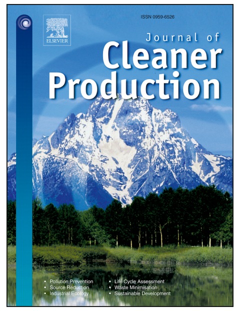

The effect of allocation above emissions and price uncertainty on abatement investments under the EU ETS

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Abstract

The European Union Emission Trading Scheme (EU ETS) –by far the largest in its kind- has inspired several other carbon markets in the world. Based on interviews with plant managers from almost all Belgian ceramics, lime and cement producers, this study is the first to describe how manager's perceptions on emission trading affected investment decisions. In line with behavioural economics, reference-dependence is found to explain why free allocation below emissions creates a greater incentive to abatement investment compared to allocation above emissions. In the ceramics sector, allocation above emissions refrained managers from including carbon gains in payback times. This contradicts the famous Coase theorem, which predicts that free allocation has no effect on abatement incentives. The results indicate that auctioning part of the emission rights will reduce barriers to abatement investment. Carbon price uncertainty is seen as a disincentive for abatement investment by some managers and as an incentive by others. Intermediate levels of uncertainty add option value to abatement investments because the associated gradual learning adds flexibility in an uncertain carbon constrained future. However, high levels of uncertainty, creating a risk of offshoring even when companies innovate, creates an option value to postpone abatement investments. Narrow framing, misperceiving the risk-hedging counter-cyclicality of carbon costs, reinforces the option value to wait. Therefore, policy should aim to reduce price uncertainty for very low and very high carbon prices, not for an intermediary price range.

Keywords: EU ETS, behavioural economics, regulatory uncertainty, over-allocation, Coase theorem

Highlights (max 85 characters including spaces)

- Allocation above emissions is perceived as a lower incentive for abatement.

- Companies combusting gas do not include carbon gains in their payback-time.
- Reference-dependent decision-making can explain observed perceptions.
- Moderate carbon price uncertainty can create option value to speed up abatement.
- High levels of carbon price uncertainty create option value to wait with abatement.

1. Introduction

The European Union Emissions Trading Scheme (EU ETS) is by far the most important cap and trade system in the world and the flagship of the European Union's climate policy (Venmans, 2012). The policy sets a cap on emissions for more than 11,000 of the largest CO_2 emitters in the 28 countries of the EU, Norway, Iceland and Liechtenstein, accounting for around 45% of total emissions (European Commission, 2015). The EU ETS was launched in January 2005 with a first trial period that ran until the end of 2007. The second period, between 2008 and 2012, covered the Kyoto period. The present third period runs until 2020.

Several large-scale top-down studies have found only a moderate effect of the EU ETS on abatement. The first phase resulted in estimated emission reductions between -2.5% and -5%, of which a major proportion was obtained by fuel switching without investment (Anderson and Maria, 2011; Delarue et al., 2008; Ellerman et al., 2010). Bel and Joseph (2015) estimate that of the 295 Mt absolute CO_2 reduction between 2005 and 2012 in the EU ETS, only 12% is due to the ETS, the major part being attributable to the economic crisis. Koch et al. (2014) also found that expectations on future economic conditions had a major impact on carbon prices, more important than other abatement related factors such as relative gas/coal prices, extra wind capacity or supply of Certified Emissions Reductions (from projects in the global South). Calel & Dechezlepretre (2014) as well as Martin, Muûls & Wagner (2011) observed a moderate effect of the EU ETS on innovation.

The aim of this study is to complement these large-scale studies by obtaining a more detailed insight into the effect of the ETS design on barriers and motivations to abatement investments. In particular, the study assesses the effect of both allocation method and price uncertainty on investment decisions. Cost-effectiveness is clearly not the only condition to trigger an investment. A large body of literature describes barriers to cost-effective investments in energy efficiency, leading to the so-called 'energy efficiency gap' (Decanio, 1998; Schleich, 2009). Perceptual biases are found to count among barriers to investment in energy efficiency (Sorrell et al., 2004; Venmans, 2014). Therefore, the objective is to open the 'black box' of industrial decision making and understand how perceptions on allocation method and price uncertainty affect investment decisions through a multiple case study based on in-depth interviews.

Assessing the way in which the carbon price signal is integrated into abatement investments is policy-relevant because it underpins the cost-effectiveness of the ETS. When barriers obstruct certain cost-effective abatement investments, the aggregate emission cap will impose other, more expensive abatement measures that are not affected (or less affected) by barriers. Barriers to abatement investments also affect the dynamic efficiency of the EU ETS because they are likely to lead to suboptimal technology development and learning.

The effect of price uncertainty is policy-relevant because the recent price decrease below 5 €/t CO_2 fuelled the debate on reducing price uncertainty and led to a proposal from the European Commission for a market stability reserve (COM (2014) 20/2). The market stability reserve will postpone auctions of allowances when banked allowances exceed 833 million. This is likely to occur when prices are low, and therefore the market stability reserve is likely to decrease price volatility.

The next two chapters review the literature and develop hypotheses, based on theory on the effect of the allocation method and carbon price uncertainty. This is followed by an empirical part which starts with a chapter on data and methods. Next the main empirical results and their underlying perceptual rationale will be discussed. These are: a) free allocation above emissions creates a lower perceived incentive to invest compared to allocation below emissions b) this is the main reason why managers do not include small but non-negligible carbon incentives in payback times c) scenarios of extremely high carbon prices, leading to lost option value when investing, is seen as a barrier to invest by the majority of managers and d) moderate carbon price uncertainty, leading to the need for a learning process protecting the company under moderately high carbon price scenarios, is perceived as a motivation to invest by investors. Chapter seven concludes.

2. Literature review and hypothesis development for allocation method

The study first investigates the perceived effect of free allocation above emissions versus allocation below emissions on investment decisions of individual companies. For a given aggregate cap, free allocation above or below emissions depends on how free allocations are distributed among companies on the one hand and on the proportion of auctioned allocations on the other. The second EU ETS period (2008-2012) was characterised by 97% free allocation. On average, the electricity sector was short on allowances and bought excess emission rights from the other industrial sectors which were long on allowances (Venmans, 2012). By contrast, during the third period (2013-2020), half of the allowances are to be auctioned and sectors that are defined as being exposed to carbon leakage will receive free allocation corresponding to a benchmark, defined as the emissions per tonne of product of the 10% most carbon-efficient companies in the EU (Directive 2009/29/EC). At the time of the interviews in 2012, all participating companies changed from 8 years of allocation above emissions to a likely allocation below emissions in the future, because free allocation was partly replaced by auctioning.

