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Technological change and the EU ETS: the case of Ireland.[*]

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Abstract

The rate of greenhouse gas reducing technological change and occurrence of environmentally friendly innovation are integral in reducing emissions levels. The European Union commenced the pilot phase of the European Union Emissions Trading System (EU ETS) in 2005 with the intent to enhance the adoption of existing low-carbon technologies and the development and of new ones by putting a price on CO_2 emissions. We survey Irish EU ETS firms to study the occurrence of CO_2 emissions friendly technological change during the pilot phase (2005-2007) as well as the reasons firms did or did not alter their technology portfolios in response to the price on emissions. Despite declining emissions prices and policy related uncertainty, 48% of responding Irish firms employed new machinery or equipment, 74% made process or behavioral changes, and 41% switched fuels to some degree that contributed to emissions reductions during the pilot phase. The effect of rising energy prices on these emissions and energy saving actions should not be overlooked. In general, we find that the EU ETS was effective in stimulating moderate technological change and also raising awareness about emissions reduction possibilities.

JEL Classification: Q550, Q540, Q580, Q480,

Keywords: European Union Emissions Trading System, Climate Policy, Innovation, Technological Change.

1 Introduction

In January of 2005 the incentives to reduce industrial CO_2 emissions in Europe changed from altruism or corporate social responsibility into financial calculation through the establishment

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of the European Union Emissions Trading System (EU ETS). Each tonne of CO_2 emissions gained monetary value and was now another cost of production, encouraging firms to optimize their level of emissions given their allocation of European Union Emissions Allowances (EUAs), abatement opportunities, and the price of EUAs. Putting a price on emissions is expected to deliver efficient abatement and induce innovation in low carbon technologies. According to the Intergovernmental Panel on Climate Change (IPCC), there is much agreement and strong evidence that innovation is needed to deliver currently non-commercial technologies in the long term in order to stabilize greenhouse gas concentrations so as to mitigate the impacts of climate change (Barker et al., 2007). However, the development and deployment of environmental technology suffers from a combination of market failures associated with environmental and knowledge externalities (See, for example, Jaffe et al., 2005). The European Union has addressed the market failure imposed by CO_2 emissions via the establishment of a price on emissions, and this price is also intended to steer the economy towards decarbonization through driving investment in low-carbon technologies (European Commission, 2008).

The ability of the EU ETS to stimulate investment towards less CO_2 intensive technology is crucial. In the wider context of the role of pollution control instruments, Kneese and Schultz (1978) argue that this might be the single most important criterion on which to judge environmental policies, such as the EU ETS, in the long run. While long term considerations are important, however, the short term performance of the EU ETS in altering the direction of technological change should not be neglected.

The pilot phase of the EU ETS (2005-2007) was the first compliance period of the largest pollution permit trading market in the world. Understanding the extent to which climate friendly technological change was induced in this short period is valuable given the abundance of countries currently discussing cap and trade policies and also the emerging scientific evidence of rapid ongoing shifts in the climate system. Short term technology responses are likely required to redirect current emissions trajectories and mitigate as much of the harmful impacts of climate change as possible.

The first period (2005-07) of trading was characterized by generous allocations in most Member States, and featured many signs of 'learning by doing' by most of the participants. One outcome of these two characteristics was that prices stayed relatively high in the first year, since there was no precise knowledge as to the overall supply and demand situation, and then began a downward trend as it became clear in mid 2006 that there was significant over supply in the market (Figure 1). The when spot prices in began to fall in 2006, expectations for the future were not significantly affected as forward contracts for 2008 vintage EUAs held their value.

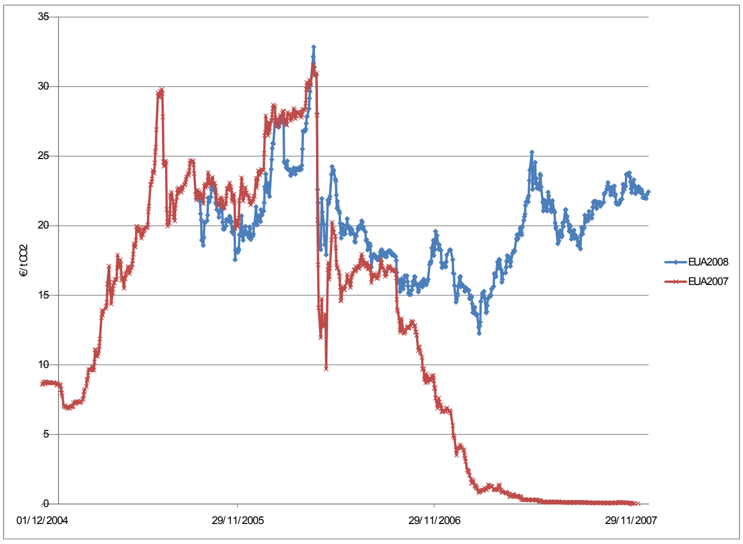

Figure 1: *2007 and 2008 vintage EUA prices for the pilot phase (in nominal Euro)*

