine. Therefore, we conclude that the trading system has led to increased diffusion of carbon abatement technology. This also means that firms incorporate the cost of carbon permits in their profit maximization.

The ETS has been criticized for having a relaxed cap and the price of permits has been lower than expected. Even though the design of this carbon trading system is not perfect, our result gives indications that it still provides incentives to invest in new technology. This supports the theoretical view that a tradable permit system can be effective in inducing diffusion. We have not compared directly to a command-and-control measure or a tax but our result is in line with the general conclusion that tradable permits can be more efficient than command-and-control measures and just as efficient as a tax.

We find that one of the most important qualifications for carbon investments is firms' earlier experience of environmental work, i.e. learning by doing. The learning by doing effect shows that encouraging firms to do green research is important to stimulate diffusion of new technology.

The energy sector stands out with significantly higher investments in carbon abatement than the other sectors in our survey. There can be several explanations to this. One explanation is the reduced allocation of free allowances to this sector. Hence, we conclude that less grandfathering is an important future change in the ETS to further stimulate carbon abatement investments. More auctioning would also enable the auction revenues to be used for further climate action. However, one should bear in mind that if grandfathering is phased out the costs would increase for European firms and the risk of carbon leakage might increase.

To further review the effect of the ETS in Sweden we suggest research that compares the sectors within the system to sectors not included. After 2012 it will also be possible to fully evaluate the effect of phase II. We also welcome similar studies for other European countries as well as studies at the aggregate European level.

Appendix 1: Examples of API description by firms

Number of investments aimed at reducing air emissions directed towards carbon dioxide

	2002	2003	2004	2005	2006	2007	2008	Total
More efficient boiler/burner/ engine/turbine	12	8	8	7	4	3	2	44
- *Examples: "better control system in bark burner", "new steam boiler", "optimization of oil burner", "more efficient turbine"*								
Energy efficiency in other processes than above	5	12	5	8	19	11	5	65
- *Examples: "new heat exchanger", "new extractor to reduce energy use", "pre-heater utilizing spillsteam"*								
Greener fuels	8	10	16	17	9	10	16	76
- *Examples: "reinvestment in solid fuel burner", "purchase of ethanol cars", "new bio fuel boiler", "oil replaced by natural gas"*								
Long distance heating/cooling	3	6	4	7	7	4	4	35
- *Examples: "transition to long-distance heating", "expansion of remote cooling", "accession of property to long distance heating"*								
Geothermal heating	1	0	0	0	0	0	0	1
- *Example: "geothermal heating from a 2 km deep hole, replaces fossil fuels"*								
Less transportation	0	1	3	2	2	0	1	9
- *Examples: "investment in railways to reduce road transport", “concentration of activities to central location, leads to less transportation"*								
Total investments	29	37	36	41	41	28	28	

Some investments aimed at reducing air emissions not directed towards carbon dioxide

Chlorofluorocarbon, cause ozon depletion - *Examples: "reduction of refrigerant use", "freon settlement", "conversion of cooling plant", "switching coolants"*
Maladorous gases - *Examples: "improved access to destructor", "treatment of diffuse gases", "new oven for destruction of maladorous gases"*
Volatile organic compounds - *Examples: "burning of voc", "closing of open vessel containing volatile solvents", "investigation of voc measurement"*
Chimney gas - *Examples: "reparation of electric filters", "flue gas purification in bark boiler", "exhaust fan, scrubber"*
Sulphur dioxide, acid rain - *Examples: "installation of pump for lime slurry", "conversion of SO2 treatment system"*
Nitrogen oxides, acid rain - *Examples: "installation of low-NOx burners", "new instrument for monitoring NOx emissions"*

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