The Coase theorem, on which the efficiency of emission trading is based (Baumol and Oates, 1971; Coase, 1960; Dales, 1968), states that in the absence of transaction costs, income effects, asymmetric information and market power, the establishment of clear property rights (on emissions in the case of the ETS) is sufficient to come to an efficient outcome. This is because once property rights are clearly established, parties can trade these rights such that marginal abatement costs are equal among firms. As a consequence, the Coase theorem predicts that, for a given aggregate cap, and for investments that do not affect the allocation of emission rights, the initial distribution of emission permits has no effect on abatement investments (Montgomery, 1972; Requate and Unold, 2003). The intuition behind this result is the following: for a company whose free allocation is lower than emissions, an abatement investment will reduce the number of purchased emission permits. The carbon market will increase the cash flow of the project by the number of tonnes abated multiplied by the market price of carbon. For a company whose free allocation exceeds emissions, the same abatement investment will increase the surplus of emission permits, which can be sold at the same price as purchased permits in the former case. Again, the carbon market will increase the cash flow of the project by the same number of tonnes abated multiplied by the same market price of carbon.

The Coase theorem assumes that the property rights are assigned in a lump sum way and do not depend on abatement. This hypothesis is violated in the case of a new plant whose free allocation depends on the investment (Ellerman, 2008; Westner and Madlener, 2012). Investments in new plants are therefore disregarded when we investigate the effect of initial free allocation. Also, emission-based updating of permits between the first and second phases may have created a small incentive to postpone abatement investments, an incentive proportional to the level of free allocation (Böhringer and Lange, 2005; Rosendahl, 2008). Companies may have feared to receive a lower level of free allocation in the second phase in case they reduced their emissions in the first phase. But this was not the case during the interviews, between the 2nd and 3rd periods, when levels of free allocation depended on output, not on emissions (Zetterberg, 2014).

During the first phase, free allocation above emissions led to an overly generous total cap and a near-zero price in 2007. We treat the aggregate cap as exogenous and do not include the potential political relationship between free allocation and the aggregate cap (Markussen and Svendsen, 2005). By contrast, we investigate effect of allocation at the company level for a given price. Since the ETS covers more than 11.000 installations, the companies in our sample are small enough to be considered as price takers. Wang & Wang (2015) show that for a duopoly on the product market, abatement decisions only depend on the total cap, not on how the free allocation is distributed among companies. Du et al. (2014) show that even for a monopolist on the product market, facing a competitive carbon price, abatement is independent of free allocation.

The insights related to the Coase theorem, allow us to test the following hypotheses:

H1: Managers perceive the level of free allocation to be irrelevant in abatement investment decisions.

The Coase theorem and the abovementioned strand of literature contrasts with insights from the behavioural economics literature. Behavioural economics adds insights from psychology to obtain a more accurate fit to observed human preferences and behaviour. In doing so, behavioural economics also takes into account possible departures from rationality. Taking these departures from rationality into account can largely increase the effectiveness of environmental regulation (Greene, 2011; Gsottbauer and van den Bergh, 2011; Pollitt and Shaorshadze, 2011). An insight from behavioural economics that is of major importance in understanding the perception of the carbon market, is reference-dependence (Kahneman and Tversky, 1979). A loss with respect to this reference point is more heavily valued than a gain, which is known as loss aversion and leads to the endowment effect. Once companies are endowed with permits, the Willingness To Accept selling allocated permits is lower than the Willingness To Pay for extra permits. As a consequence, companies are reluctant to sell gained permits from efficiency investments. "An implication of the endowment effect is that people treat opportunity costs differently than 'out of pocket' costs. Foregone gains are less painful than perceived losses. Endowment effects are predicted for property rights acquired by historic accident or fortuitous circumstances, such as government licenses, landing rights, or transferable pollution permits" (Kahneman et al., 1990). The endowment effect casts doubt on the Coase theorem because this theorem assumes that people value foregone gains in the same way as perceived losses. This was observed in a laboratory setting by Murphy and Stranlund (2007). This leads us to the alternative of hypothesis 1:

H2: Managers perceive free allocation above emissions as a lower incentive to invest in abatement.

Reference-dependence, which is at the heart of the endowment effect, also poses the question of what the reference dependence is. There can be different references at play at the same time. This will be tested as part of hypothesis 2.

To the best of our knowledge, this is the first study testing how sum free allocation is perceived by managers and why these perceptions deviate from standard theory. It will be shown that initial allocation does matter for investment decisions because firms are less motivated to increase carbon gains compared to reducing carbon costs. This is in line with Martin *et al.* (2011), who found that firms expecting to receive a 100% benchmark allocation were less engaged in product innovation than firms that were going to be allocated an 80% benchmark allocation.

3. A literature-based model for the effect of carbon price uncertainty

Hoffmann (2007) and Sandoff and Schaad (2009) conclude that the impact of the first phase of the EU ETS on large-scale investments was limited, essentially because carbon price uncertainty was a barrier to abatement investments. However, Sandoff and Schaad (2009) describe that under certain conditions, when companies see regulatory risk as highly disruptive and focus on internal abatement as the major way of compliance, investments are made because managers are willing to decrease the exposure to this uncertainty. In this case, higher uncertainty leads to higher investment. In their survey of 114 Swedish ETS companies, they found that internal reduction of CO_2 was seen as the most important measure for handling a potential deficit (see also Hoffmann and Trautmann, 2008).

The aim of this study is to get a deeper understanding of managers' perceptions on how price uncertainty affects investments. In order to give meaning to the perceptions of managers, we develop below a literature-based theoretical model which will allow us to formulate hypotheses. There are different ways in which carbon price uncertainty affects the value of a project. In the following section, first, the effect of carbon price volatility and pro-cyclicality will be considered. This is relevant for projects with short payback times and where quick adaptation is possible. Next, gained option value, expressing the value of increased future flexibility from a project, is investigated. Gained option value from carbon cost uncertainty exists when an investment leads to a gradual learning process that lowers the probability of a plant closure or market share loss under high carbon costs. Thirdly, reduced future flexibility from investment is discussed. An irreversible investment eliminates the option of waiting and investing later. Waiting allows a company to avoid losses in case future information shows that the project is unprofitable. Lost option value is mainly driven by the probability that the plant will close shortly after the investment (at least sooner than the payback period).

Next, insights from behavioural economics are applied to predict how managers' perceptions may deviate from standard economic views on project valuation. A key insight from behavioural economics in this respect is that framing, the way a problem is contextualised, has an impact on choices (Tversky and Kahneman, 1981). A decision maker with narrow framing considers each risk in isolation without taking into account the correlation structure of different sources of uncertainty (Barberis et al., 2006).

The riskiness of the future carbon cash flow when there is no option value

According to standard expected utility theory, a firm's financial performance is not only affected by the expected profit, but also by undiversifiable risk. Risk depends on the volatility of profits (a measure of its uncertainty) and its correlation structure. For investors who have a diversified portfolio, the contribution of a project's uncertain cash flow to the value of a firm depends crucially on its correlation with the market return. This is the main idea behind the Capital Asset Pricing Model (Lintner 1965, Sharpe 1964) which is the most widely used framework for risk analysis and portfolio management. The value of a simple abatement investment is represented by equation 4.

$$Value = \underbrace{-investment_{t_0} + \sum_{t_0}^{\infty} \frac{E[fuel\ gains_t - mainenance_t]}{(1+\mathrm{R}')^t}}_{NPV_{without\ ETS}} + \sum_{t_0}^{\infty} \frac{E[p_t a_t]}{(1+\mathrm{R})^t} \quad \text{(eq. 4)}$$

With p_t the carbon price,

a_t the avoided emissions from the abatement investment,

R' the risk adjusted discount rate for the net fuel gains and

R the risk-adjusted discount rate for the carbon cash flows.