Source: Point Carbon

We use Irish firms as a case study to understand the impact of the EU ETS on technology related decisions in the pilot phase. Information related to technology adoption, behavioral or process change, fuel switching and management issues was gathered by mail survey and follow-up interviews with selected respondents. Despite the prevalence of opinions that the pilot phase EU ETS was a policy failure due to the price collapse, the Irish trading sector was generally highly responsive with 48% of responding firms employing new machinery or equipment, 74% making process or behavioral changes, and 41% of respondents switching fuels to some degree during the pilot phase in order to achieve emissions reductions.

The rest of this paper is arranged as follows: section 2 reviews the existing literature on innovation and environmental policy, with a focus on the relevant theoretical arguments pertaining to the pilot phase. Section 3 discusses the methodology used to study the response of the Irish trading sector and section 4 briefly summarizes the details of the Irish EU ETS trading sectors in terms of composition and coverage. Section 5 discusses results from both the mail survey and interviews and finally, section 6 discusses the implications of the findings and concludes.

2 Technological change and the EU ETS

Sub-optimal levels of environmentally friendly technological change is caused by the interaction of market failures related to environmental externalities and in technology development, where knowledge and adoption externalities work in concert with information problems to depress levels of technological innovation (Jaffe et al., 2005). Some form of policy intervention is required to correct the environmental externality and there is a general consensus among economists that market based tools are preferred to traditional regulation (also known as command and control, CAC) in order to promote pollution reduction due to cost efficiencies. Milliman and Prince (1989) and Jung et al. (1996) both rank auctioned permits as the preferred policy tool followed by taxes and subsidies, free permits, and lastly, emissions standards for promoting the adoption of advanced pollution abatement technology. As these rankings are based on calculating aggregate cost savings by universal adoption of new technology under different policy regimes, Requate and Unold (2003) extend the analysis to examine firm level incentives to adopt pollution abatement technology in equilibrium. They find that when the regulator does not anticipate the arrival of new technology, taxes provide stronger incentives than permits (auctioned and free permits offer identical incentives), and standards may give stronger incentives than permits. When the regulator anticipates the arrival of new technologies, however, first best outcomes can be achieved with either taxes or permits as long as policy stringency is announced after firms invest. In an earlier study of firm level incentives to adopt abatement technology, Malueg (1989) also finds that these rankings of policy instruments are not absolute, and depend on a firm's position as either a permit buyer or seller, before and after technology adoption when comparing permit trading to CAC regulation.

While a carbon tax or an emissions trading system with auctioning might be the preferred policy tool depending on whether it is preferable to regulate prices (via taxes) or quantities (via permits) of pollution, experience with the acid rain trading program in the U.S. has shown that trading systems with freely distributed permits can deliver the desired technology related incentives. As part of a thorough analysis on the U.S. acid rain (SO_2 reduction) program Ellerman et al. (2000) find that "the effect of trading on abatement behavior at the unit level during Phase I (1995-99) has been considerable...", and estimate aggregate cost savings of 33-67% (*ibid.*, p.296) realized through the flexibility of the policy tool. Regarding the effects on innovation, Lange and Bellas (2005) find that trading did not stimulate the advancement of scrubber technology[1] over the entire life of the program, but rather only at the beginning. The industry experienced a significant drop in both operating and capital costs with the Clean Air Act Amendments of 1990, with no statistically significant difference in the annual rate of change of costs subsequently. As pollution policy changed regimes in 1990 from technology performance standards to emissions trading, the level of patent counts in scrubber technology fell, but the nature of innovative activity changed. Popp (2003) explains that prior to 1990, it was required that scrubbers had a 90% removal rate and so R&D was focused on reducing the costs of achieving the 90% removal rate (as found by Lange and Bellas, 2005), but after emissions trading began in 1990 the focus of R&D shifted to increasing the efficiency of scrubbers. In short, innovation efforts were redirected from cost reduction to improved environmental performance with a switch from performance standards to emissions trading with freely distributed permits.