Since we work with expected values in the numerators, we consider the effect of mean-preserving uncertainty, not the effect of believes about future price trends, which we assume to be integrated into the price already.[1] When companies are allocated above

[1] Note that the mean-preserving volatility of the carbon price may have a small effect on the expected value of the carbon gain in equation 4, since $E[p_t a_t] = E[p_t]E[a_t] + \rho_{p,\mathrm{a}}\sigma_{p_t}\sigma_{\mathrm{a_t}}$. When both abatement and the carbon price increase during an economic upturn, the resulting positive correlation will increase the expected value of the total carbon gain. However, since this correlation will also increase the pro-cyclicality of the carbon gains, the increase of the expected value is more than offset by a higher risk-

emissions, the carbon cash flow is an increased carbon gain. If this carbon gain is pro-cyclical (positively related to the market return), this adds undiversifiable risk, increasing the discount rate R (Fama, 1977). However, in the case of an allocation below emissions, the carbon cash flow in equation 4 expresses a reduced cost. There has been some confusion in the past about the riskiness of costs that are positively correlated with the market return (Ariel, 1998; Armitage, 2005, p. 131; Patterson, 1995, pp. 202–204). A consensus has emerged that a pro-cyclical cost, being high in good times and low in bad times, has a lower risk than a counter-cyclical cost or than a cost which is uncorrelated to the market return. This is intuitive in the sense that a pro-cyclical cost – high when there is an economic upturn and low when there is an economic downturn- will have a stabilising effect on profits. Thus, a pro-cyclical cost will be discounted at a higher discount rate, leading to a lower certainty-equivalent.

Consequently, equation 4 is the same for carbon costs as for carbon gains, but the interpretation, in terms of risk profile, is the opposite. In the case of pro-cyclical *gains,* the volatility of the gains *adds* risk to the company, reducing the certainty equivalent of the gain. On the contrary, in the case of pro-cyclical *costs*, the volatility of these costs *reduces* the overall risk to the company, again reducing the certainty equivalent of the cost. Volatile pro-cyclical carbon *gains* are risky, so firms are less motivated to invest to *increase* these gains. Whereas volatile pro-cyclical carbon *costs* are risk-hedging, so firms are less motivated to invest to *decrease* these costs.

The above reasoning is based on the fact that the future correlation between the cash flow resulting from the EU ETS and the market return is known to be positive. This is a reasonable assumption for three reasons. First, the very design of a cap and trade leads

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adjusted discount rate for medium term and long term investments. Since no interviewee mentioned this relationship we do not go deeper into its effect.

to a pro-cyclical carbon price (p_t in equation 4). It is known in advance that the effect of a higher level of aggregate output creates greater scarcity of emission allowances. Next, the quantities of emissions avoided by an abatement investment (a_t in equation 4) are likely to be pro-cyclical because they are higher when installations run at full capacity during an economic upturn. Finally, if any causal link with the business cycle and regulatory uncertainty of future allocation rules is to be assumed, it will be a positive correlation. For a given carbon price level, a downturn -with increased industry plant closures- creates a political context for a non-stringent cap while an economic upturn is a political argument for a more stringent cap. The correlation between the carbon price return (Continuous future price one month ahead EEX) and the market return (Eurosstoxx Total Market Index Basic Materials) for the period from 25th April 2005 to 5th March 2012 was indeed positive: 21%. The correlation with Eurostoxx 600 was 19% for the same period. When the first period before 1st January 2008 is excluded (abstracting from regulatory risk), the correlations were slightly higher, 27% and 25% respectively.

Gained option value induced by abatement investments

Investments may induce a slow process of learning. Therefore, investing in abatement may increase flexibility in the future. Future carbon costs might be high and lead to the closure of the least carbon efficient companies, since they have not innovated and do not have the time to adapt. The time needed for the innovation process is crucial. This is because if innovation is possible in a very short time period, companies can still adapt once the high carbon cost is observed and there will be no increased option value from early (precautionary) innovation. The option value of innovation can be regarded as an interaction term between the project and other assets: investing today reduces the probability that the rest of the assets become worthless in the case of a plant closure. This value can be considered as the value of extra future flexibility induced by investing (Dixit and Pindyck, 1994; Wesseh and Lin, 2015). The option value increases with the uncertainty of future carbon costs, because this uncertainty increases the probability that high carbon costs lead to a plant closure or market share loss for the late innovators. This incentive, driven by uncertain carbon prices, is most relevant for investments that are related to learning and R&D. Since option value is a matter of avoiding carbon losses it is mainly driven by potential future scenarios where companies that are allocated below emissions.[2]

Lost option value induced by abatement investments

Some investments, such as the replacement of a motor or kiln that is at end-of-life, cannot be postponed. In other cases, investments can be postponed, for example in the case of a cogeneration installation or an upgrade of heat recuperation from the cooling zone to the dryer. When there is an option to wait, there may be an option value that is lost when the investment is made (Dixit and Pindyck, 1994). Investing today eliminates the option value of making the investment in the future under more favourable conditions (when technology might be cheaper) or the option not to invest if conditions turn out to make the investment unprofitable (when carbon price turns out to be low). When this option value is higher than the static NPV of investing today, it is better to wait, even if the static NPV is positive.

Lost option value can be driven by very low or very high carbon prices (see Figure 1). First the probability of very low prices will be considered. Abadie, Chamorro and

[2] In theory, allocation above emissions, where carbon income leads to lower sales prices can also lead to market share loss or plant closure. This is however unlikely and not how plant managers perceive allocation above emissions.

Gonzalez-Eguino (2013) investigated the option value for an investment with uncertainty over fuel prices, carbon prices and investment costs. For an investment in coal efficiency where the carbon advantage increases the spot gains by 96%, and where the carbon price is expected to increase by 5% per year, doubling the volatility of carbon price leads to a decrease of the maximum investment cost by 20%. Applied to the context of the interviewed companies, the option value would be fairly low. This is because during the years preceding the interviews, the relative carbon gain of an energy efficiency investment was ten times lower for companies combusting gas and two times lower for companies combusting coal, compared to the example in Abadie *et al.* (2013).

Option value related to low carbon prices applies only to projects with net present values close to zero, where waiting for new information makes it possible to avoid an unprofitable investment and where this advantage exceeds the benefits of immediate investment. For the majority of the investigated projects in this study, with a payback time below 3 or 4 years as a rule of thumb, the NPV would still be profitable under a zero carbon price (combined with moderate energy prices), and therefore option value is inexistent for downward carbon price uncertainty.

Option value can also result from avoiding an unprofitable investment under very high carbon prices, in case high carbon costs lead to a plant closure. This plant closure needs to be unavoidable by investing today in low carbon technologies, since plant closures that can be avoided by early low carbon investment add option value, they do not reduce option value (see Figure 1). Also, since negative option value is driven by scenarios in which the investment is unprofitable, the plant closure needs to happen before the end of the payback time. Therefore, negative option value related to high carbon prices is only important for investments with long payback times. Since lost option value is related to plant closures, it is only driven by scenarios where companies are allocated below emissions.

Equation 4 can be completed by adding both positive and negative option values to the value of a project. Equation 5 shows that carbon price uncertainty has an ambiguous effect on the incentive to invest: it may create a gain or a loss in flexibility (option value) and it increases the discount rate at which the carbon advantage is discounted. Figure 1 highlights the fact that lost option value is typically driven by scenarios with extreme carbon prices (low or high), while gained option value is driven by intermediate carbon price scenarios.

$$Value =$$

$$NPV_{without\ ETS} + \underbrace{\sum_{t_0}^{\infty} \frac{E[p_t a_t]}{(1+R)^t}}_{\substack{Value \searrow with\ uncertainty \\ Both\ over-and\ underalloc}} +$$

$$\underbrace{option\ value_{learning}}_{\substack{value \nearrow with\ uncertainty \\ Only\ under-allocation \\ Also\ when\ waiting\ is\ impossible}} \underbrace{-option\ value_{plant\ closure}}_{\substack{Value \searrow with\ uncertainty \\ Only\ under-allocation \\ Only\ if\ waiting\ is\ possible}} \underbrace{-option\ value_{low\ p_{carbon}\ and\ p_{energy}}}_{\substack{Value \searrow with\ uncertainty \\ Both\ over-and\ underallocation \\ Only\ if\ waiting\ is\ possible}} \quad \text{(eq. 5)}$$

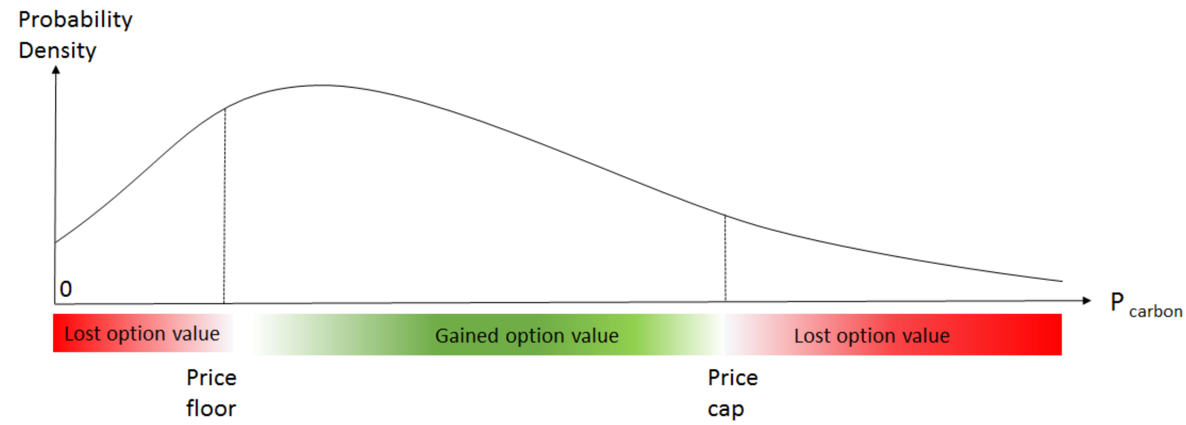

Fig. 1. A stylized representation of the effect of potential future carbon price scenarios on option value for investments that can be postponed (condition for lost option value)

and that induce a slow learning process (condition for gained option value). Lost option value can be reduced by a price floor and a price cap.

Narrow framing of cost volatility

We now add insights from behavioural economics into the model, mainly to complement the perceptions of uncertainty that are not related to option value. In the case of carbon gains (free allocation above emissions), interpreting the effect of carbon price uncertainty is straightforward and intuitive: pro-cyclical carbon gains are risky and this risk is a disincentive to invest. In the case of carbon costs (free allocation below emissions) however, we will test for 2 types of narrow framing. First, if projects are considered isolated from the rest of the economy (and the rest of the company) it is tempting to disregard the pro-cyclicality of carbon costs and perceive carbon cost uncertainty as risky. If that is the case, increased carbon price uncertainty will be perceived as increasing the riskiness of a cost and create a larger incentive to avoid these costs. Next, there can also be a second narrow framing perceiving an abatement project as adding a carbon gain instead of a reducing a carbon cost. If the carbon cash flow is considered as a risky gain instead of a risky cost, the risk will create a disincentive to invest. This allows us to distinguish the following hypotheses:

	allocation> emissions	Allocation< emissions
H3: Carbon price uncertainty is perceived as a disincentive to invest because:		
a) Pro-cyclicality of carbon gains is perceived as risky (abatement increases a risky gain)	X	
b) Pro-cyclicality of carbon costs is perceived as risk-hedging (abatement reduces a risk-hedging cost)		X

c) Pro-cyclicality is disregarded, therefore carbon cost uncertainty is perceived as risky (first narrow framing). Risky avoided costs is perceived as a risky added gain (second narrow framing). By consequence, risk-hedging carbon cost uncertainty is framed as risky carbon <u>gain</u> uncertainty.		X
d) Lost option value driven by high prices		X
or low prices	X	X
H4: Carbon price uncertainty is perceived as an incentive to invest because:		
a) Pro-cyclicality is disregarded (first narrow framing). Risk-hedging carbon cost uncertainty is perceived as risky carbon <u>cost</u> uncertainty.		X
b) Gained option value.		X

Note that when companies are certain to be allocated above emissions in the future, uncertainty of the price can only decrease the incentive to invest. Gained option value, resulting from carbon-induced plant closures or market share losses are typically induced by an allocation below emissions. Also, the narrow framing described above cannot happen when companies are allocated below emissions. This relationship between allocation and price uncertainty will also be tested in the empirical part of the paper.

4. Data and methods

This study aims to open the 'black box' of decision-making on abatement investments in ETS-regulated firms. We focus on managerial perceptions and on how these perceptions depart from assumptions in standard economic models. This allows us to include insights from behavioural economics on decision heuristics and real-life preferences. Therefore, a multiple case study and qualitative methods were used. We follow an inductive approach, focus on internal validity and try to find new insights in a homogenous set of companies (same sector, same country). Further research, with a greater focus on a deductive approach, quantitative methods and external validity will be needed to test how these insights can be applied under other circumstances.

The study is based on in-depth interviews with managers of 16 Belgian companies. This corresponds to all but two companies in the ETS-regulated building materials sector: nine brick producing companies or groups, three companies producing other baked construction materials, two cement and two lime producing groups. The ceramics, cement and lime sectors are important sectors in the Belgian economy since Belgium is a net exporter of these products. The building materials sector is also highly carbon intensive (Huisingh et al., 2015): the companies investigated emit around 15% of Belgian ETS-covered emissions. Nine plants investigated are part of a multi-national corporation, while seven plants investigated are only based in Belgium (including one intermediate case of a small Dutch-Belgian group). The value added per plant varies between €7 and €25 million per year for bricks and between €25 to €50 million per year for cement and lime. For a general overview of the plant properties, see Table 1.