The EU ETS seeks to directly correct the environmental market failure by pricing CO_2 emissions, and also serves as a “demand pull” for less emissions intensive technology by improving the financial viability of greener technology. While many factors may affect CO_2 price dynamics (fuel prices, weather conditions, industrial activity levels) the stringency of the overall allocation plays a central role in determining price levels, and consequently technological incentives. If allowances are scarce, the price will rise and direct technical change towards reduction in the relatively more costly factor of production, namely CO_2 emissions. The relationship between environmental policy stringency and innovation efforts has been demonstrated empirically by Brunnermeier and Cohen (2003), Lanjouw and Mody (1996) and Jaffe and Palmer (1997) where increases in pollution abatement control expenditures (assumed to be correlated to policy stringency) lead to jumps in environmental patent counts. Generous allocations in the pilot phase contributed to declining permit prices in 2006-07 and may have reduced the incentives and stability that industry requires for effective planning of emissions reducing technology investments (Grubb et al., 2005). Despite the findings of Ellerman and Buchner (2008) and Anderson and Di Maria (2011) that abatement did occur in certain member states during the pilot phase, over-allocation was also detected.

The first choice of carbon pricing in the EU was a carbon tax but that proved to be impossible for a number of reasons, and permit trading emerged as the best possible emissions control policy tool that was politically infeasible.[2] Permit trading emerged as the feasible policy tool and in the EU ETS pilot phase, firms were given an allocation of permits for free based on

[1] Flue gas desulfurization units or “scrubbers” are the end of pipe abatement retrofit for SO_2 emissions.

[2] Convery (2009) gives an extensive account of how current EU climate policy came to be.

their past emissions, projected growth and the Kyoto Protocol obligations of their countries under the EU's Burden Sharing agreement. Free allocation is considered by some as an impediment to climate friendly technological change (Gagelmann and Frondel, 2005; Neuhoff et al., 2006). Conversely, Montgomery (1972) points out that the initial permit distribution mechanism should have no effect on the final efficient equilibrium of permit trading system. Regarding technological change, this means that technology is optimally introduced or adopted in order to meet an efficient final equilibrium, regardless of the initial permit distribution mechanism. Whether permits are free or auctioned, the incentives firms face are identical as technology-enabled decreased demand for permits puts downward pressure on permit prices regardless of the distribution method (Requate, 2005).

Uncertainty and lack of information about the EU ETS in both the pilot phase and also the future of the policy was widespread throughout the European business community prior to the start of the trading period (Brewer, 2005). This ex ante uncertainty was matched by generally low expectations about the significance and effectiveness of the EU ETS, and created an atmosphere likely to cause the option value of environmentally friendly investments to grow, and investments to be postponed until better information became available. The uncertainty of future policy was compounded by the investment profile of the regulated firms. Most pilot phase participants were either power generators or heavy industry with long capital cycles and large investments with a degree of irreversibility. Since the arrival of increasingly environmentally friendly technologies in the future is unknown, then the option of waiting to invest or adopt technology grows again (Van Soest, 2005). Results from a survey conducted by the European Commission in conjunction with Ecofys and McKinsey (McKinsey and Ecofys, 2006) provide evidence of the link between uncertainty and the EU ETS during the pilot phase. The survey was carried out between June and September of 2005 with respondents represented by different types of stakeholders. While this is not precisely an ex ante analysis as firms had already gained some exposure to the EU ETS and to a significant EUA price at that time, they had not yet gone through the first verification process and thus not gained the perspective that verification eventually offered. The report shows that the EU ETS moderately (17%) or strongly (11%) increased mid and long term uncertainty in technological discussions concerning the production mix in existing assets. Uncertainty about the future of technological decisions – such as portfolio expansion and replacement – however, was more commonplace with 29% and 25% of firms claiming that the EU ETS had a strong and moderately strong influence on their uncertainty, respectively. Despite the fact that roughly half of the responding firms reported that they 'priced in' CO_2 at the time of the survey, 30% also claim that the uncertainty they faced on account of the EU ETS made it very difficult for them to make credible forecasts. 53% of firms claimed to be able to recognize a range of possible scenarios but have little basis for discriminating amongst those, and only 3% felt confident in their ability to craft a credible strategy, given the available information.

In summary, it appears that the literature points towards the conclusion that a mild to moderate technology response can be expected in the pilot phase of the EU ETS while the lack of overall stringency and regulatory uncertainty might lead to decreased incentives for technological change. As we illustrate below, the Irish experience seems to support this view. Before we discuss our results, in the next section we describe the research methodology used to understand the Irish response during the pilot phase.

3 Research Methodology

Collecting reliable data via surveys or questionnaires is fraught with difficulties and the opportunities to induce biased responses are many. Bertrand and Mullainathan (2001) summarize the main issues that can cause bias as cognitive problems dealing with wording, question ordering, social desirability – whereby respondents might not want to look bad in front of interviewers – and non-attitudes, wrong attitudes, and soft attitudes – whereby answers to subjective questions may or may not be good representations of the respondents actual beliefs about the question being asked, if they exist at all.