The present paper is part of a larger research project where, for every company, 13 motivations and 16 barriers were discussed for the 3 or 4 most relevant past or future potential investments in energy/carbon efficiency. In total, 53 investment projects were discussed in great detail (including 15 projects on electricity efficiency, which are less relevant for the impact of the EU ETS). A description of these barriers and motivations, their interaction with the EU ETS and a voluntary agreement can be found in Venmans (2014) and the entire questionnaire can be found in the appendix.

Table 1. Characterisation of plants interviewed according to international scope, turnover and emission allocation.

	Bricks	Other construction materials	Cement & Lime

Part of multinational corp. (number of plants)	3	2	4
Not part of multinational corp. (number of plants)	6	1	0
Value added per plant 2011 (million €)	7-25 One case of 1.5	7-30	25-50
Range of yearly allocated emissions per plant (t CO_2)	10,000-80,000	30,000 – 70,000	400,000 – 1,500,000
Fuel	Natural gas	2 Natural gas 1 petroleum coke	coal/ Lignite/ waste/ biomass
% CO_2 emissions from decalcination	Generally below 5% Exceptionally up to 35%	Between 5% and 50%	Above 60%
Belgian production 2009-2011 compared to 2006-2008 [a]	-16%	n.a.	Cement -10% Lime -10% [b]
Belgian net exports 2011 as % of production[a]	15%	n.a.	Cement 5% Lime positive [c]

[a] Annual Report 2011 Fédération Belge de la Brique, Febelcem, Fediex
[b] Based on lime stone extraction
[c] Exact numbers are not available

In some of the 16 companies, 2 managers attended the interview. For every company, the most relevant person, responsible for preparing, executing and following up investments with energy efficiency gains, was interviewed. In total we interviewed 8 plant managers, 5 production managers, 4 mangers at the group level and 2 environmental managers. The difference in perception between the above categories was too small to be analysed and this was not the focus of the study. Also, four representatives from the professional federations and one person from an equipment supplier were interviewed. Interviews lasted between 75 minutes and 2 hours, resulting in approximately 30 hours of interviews. Information from annual reports, where available, and follow-up reports from a voluntary agreement were also included.

5. The effect of allocation above emissions vs. allocation below emissions

Managers were asked to score 13 triggers and 16 barriers to abatement investments in three ways: a) for their company as a whole, b) for specific completed projects and c) specific potential future projects (Venmans, 2014). Motivations related to the EU ETS are reported in Table 2. Answers to the most important company-wide questions related to the EU ETS can be found in Table 3.

Table 2. Importance of energy prices, the EU ETS and the voluntary agreement for triggering investments in energy efficiency. Scores in column 3-7 are the mean (for different projects and companies) of the following ordinal values: Very important=3; important=2; moderately important=1; not important=0.

	Number of companies and projects	All companies and projects (scores)	Natural gas as only heat source (scores)	Various fuels as heat source (scores)	Completed projects only (scores)	Future projects only (scores)
Increasing energy prices	61	2.4	2.6	2.2	2.3	2.6
Expected gains or cost savings from Emission Trading Scheme	48 (1)	1.1	0.7	1.9	0.7	1.3
Avoid uncertainty induced by future ETS (unknown prices, future cap, proportion of free allocations)	48 (1)	0.9	0.7	1.4	0.5	1.1
Mentality change induced by Emission Trading Scheme	48 (1)	0.8	0.5	1.3	0.5	0.8
Voluntary agreement	58	1.5	1.7	1.3	1.7	0.9

[1] Projects yielding only electricity efficiency which were not questioned about the incentive from the carbon market.

Table 3. Answers to closed form questions related to the EU ETS on company level (number of companies).

	Sample size	All companies	Natural gas as only heat source	Various fuels as heat source
Allocation below emissions greater incentive to invest than allocation above emissions?	16	Higher 11 No effect 2 Lower 1 Do not know 2	Higher 8 No effect 1 Lower 0 Do not know 2	Higher 3 No effect 1 Lower 1 Do not know 0
Carbon price in payback or IRR calculation?	15 (1)	Included 5 Not included 10	Included 0 Not included 10	Included 5 Not included 0
Bounded price (floor €14 and ceiling €16) higher incentive than volatile price with expected mean of €15?	16	Higher 9 Lower 3 Do not know 4	Higher 5 Lower 2 Do not know 4	Higher 4 Lower 1

[1] This question was asked for every completed project with fuel gains. One company was excluded because it had only completed abatement projects with electricity gains.

3.1. Allocation below emissions creates a higher incentive to invest, expressed in three ways

Managers were asked directly if they perceived allocation below emissions to be a greater incentive to invest compared to allocation above emissions. The vast majority of them thought that allocation below emissions was a greater incentive to invest (first line in Table 3). Only two managers thought that both created the same incentive, like the Coase theorem predicts. Finally, only one company considered that future allocation below emissions would create a smaller incentive to invest in important strategic investments, because allocation below emissions may increase the risk of transferring production to plants outside the EU. This last argument is in accordance with economic theory on option value, which will be discussed below.

Secondly, managers explained that they perceived the ETS to be a greater motivation for future investments (Table 2, two last columns) because they would have an allocation below emissions, while they had received an allocation above emissions in the past. The interviews were conducted in 2012, when the carbon price had fallen to 7 or 8€/t CO_2, whereas in the 3 preceding years the price was relatively stable at around 15 €/t CO_2. Therefore, the future importance of the ETS was not driven by an expected high price, but by the increased proportion of auctioned allowances.

> *Since 2008, the market has busted, and we have excess allowances. Luckily, we are allowed to keep them but of course they will be exhausted soon if you receive less allowances then you will be emitting. So in the future the carbon market will certainly play a role, but in the past we never took it into account.*

Thirdly, allocation above emissions was the reason given for gas-fuelled companies to omit carbon gains in payback times of energy efficiency investments.[3] This is one of the most surprising findings of the study. For companies combusting gas, the avoided CO_2 emissions related to energy efficiency investments were never included in payback times or internal rate of return (IRR) calculations to trigger these investments (except for one single investment). Carbon gains from gas efficiency are not very great, but they are far from negligible. At a price of 15 €/t CO_2 (mean price of the period in question),

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[3] In line with this observation, eight out of nine brick producers had not considered to reduce emissions by decreasing the lime content of his bricks as a result of the carbon market. Lime is an additive in order to obtain whiter bricks and can be substituted by kaolinite. Producers take market demand as given:

> *" We produce bricks for the market and we won't say, we don't make white stones. We try to capture all market opportunities, and certainly now. Will the carbon market have an effect on it? I don't think so. In the end, the customer is king." "It might trigger a communication strategy?" "Yes, but it depends on the architects, to what extent do they take that up? They prescribe."*

the carbon market increases the income of energy efficiency investments by 12% (for methane at 25 €/MWh and a carbon intensity of 0.2 tCO_2/MWh). Companies combusting natural gas stated the availability of excess permits as the main reason for not including the carbon advantage of efficiency investments when assessing payback values. Two companies argued, as a complementary reason, that the carbon gain was negligible, which is disputable given that the carbon advantage had increased profitability by 12% in the past. All companies combusting gas planned to include the carbon gains in their payback calculations in 2013, when they would be allocated below emissions. This is puzzling and a contradiction to standard economic models on the reaction of companies to a carbon price. As put forward by the Coase theorem, when a company is allocated above emissions a carbon efficiency project increases carbon income whereas when a company is allocated below emissions the project reduces carbon costs. However, the effect on the profitability of an efficiency investment is the same; the allocation method has no effect on net present value, IRR or payback calculations. For one plant manager, this fact only became clear during the interview.

All five companies that used carbon intensive fuels (cement, lime and 1 'other' building sector company) included the carbon advantage in their profitability calculations of energy/carbon efficiency investments. This is understandable, since at a mean price of 15 €/t over the period in question the carbon advantage of a coal efficiency investment is up to 50% of the fuel advantage (for coal at 90€/t_{coal} and a carbon intensity of 3 tCO_2/t_{coal}). Besides high energy carbon intensity, these companies have process emissions that considerably exceed energy emissions. This is in line with the fact that the ETS was seen as a moderate to important motivation for investments in energy/carbon efficiency (score between 1.9 and 1.3 in Table 2), twice as much as for companies combusting only gas. So the contradiction with the Coase theorem when assessing the profitability of energy saving investments seems to be more generalised in those companies where carbon effects are low. This is in accordance with other findings where behavioural departures from rational choice models diminish with trading experience and market pressure (DellaVigna, 2009; List, 2004; Plott and Zeiler, 2005).

5.2. The rationale behind the perceptions

When asked for the rationale behind the different incentives of allocation above emissions and allocation below emissions on investments, managers' perceptions fit the behavioural theory of reference-dependence very well. Managers put forward three reference points that they found relevant to explain the perceived difference: a) the situation before the EU ETS, b) the endowment of free allocations and c) competitors. All effects lower the incentive to invest when a firm is allocated above emissions.

The first reference point is the situation before the EU ETS. When a firm is allocated above emissions, the ETS tends to create a gain, and investing allows to increase this gain. When a firm is allocated below emissions, the ETS creates a loss, which has more weight than a gain and attracts more attention.

Note that allocation above emissions does not always lead to a gain, nor does allocation below emissions always lead to a loss, once feedback on price dynamics is taken into consideration. Equation 1 gives a stylised representation of the effect of the ETS on the profits of a company.

$$\pi = \underbrace{p_{no\ ETS}q - C_{no\ ETS}}_{reference} + \underbrace{\Delta pq - C_{abatement} + \overbrace{(A - eq)p_{carbon}}^{\substack{gain-loss\ with \\ narrow\ framing}}}_{gain/loss} \text{(eq. 1)}$$

With π = profit,

p = the sales price,

$\Delta p = p - p_{no\ ETS}$ = the effect of ETS on price, C = the total cost = $C_{no\ ETS} + C_{abatement}$,

q = quantity produced (an effect of the ETS on q may also be considered, but this doesn't alter the conclusions),

e emissions per tonne,

p_{carbon} = the carbon price and

A = free allocation of emission permits.

For example, in a competitive equilibrium market, where companies set their sales price at the marginal cost including the opportunity cost of free emission allocations, $\Delta pq = eqp_{carbon}$ and both allocation below emissions and allocation above emissions lead to gains (Sijm et al., 2008). In contrast, if not the opportunity costs but only cashed costs/gains are passed through in sales prices then $\Delta pq = C_{abatement} + (A - eq)p_{carbon}$, and the effect on profits of both allocation above emissions and allocation below emissions is zero. So the perception of allocation above emissions as a gain and allocation below emissions as a loss assumes a certain level of narrow framing where the feedback on sales prices is disregarded.

A second reference point is the endowment of free allocation (A in equation 1 and 2), known as the endowment effect. The endowment effect creates a higher perceived value for permits that companies already possess compared to the money they could get from selling the permits.

$$permits\ at\ end\ of\ period = \underbrace{A}_{Reference} - \underbrace{permit\ sales\ or\ purchases}_{gain\ or\ loss} \quad \text{(eq. 2)}$$

The gain or loss is not framed in monetary terms as in equation 1, but in terms of a commodity that has a use-value (permits). The Willingness To Accept selling allocated permits is lower than the Willingness To Pay for extra permits.

Since the endowment effect creates reluctance to sell excess allowances, when a firm is allocated below emissions, an abatement investment yields diminished cash costs and when the firm is allocated above emissions, an abatement investment yields a greater reserve of permits for future use. Where cash has a lower value than the permits in the sell/hold decision, cash has a higher value than the permits in the investment decisions. The impression is that a cash incentive is larger than a non-cash incentive with the same economic value: *"cash is king"* was mentioned three times by an interviewee. When the firm is allocated above emissions, the ETS is seen as an environmental regulation with which they comply and thus to which no attention is required, even if the regulation creates opportunities with an interesting yield in terms of extra permits. This is was expressed as follows by a production director:

> *Interviewer: "Isn't it the case that when you save gas, you emit less CO_2 and those permits will remain unused and at a given moment they can be sold?"*
>
> *"I suppose that is the case, but we didn't consider it at all, because the carbon aspect is dealt with by somebody who is closer to the accounting department. It is disconnected from the one who is dealing with production... I think that for us this is somewhat too abstract."*

The above quote shows that the endowment effect leads to a perception of the EU ETS that is very much like a command and control regulation. Since emissions are below the allocation level, which is interpreted as an emission standard, no attention is required.

The third reference point is competitors. According to standard economic theory, any investment with a positive Net Present Value (NPV) will result in a competitive advantage that takes the form of extra-profits or a decrease in sales prices. Since both allocation above emissions and allocation below emissions have the same effect on the NPV of a project, standard economics assumes that the position compared to competitors does not affect a decision to invest in an abatement investment. So, even if allocation above or below emissions may create a different effect on competitiveness, it does not create a different incentive to invest for a profit-maximising company. Nevertheless, the effect on competitiveness was a major argument given by managers to see allocation below emissions as a higher incentive to invest.

Extra-European competition is limited for the interviewed companies, because bricks, cement and lime are costly to transport. Most competitors are located inside Europe. Competitors as a reference point is even more puzzling for European competitors, since allocation above or below emissions does not create a systematic effect on intra-European competitiveness. Equation 3 expresses the competitive disadvantage of firm i over firm j per tonne of product for intra-European competition (the effect of the ETS on q is not modelled, but is of secondary importance).

$$\frac{C_i}{q_i} - \frac{C_j}{q_j} = \underbrace{\frac{C_{i,no\,ETS}}{q_i} - \frac{C_{j,no\,ETS}}{q_j}}_{Reference} + \underbrace{\frac{C_{i,abatement}}{q_i} - \frac{C_{j,abatement}}{q_j} + \overbrace{[e_i - e_j]p_{carbon}}^{\substack{loss\,/gain \\ in\ case\ of\ benchmark \\ and\ narrow\ framing}} - \overbrace{\left[\frac{A_i}{q_i} - \frac{A_j}{q_j}\right]p_{carbon}}^{\substack{zero\ in\ case\ of \\ benchmark}}}_{loss/gain} \text{(eq.3)}$$

Within Europe, the carbon market will create a competitive disadvantage per tonne of product for a company i which is composed of: a) the difference in abatement costs b) the difference in carbon intensity and c) a lump sum amount dependent on luck or lobbying power towards the regulator. In case of benchmarked allocation the third component is zero. Hence, competitiveness depends only on different emission intensities and abatement opportunities and is independent of the amount of the free allocation method. If not only the NPV of investments but also the effect on intra-European competitiveness is unaffected by the allocation method, having European competitors as a reference point seems even more puzzling.