The EU ETS is a highly politicized environmental policy and it is likely that participating firms have strong feelings about its necessity, credibility or ability to deliver socially desirable results. Innovation is also publicized as one of the main goals of implementing emissions trading, along with meeting climate goals, of course. The European Commission DG Environment's own EU ETS home page has a link prominently displayed at the time of writing called, "EU action against climate change: EU emissions trading – an open scheme promoting global innovation."[3] It is clear that firms are likely to have the impression that being innovative is a positive trait to display, and that firms participating in the system should be innovating towards meeting their compliance goals.

To avoid the social desirability bias, surveys were sent in the mail to contacts for each firm

[3] See *http://ec.europa.eu/environment/climat/emission/index_en.htm*, last accessed on August 10, 2010.

as provided by the Community Independent Transaction Log (CITL).While the fact that the survey authors are researchers in environmental matters may induce some social desirability bias, the survey was crafted to appear as a fact gathering exercise, with no motivation other than understanding the experience of EU ETS participants. Close-ended questions were used for the most part in order to encourage higher response rates and avoid the biases created by non-attitudes, wrong attitudes and soft attitudes that could easily permeate responses from open ended questions. In short, we asked respondents what actions were taken during the pilot phase of the EU ETS, instead of asking them for their opinions.

We surveyed all firms that have EU ETS installations in Ireland in order to gain an accurate understanding of the entire Irish trading sector[4]. 72 firms (106 installations) were included in the trading sector in Ireland when the pilot phase commenced, but 4 closures led to a total of 68 potential respondents. Surveys were mailed to contacts for each firm, and a total of 27 firms completed and returned the questionnaire. This represents a response rate of 40%, covering approximately 70% of the total Irish allowance allocation. After analyzing the results of the mail survey we arranged semi-structured interviews with 7 firms that represent the different groups of the Irish trading community in terms of emissions magnitude, industry, and structure as either indigenous Irish firms, or a part of a larger multi-national group, of which there are many in Ireland.

Given the markedly skewed distribution of emissions by firms in the Irish trading sector, in order to protect the confidentiality of the survey respondents and interviewees, we are not able to relate the actions taken towards different aspects of technological change as a percentage of total allocated permits, or another metric that would signify what portion of the Irish CO_2 trading community gave certain responses. Instead, we elect to present our results as percentages of responding firms that took the indicated actions. In what follows there is no intent to signify if the respondents are large or small players, or members of certain industries.

4 Ireland and the EU ETS

Before we present the results of our survey and interviews, it is useful to understand to what extent the results of our investigation of Irish firms can be generalized to the wider European community. While Ireland's macroeconomic profile and recent growth trends may not be representative for all member states participating in the EU ETS, we believe that the Irish trading

[4]A copy of the survey is available from the authors upon request.

sector does serve as a good sample of the entire EU ETS landscape. The Irish emissions trading sector is roughly proportionate to the EU-wide one (see Table 1) in that the majority of EUAs went to the power generation sector, and a large share (approximately 21%) was allocated to an internationally competitive sector (cement) considered to be at risk of carbon leakage and competitive losses.

Table 1: Distribution of Irish Allowances

Sector	EU27	Ireland
Combustion installations	69.9%	77.0%
Mineral oil refineries	7.6%	2.1%
Coke ovens	1.1%	0.0%
Metal ore roasting or sintering installations	0.6%	0.0%
Production of pig iron or steel	8.1%	0.0%
Production of cement clinker or lime	9.0%	20.5%
Manufacture of glass including glass fibre	1.1%	0.2%
Manufacture of ceramic products by firing	0.9%	0.2%
Production of pulp, paper and board	1.8%	0.1%
Other activity opted-in	0.0%	0.0%
All installations	100%	100%

Source: CITL

One of the main differences between the Irish EU ETS experience and that of the larger European community was the fact that over the pilot phase trading period Irish installations were net short as a group; the gap between EUAs allocated and required to cover existing emissions was approximately 13% while the EU as a whole was net long by approximately 2.5%.[5] Figure 2 compares the stringency of the Irish allocation to new (EU10), and incumbent (EU15) member states and the EU25.

It is apparent that the Irish allocations is most comparable to those of its western European neighbors, and least similar to the predominantly eastern new member states. While this does not directly stimulate a heightened technological response in Ireland due to access to the larger EUA market, it is possible that Irish firms may have attempted to reduce their emissions with low cost, low risk changes as opposed to buying EUAs as an early compliance strategy. Due to the relatively stringent allocation in Ireland it is quite possible that Irish firms were on the upper

[5] Source: CITL

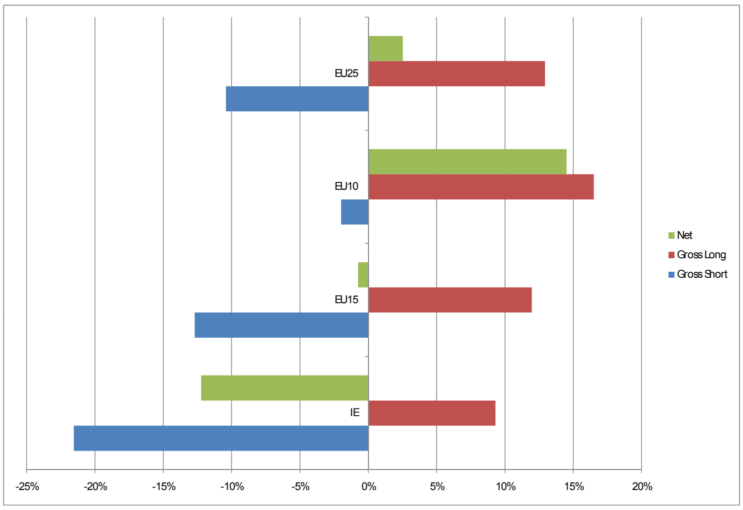

Figure 2: Relative final positions for 2005-2007

Source: EPA and own calculations

end of the "technology response" gradient for the simple reason that many faced a binding CO_2 constraint early in the pilot phase whereas many of their European counterparts with more generous allocations did not.

The Irish allocation methodology contained a few features that may differentiate it from other European allocation plans. Allowances were set aside specifically for combined heat and power (CHP) activities, and Ireland committed to auctioning more allowances than most member states. However, given the magnitude (<2% of national total) of these two features that would in theory induce more innovation or technology diffusion in Ireland than in other member states, we feel it is reasonable to conclude that Irish firms faced incentives similar to other EU firms to engage in various aspects of technological change.

Table 2: Irish EUA Allocation 2005-07

	No. EUAs	% Irish total
Installations permitted before 31/03/2004	65,006,999	97.1
New Entrant Set Aside	1,004,400	1.5
CHP Set Aside	446,400	0.7
Auction	502,201	0.8
Total	66,960,000	100.0

Source: EPA and own calculations

Overall, Ireland makes for an interesting and worthwhile case to study the firm level technological response to the EU ETS. Moreover, as allocations become more stringent in future versions of the EU ETS – and with a move towards auctioning as a distribution mechanism – the actions taken by Irish firms in the pilot phase may be a good indicator for what can be expected across Europe in the future. The next section describes the results according to the grouping of questions in the survey.

5 Results

We considered the possible responses to the EU ETS in terms of the various aspects of technological change and divided questions into the areas of machinery and equipment adoption, process or behavioral changes using existing equipment, and fuel switching as possible abatement strategies. We also asked firms about their strategies for compliance, such as investing in R&D, and the effect of the pilot phase on plans for the future. Within each question group, firms were asked to "tick all boxes that apply" and therefore responses (presented as percentages of respondents) may not sum to 1.

5.1 Machinery and Equipment

While the necessity for new and innovative technologies to realize deep emissions cuts is undisputed, the reality is that significant reductions in CO_2 emissions are feasible with increased diffusion of currently available climate friendly technologies. The most recent global abatement cost curve produced by McKinsey and Co. (2009) visualizes both the currently available and "horizons" technologies with a significant proportion of the possible abatement options having negative net costs. A rational economic actor should immediately adopt any beneficial technology with a negative cost. However, diffusion of these negative cost climate friendly technologies is not absolute, and a variety of factors can act as barriers to adoption. It appears that during the pilot phase there was a significant amount of technology adoption as 48% of firms report employing some form of new machinery or equipment that contributed to decreasing their CO_2 emissions. The possible objectives accomplished through the use of new machinery are displayed in table 3.

Respondents were also asked about the origins of their newly employed technologies and the majority (92%) were purchased from external suppliers with the remainder of new technologies developed internally. Reasons for not adopting new technology were that no equipment

Table 3: Results of deployment of new machinery and equipment

Action taken	% respondents
Reduce direct energy use/ emissions from combustion	44%
Reduce direct energy use/ emissions from heat generation	33%
Reduce direct energy use/ emissions from mechanical power	11%
Reduce use of electricity	33%
CO_2 capture	0%
No equipment or machinery was purchased	52%
Other (please specify)	0%

Source: Own calculations based on survey data.

currently existed that would significantly reduce emissions (36%), or that the cheaper compliance option was to purchase EUA's on the market rather than reduce emissions (13%). These results are generally consistent with the findings of McKinsey and Ecofys (2006) where 35% of responding firms cite the EU ETS as a medium or greater impact on retrofitting actions.