As behavioural economics on reference-dependence predicts, managers perceived a loss compared to the reference to be more threatening than an extra gain compared to the reference. Moreover, both intra- and extra-European competitors as a reference point make the first reference point and the endowment effect more salient. When firms are allocated above emissions, profit margins tend to increase for all European producers (see equation 1), which makes a competitive disadvantage less urgent to absorb. On the contrary, when firms are allocated below emissions, profit margins decrease for all producers, which makes a competitive disadvantage more urgent to address (given that the ETS is framed without its effect on sales prices). Companies feel that avoiding lagging behind is a more compulsory investment motivation than building up an extra advantage compared to competitors. This difference is further accentuated by the fact that, when firms are allocated above emissions, and the endowment effect impedes selling excess emission rights, the competitiveness effect is immediately apparent as a cash flow.

> *"In plant X the situation is very critical, due to the quarry. Because we are above the benchmark. So at any price, what can we do, because it will cost us money... A new fundamental element in this is the production costs. The one that will survive tomorrow, because there is a terrible competition, will be the one that has the lowest costs. We are in a commodity market. We have new competitors that are arriving..."*

The NPV of abatement measures, and thus their effect on competitiveness, has not changed with the switch to benchmarked allocation, nor has the impact of the ETS on competitiveness (the difference in former carbon gains will be a future difference in carbon costs), but the competitors as a reference point creates a perception of urgency.

> *"X has a higher specific energy consumption compared to us. So even if I would have to buy allocations, I would need to buy less than them. So this may not be a motivation to invest for me, because for a given time it allows me to have a competitive advantage. For them it may*

motivate them to invest because they will have a higher production cost, their margin in the market will change."

Again, the NPV and hence the effect on competitiveness of an abatement investment is the same, but the comparison with competitors creates a different perception. Despite the fact that the quoted company at another moment of the discussion considered that the marginal effect of allocation below or above emissions was the same for abatement investments:

"For the moment we are over-allocated. All the CO_2 reductions we will be able to achieve will translate into sales opportunities and so this means that it amounts to the same thing."

Under benchmarked allocation, the endowment coincides with the best available techniques. Firms that do worse than this benchmark are confronted with the fact that their competitors are more carbon-efficient, which could have been more difficult to observe before the benchmark existed. One producer, with good energy efficiency but with high levels of process CO_2, was considering a new kiln to be able to make whiter stones with other materials (kaolinite). The trigger was the discovery that their carbon content was far above the EU benchmark for bricks from 2013 (139 kg CO_2 per tonne of bricks), even though they will continue to be allocated above this benchmark after 2013. Another link between the costs without the ETS and the competitors as references, is that in the ceramics, cement and lime sectors competition is typically price-based, and less a matter of differentiation. Winning competition is essentially a matter of reducing costs. Hence, reducing costs is seen as the core business while increasing carbon income is seen as a secondary business or a side-product.

"Are companies more motivated to minimise losses compared to maximising extra income?"

"Indeed. Because what's our core business? We have a company that does the trading of the emission permits for us. But they do not dictate what we must do. They always come with a

proposal, are you ready to sell at this price? If we would like to maximise our CO_2 revenues, it would be them who dictates the law by saying, you should sell immediately, etc. That's not the way it works. The decision is taken by the operational unit."

Interviewer: "For the moment, an energy efficiency investment increases your CO_2 revenue, in the future this same line in your payback time calculation will express a decrease in carbon cost. Will this change increase your incentive to invest in this type of project?"

"Surely, because it will be part of my production costs."

Interviewer: "So you are more motivated to diminish production costs than to maximise side-revenues for this type of project?"

"That's sure. Why? Because it's our core business"

As a conclusion, among the 16 companies interviewed, 11 perceived allocation below emissions as a greater incentive to invest. The reasons given for this non-orthodox perception were the reference-dependence with respect to the situation before the ETS, the endowment of free allowances, reference-dependence with respect to competitors and the consideration that cost minimisation is part of the core business. These reasons were also sited by companies that consumed only gas to explain why they did not include carbon market effects in their payback time calculations.

6. Perceived effect of carbon price uncertainty

In general, managers did not consider the risk-hedging potential of the pro-cyclicality of carbon costs. No single interviewee mentioned that a volatile carbon cost may hedge against the pro-cyclicality of profits and, hence, may reduce risk. In other words, we did not find any support for hypothesis 3b.

> *"A stable price decreases the risk. That's why in the US, many of our colleagues, in their discussions with the Obama administration, argue more for a carbon tax. There is a price foreseeability."*

The non-recognition of the risk-hedging potential of pro-cyclical carbon costs can easily be understood by 'narrow framing' heuristics described above. A project is analysed as an independent entity, in isolation from the rest of the company and the rest of the market. So the only dimension of risk is the uncertainty (volatility) of the future cash flows, without considering how this uncertainty is correlated to the market return or the profit of the entire company.

There is also an element of professional lock-in. The idea that adding an uncertain cash flow may reduce the overall uncertainty because of the correlation structure, may sound very familiar to portfolio managers and financial experts, but much less to engineers and production managers. The focus of engineers and production managers is typically on controlling processes, mastering hassle, predicting technical outcomes. The idea that increasing one source of uncertainty may decrease the overall uncertainty may sound very odd in that profession.

We found support for our hypothesis 4, stating that uncertainty may increase the incentive to invest. Companies were asked to score the importance of "Avoid uncertainty induced by future ETS (unknown prices, future cap, proportion of free allocations)" as a motivation to invest. As shown in Table 2, this motivation to invest had a mean score of 0.92, which is almost as high as the motivation "Expected gains or cost savings from Emission Trading Scheme" (score 1.10). Since carbon price volatility was perceived to be risky (narrow framing described above), it is logic that companies are motivated to decrease this risk through abatement (H4a). This was the main rationale during the interviews. The result also suggests that positive option value is an important motivation to invest (H4b).

To obtain an idea of the total effect of carbon price uncertainty on investments, companies were asked to state in which case the incentive to invest would be greatest: a) a stable price obtained by a price floor of €14 and a price cap of €16, b) the observed volatile price of the preceding years with an expected mean value of €15 (last line in Table 3). In line with hypothesis 4, three companies –a minority- argued that an uncertain price would create a greater incentive to invest. This is coherent with the fact that these companies indicated that "avoiding uncertainty from the ETS" was an important motivation to invest and that pro-cyclical cost volatility was perceived to be risky.

In contrast, nine companies -the majority- thought that the uncertainty of carbon costs was a disincentive to invest (hypothesis 3).