The semi-structured interviews that followed the survey yielded insights into two separate mindsets of firms that did not deploy new equipment. One type of firm was generally climate technology curious and explored possibilities for micro-generation such as wind turbines or solar panels but could not follow through due to costs or other reasons. One example of an institutional barrier was that the firm in question judged that planning permission would never be granted to install wind turbines for a rural installation. The other class of firms that emerged was those businesses already employing best available technologies, with no real scope for improved environmental performance through improved capital. These respondents also displayed a lack of understanding about why compliance should be a more expensive endeavor for them (through the purchase of EUAs) than it is for their competitors in other member states with more generous allocations. For those firms that did adopt new machinery or equipment, it was made clear that while the EU ETS was a consideration, rising energy prices and the expectation of high future prices delivered the major incentive for the actions taken.

5.2 Process and behavioral change

In light of the uncertainty surrounding the pilot phase of the EU ETS and the unclear expectations about the future, it is plausible that many firms would postpone large capital expenditures in emissions reducing technology or risky R&D, and instead focus on fine tuning their existing processes or switching fuels until more certainty appears. It is also possible that firms that had already taken carbon reduction action, that no technology adoption opportunity existed that would significantly reduce emissions.[6] These process/behavioral or "soft" changes do not have the sunk costs nor irreversibility profile that may have delayed the adoption of less pollution-intensive technology in the pilot phase and are likely to represent the "low hanging fruit" of emissions reduction.

Table 4 displays the different objectives firms realized by changing the way current machinery and equipment was used. 74% of respondents report some type of altered behavior with many firms achieving reductions in energy usage/emissions in multiple categories.

Table 4: Objectives of process or behavioral change

Action taken	% respondents
Reduce direct energy use/ emissions from combustion	56%
Reduce direct energy use/ emissions from heat generation	48%
Reduce direct energy use/ emissions from mechanical power	15%
Reduce use of electricity	41%
CO_2 capture	0%
No actions or processes were changed	26%

Source: Own calculations based on survey data.

These results are generally what one would expect given the fact that the Irish trading sector was net short, and the levels of uncertainty about climate policy. As in the case with technology adoption, responding Irish firms claim to be driven more by energy prices rather than by EUA prices. Only 30% of respondents report either a marginal or a strong influence of carbon prices on their decisions to alter processes or behaviors.

The other low-risk process change available for emitters is the switch to less emissions intensive fuel sources. According to the analyses of Delarue and D'haeseleer (2007) and Delarue et al. (2008), fuel switching offers promising opportunities for significant short term emission reductions in Europe. However, it is important to keep in mind the opportunities and constraints for fuel switching that exist in EU ETS installations. It is useful to think of the EU ETS market as segmented between power generators and heavy industry. The scope for fuel switching for power

[6] 19% of respondents cite this as the reason for no adoption.

generators may be much greater than for industrial installations, as non-generators often face barriers in terms of fixed infrastructure (e.g. pipelines) and a number of other non-economic reasons[7]. An illustrative example of this is the case where power generators own multiple installations and can produce electricity using different fuels in different sites depending on EUA prices, fuel prices and electricity demand. This is fuel switching from the generating firm's point of view. On the other hand, cement or steel factories are likely not to have a variety of sites to shift production as fuel prices fluctuate, and therefore fuel switching is an entirely different procedure. Of course, fuel switching can be done on site at any plant so long as boilers will permit the necessary engineering alterations. The changes required to burn different fuels in existing equipment are not costless and in the interviews firms expressed an aversion to making these changes unless a long term stable supply of fuel was available to switch to permanently.

While more than half of firms reported no fuel switching took place, a significant proportion (41%) claimed to have switched fuels at some point of the pilot phase in order to reduce their CO_2 emissions. Reasons cited for not switching fuels were the inability of equipment to accept alternative fuel sources (22%), lack of dependable alternative fuel supply (11%), and that fuel switching was not required in order to meet emissions reductions targets (41%). Most firms interviewed considered the option to switch to less emissions intensive fuels used in combustion such as common waste, biomass, or bio-wastes. Generally, reasons for not switching can be divided into areas of security of supply and infrastructural barriers. Industrial firms included in the EU ETS under the category of "Combustion-other" generally are installations with boilers of significant size and heat/power generation is not their main business objective. This leads to fuel inflexibility as regular and consistent supply is crucial, due to the cost and inconvenience of tweaking boilers constantly for different fuel types. Many of these installations are also served by fixed infrastructure such as a heavy oil pipeline nearby. In this case, the possibility of a switch to natural gas, for example, is severely impeded by planning permission and infrastructural barriers.

One of the major benefits of implementing the EU ETS was that firms were forced to become aware of their emissions and adopt a verifiable system of emissions accounting. Some interviewed firms report that the implementation of energy management systems allowed for calculated behavioral changes leading to reduced emissions in the areas of heating/cooling and

[7] One respondent intended to co-fire with meat and bone meal (MBM), a waste product from the livestock rendering industry. Even though burning the bio-waste was permitted, the respondent's firm was not given permission to transport the MBM through the local municipality, the only way to the site.

ventilation. No interviewee gave the impression that any major re-engineering had taken place on site, rather incremental improvements in energy/emissions efficiency were realized through enhanced energy accounting.

An important thing to keep in mind is that the EU ETS took place against the backdrop of an energy price upswing. The respondents were very clear in stating that much of their energy and emissions savings actions were encouraged by energy prices rather than by the spot price of EUAs[8]. Figure 3 below displays the spot prices (in USD) per barrel of European Brent crude oil as well as the prices of natural gas and electrical energy[9] paid by industrial end users in Ireland. The time series runs from 1985-2007 with the price in nominal USD (2000=100) on the vertical axis. It is evident that the prices for the pilot phase trading period are significantly higher than the 15 year period prior to the commencement of emissions trading and therefore makes it difficult to distinguish between CO_2 emissions reduction actions, and energy cost savings measures.

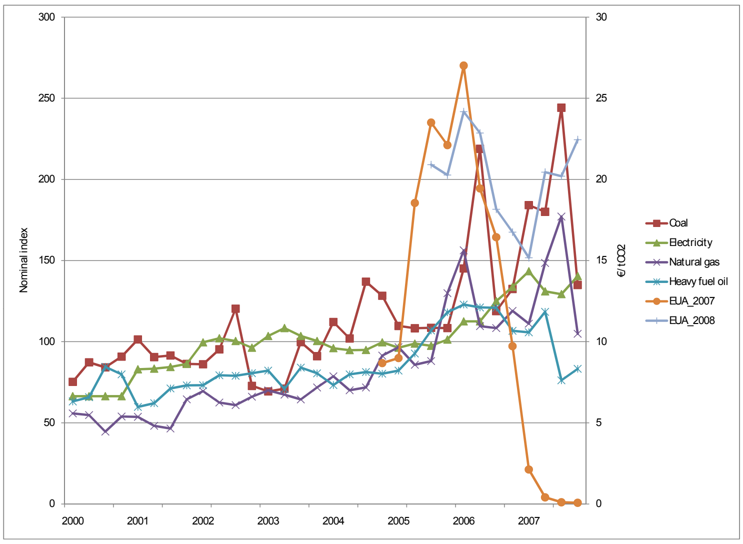

Figure 3: *Historical Prices in Ireland*

Sources: International Energy Agency Energy Prices and Taxes Database (electrical energy and natural gas) and Energy Information Administration Spot Prices for Crude Oil

The admission by many respondents that the EUA price did not immediately affect their behavior is hardly a surprise, given the downward trend of EUA prices in the last half of the pilot phase. This result is supported by the findings of McKinsey and Ecofys (2006) through a study

[8] 74%, 70% and 78% of respondents report that the price of EUAs had no effect on their decisions relating to machinery and equipment, behavioral and process change and fuel switching, respectively

[9] The units for both natural gas and electrical energy are USD per ton of oil equivalent net calorific value

conducted early in the pilot phase that 37% of firms claimed that technological decisions were mostly aimed at increasing energy efficiency, 51% focused on both emissions reductions and energy efficiency, while only 12% were solely interested in reducing emissions.

In summary, when asked to allocate their emissions reductions to specific actions taken, 22% of Irish firms in our sample stated that they had made no changes at all. Average shares of total reductions achieved can be attributed to changes in machinery and equipment (11%), process/behavioral changes (33%), fuel switching (23%). These results confirm the hypotheses of Schleich and Betz (2005) that low-cost, low-risk abatment opportunities would be exploited first in the pilot phase of the EU ETS, as uncertainty and non-stringency threatened to deter ambitious investment in emissions abatement.

5.3 Management Strategies, Compliance and Planning and future consideration

Economists favor market based instruments for their static efficiency as those with the best information (firms) can decide where the cheapest emissions reductions occur, as opposed to centrally planned emissions reduction mandates, which are likely not to achieve the same aggregate reduction at comparable costs due to information asymmetry. Flexible tools such as emissions trading are also considered more dynamically efficient than CAC regulation since emissions reductions will continually be directed towards the least cost opportunities, which are likely subject to change over the lifetime of the policy.

Firms may invest in R&D as a means of reducing future marginal abatement costs and ensuring less costly compliance. While the EUA spot price during the pilot phase was likely not high or stable enough to induce large investment in R&D, the price of EUA futures contracts was not insignificant and expectations about the future may have encouraged firms to invest in knowledge capital as a means of future cost reduction. Table 5 displays the different forms of intellectual property firms invested in as a reaction to the pilot phase, and their expectations for the future.