> *"For us, a stable price creates a higher incentive to invest. Because we are very (risk) exposed. A stable price is clearer to us."*

A first interpretation is that, for these companies, lost option value (H3d) exceeds the gained option value (H4b).

However, the same subset of nine companies answered that price uncertainty is an important motivation to invest (hypothesis 4). They considered "Avoiding the uncertainty of the ETS" as a motivation to invest (score 0.9), to be almost as important as the motivation "Expected gains of cost savings from the ETS" (score1.1). The change of perception with the framing of the question, when further analysed during the unstructured part of the interviews, confirmed the double narrow framing hypothesis (H3c) described above: 1) carbon price volatility is perceived as risky instead of risk-hedging and 2) the carbon advantage is framed as an increased gain instead of a decreased cost. Since almost all future cash flows resulting from an investment are risky gains (first term in equation 5), it is tempting to also interpret the carbon cash flow (second term in equation 5) as an added risky gain, instead of a reduced risk-hedging cost. Since both narrow framings lead to a conclusion in line with standard economic thinking (hypothesis H3b) these framings are less likely to lead to cognitive dissonance.

We also found support for hypothesis 3d. Even though no operator thought it was likely that the carbon market would lead to plant closure, lost option value was mentioned by three producers.

> *"So the uncertainty of your future competitive positioning with respect to countries outside Europe is a barrier to investment?"*
>
> *"Exactly, at least if the shareholder has to put in several hundreds of million euros, the general context of the evolution of the carbon allocations and prices is of major importance today... The system creates a lot of uncertainties and thus, for the moment, it is a source of inefficiency... Next, for smaller investments, like optimisations, this problem is not really relevant, because payback times are reasonable, and the considered cash flows do not really compromise our future."*

As mentioned above, narrow framings (H3c and H4a) and option value (H3d and H4b) create a link with volatility and the allocation method. Hypothesis 4 (uncertainty increases incentive to invest) is only driven by scenarios where firms are allocated below emissions. This was also observed. The score on "avoiding uncertainty of the EU ETS" as a motivation to invest, is much higher for future investments (1.1), when firms are likely to be allocated below emissions, compared to past investments (0.5). On the other hand, the single company that considered that free allocation below emissions created a lower incentive to investments explained this by the uncertainty over plant closure, referring to negative option value (H3d).

As argued above, very high prices are likely to be seen during an economic upturn, when it is likely that the company is producing at full capacity and plant closures are not on the agenda. Since the risk-hedging nature of carbon price volatility under an allocation below emissions is not perceived by managers, the magnitude of option value is likely to be over-estimated.

7. Conclusions and policy recommendations

This paper assesses the way managers perceive the impact of the carbon market on their investment decisions. For companies with gas as their sole heat source (ceramics sector), the gain in carbon allowances induced by energy efficiency investments was never included in payback times or IRR calculations. The major argument for not including the carbon gains was that they were allocated above emissions.

The Coase theorem predicts that allocation above emissions or allocation below emissions, for a given carbon price, creates the same incentive for investments. This view was only expressed by two companies. In contrast, 11 companies argued that allocation below emissions was perceived to be a greater incentive to invest. They justified this choice by reference-dependent preferences, well described by behavioural economics. There were three references: the situation before the EU ETS, the endowment of free allocations and competitors, all of which worked in the sense of a lower perceived effect of allocation above emissions on investments. One company perceived allocation below emissions as a lower incentive to invest, because the risk of a future plant closure under very high carbon costs creates a value to wait (option value).

There is a new strand of literature arguing that policy design is more effective when it takes into account the perceptions driving people's and companies' reactions to incentives. Insights from behavioural economics help to understand and anticipate these reactions more accurately. The findings in this paper are an extra argument, besides other market distortions from free allocation under perfect rationality, to auction at least a small proportion of allocations to companies. The new allocation rules since 2013, based on partial auctioning, were perceived as a stronger incentive to invest compared to the fully grandfathered allocation before 2013, despite the lower carbon price.

To the best of our knowledge, this is the first study to empirically investigate the effect of carbon price uncertainty on the incentive to invest. When no option value is involved, standard economic theory predicts that pro-cyclical costs -high in good times and low in bad times- are less risky than counter-cyclical costs. This insight was not perceived as such by any of the managers, which can be understood by narrow framing, observed in a wide range of situations in behavioural economics research.

When investing in low carbon technologies is related to a slow innovation process that cannot be achieved in a short time scale, the investment adds flexibility in the future. This increased option value may help to avoid a plant closure under high carbon costs and creates a higher incentive to invest under uncertain carbon prices. Indeed, avoiding uncertainty from the EU ETS was an important motivation to invest in energy efficiency, certainly for future projects when companies are likely to be allocated below emissions. The fact that pro-cyclical price volatility was perceived as risky instead of risk-hedging, made the perception of avoiding risk as an investment motivation even more important. However, when a comparison between an uncertain price and a certain price was questioned in a direct manner, a majority of companies (nine) perceived an uncertainty over future carbon costs as a disincentive to invest. This result is partly driven by the perception of pro-cyclical carbon cash flows as risky gains instead of risk-hedging costs.

Also, lost option value is a second reason to perceive the uncertainty of carbon costs as an obstacle to invest. Extremely high carbon cost scenarios that would lead to an unavoidable plant closure, create an option value of waiting with green investments. Very low carbon price scenarios, in which a given energy efficiency investment would not be profitable, also create an option value of waiting.

The distinction between different types of option value has important policy implications. As shown in Figure 1, the lost option value is related to the tails of the probability distribution of the carbon price and can be avoided with a price stabilization mechanism. A price floor, or the recent Commission's proposal for a market stability reserve, is beneficial for investments that may be unprofitable under low carbon prices. Next, potential carbon cost scenarios in which early innovation allows managers to avoid a market share loss (or a plant closure) will lead to a higher level of investments. Intuitively, when there is a threat of high but supportable future carbon costs companies 'buy insurance' by investing in extra green technology. In this carbon cost zone, no price policy is needed.[4] Finally, potential carbon cost scenarios in which plant closure is unavoidable, will lead to a lower level of investments. If confronted with a threat of very high future carbon costs, companies have an incentive to postpone abatement investments with positive NPV. This can be seen as an 'insurance cost' to make potential future off-shoring less costly. Therefore, a carbon price stabilisation mechanism, reducing the likelihood of extremely high carbon prices and increasing foreseeability of levels of free allocation in leakage exposed sectors, will increase the incentive for abatement investments.

[4] Uncertainty in this price zone leads to a lower incentive to invest because pro-cyclical costs are risk-hedging, but reducing this risk-hedging potential is not desirable from a policy perspective.

Note that both gained option value and lost option value related to high carbon price scenarios only apply to carbon costs –not carbon gains- and hence will be more important in the future when companies are allocated below emissions. Therefore, depending on the sector and the perceived probability distribution of future carbon prices, allocation below emissions creates option values that may increase as well as decrease the incentive to invest. The way in which the Coase theorem is invalidated by option value is an innovative contribution of this paper and a fruitful future research area.

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