More than half of responding firms (56%) engaged in some type of knowledge building activities and a third of firms performed in-house R&D with a small amount (7%) of R&D outsourcing. Approximately a fifth of firms acquired some form of knowledge related assets (patents or know-how) in order to help with current or future compliance cost reductions. For those firms not investing in knowledge related capital, 19% cited the uncertainty of EUA prices as a reasons for their lack of action, and approximately a quarter of firms cited lack of funding, both internal

Table 5: Investments in Knowledge Capital

Actions	% respondents
In-house R&D	37%
Acquisition of external R&D services	4%
Acquisition of other external knowledge (patents, non-patented inventions, know-how or other types of knowledge)	22%
Did not engage in any of the above activities	44%
Other (please specify)	4%

Source: Own calculations based on survey data.

(15%) and external (11%), as a roadblock to investment.

During the interviews a common theme regarding climate-related R&D was that Irish firms are small relative to their European or global competitors and do not have the critical mass to invest heavily in climate related R&D since it is not their core business. Firms characterized themselves as technology takers in the area of climate, where their primary research efforts were in remaining competitive in their industries and the small CO_2 related R&D spending which occurred was largely dedicated to exploring behavioral or process related efficiency gains.

The attitudes of firms regarding investments in technology development did not seem to evolve greatly since the beginning of the trading period as the DG Environment Survey (McKinsey and Ecofys, 2006) had similar findings. They find that 19% of respondents report the EU ETS as having a strong impact on their decisions to develop innovative technologies, while 34% and 31% report moderate and small EU ETS impacts, respectively.

6 Discussion

The purpose of this paper is to use Ireland as a case study to understand the technological response to the CO_2 price signal created by the EU ETS. The theoretical literature leads us to expect the pilot phase EU ETS to deliver moderate incentives given the relevant characteristics of both the allocation plans and the over-all cap. The empirical literature on environmental policy induced technological change on the one hand supports this expectation with numerous examples of induced technological change, and with evidence of the favorable performance of market-based policy tools over CAC regulation. On the other hand, the same literature warns us that the lack of stringency in the pilot phase may depress incentives to invest in technological change.

Given these theoretical and empirical findings we are not surprised by the nature of actions taken in Ireland during the pilot phase. Despite declining EUA prices over the final part of the period, 48% of firms report technology adoption, 74% report some form of process or behavioral change, and 41% engaged in fuel switching in varying degrees. Not only did the EU ETS affect current practices, but also altered the way Irish firms prepare for the future. 46% of Irish firms report that the EU ETS has influenced the way investments in capital and infrastructure are analyzed. The validity of these findings as a reasonable proxy for the European Community is confirmed as also McKinsey and Ecofys (2006) reports that about half of EU ETS firms sampled in their survey “priced in” EUAs as of mid 2005, and 50% of respondents in their pan European survey claim the EU ETS as a strong effect on long term issues such as investment decisions. In the same sample, 48% of firms recognize the impact of the policy, but it is only one of the factors they currently consider.

The partial adoption of existing technology as a cost minimization technique by some firms validates the assertions of Requate and Unold (2003) that the complete diffusion of new technology is unlikely in the real world, as firms evaluate investment decisions based on a number of criteria. It is entirely possible, however, that higher than expected levels of abatement occurred in the early pilot phase simply as a result of the requirement for firms to monitor their emissions. The occurrence of firms making changes to their practices gives the impressions that the assertions of Ellerman and Buchner (2008) and the findings of Anderson and Di Maria (2011) that abatement did occur in the pilot phase in some cases are indeed correct. Due to uncertainty and low EUA prices, this is a perfectly reasonable response which is likely compounded by the fact that the majority of Irish firms (56%) did not perform any form of ex-ante assessment to determine their options for cost-effective compliance.

In general our findings bode well for the future of the EU ETS as a tool in both controlling aggregate amounts of pollution, but also encouraging technological change through a price signal. The pilot phase did not have ambitious reduction targets, or certainty about future policy design, but still generated a significant amount of awareness throughout Europe which probably lead to the take up of some very inexpensive abatement opportunities. As the EU ETS moves increasingly towards auctioning and the total emissions cap is lowered according to the schedule revealed in the Energy and Climate Package legislated by the European Commission in January of 2008, the incentives to innovate or adopt cleaner technologies will become accentuated. In so far as one is willing to accept that Irish firms are representative of the European trading community, this study shows that there is already a significant appetite for innovation, and that firms are indeed responsive to both current and future expected prices of CO_2 emissions.

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