Environmental Policy and Bounded Rationality

A Thesis
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by

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To Lydie. Noah and my parents Grisha and Sveta.

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1 Preface

I divide my findings into three chapters. In the first chapter I study the effect of the Prospect Theory (PT) type of risk aversion, with a dynamic reference, on the decision to undertake sustainable development projects as defined in Articles 6 and 12 of the Kyoto Protocol. Examples of such projects are rural electrification project using solar panels in San Ramon, Bolivia or the installation of more energy-efficient boilers in Egypt.[1] In the second chapter I examine whether institutional constraints of the ETS have an effect on the risk perception of traders. Specifically, I test whether the price is affected by the Disposition effect (a tendency to realise gains and postpone losses), and how this varies throughout time. In the third chapter, I analyse an output decision of installations under conditions of uncertainty with regard to future environmental policies beyond 2012. I will focus on the output implications of a three-period model where the representative installation displays ambiguity aversion. In the next three sections I briefly outline my main findings.

1.1 Chapter 1

Valuation of an outcome relative to a reference point is well established in economic literature since Kahneman and Tversky (1979). Recent empirical evidence shows that sometimes a valuation of an outcome with respect to a dynamic, rather than a static, reference can better explain behaviour anomalies under uncertain scenarios (among others see, Gooding *et al.*, 1996 and Heath *et al.*, 1999). Relative evaluation of projects that are originated from market-based mechanisms such as the Clean Development Mechanism (CDM) and Joint

[1] For more details visit: http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

Implementation (JI), against the price of the carbon permits and their continuous value evolution makes them natural candidates for the application of a dynamic framework[2].

Unlike carbon permits, where the exchange of a commodity takes place among market participants and where no substantial benefit is provided to society, the CDM and the JI benefit both the entrepreneurs and host countries. An entrepreneur gains the desired carbon credits, and host countries achieve a valuable technology transfer. Such technology can support sustainable development in host countries and sustain the needs of the current generation without compromising the ability of future generations to meet their own needs (WCED, 1983). However, unlike carbon trade, these projects are characterised by high uncertainties and risks due to political and economic instability in the host countries. The application of a dynamic framework to such sustainable investment opportunities would assist policy makers in understanding the dynamics of decision-making and steer the market towards the desired path of emissions abatement.

To study the effect of the PT type of risk aversion with a dynamic reference, I extend the Kyle *et al.* (2005) model of static reference valuation. I find that in contrast to the static framework, in a dynamic framework an agent considers risk and returns of both investment opportunities. I also show that, under condition of complement investment opportunities, agents would exhibit a Disposition effect relative to a static reference if they were to exhibit a Disposition effect relative to a dynamic reference.

Based on these results I demonstrate that to encourage sustainable investments, both

[2]Both the CDM and the JI are cost effective measures established by the Kyoto Protocol, to reduce emissions by way of technology transfers to developing countries.**Articles 6 and 12 of the Protocol, define CDM and JI, respectively.**

host and domestic policy makers should reduce the relative risk of a sustainable investment opportunity. It should be done with respect to the risk of a carbon permits portfolio, rather than merely an absolute risk of the sustainable projects. This can be achieved through the active intervention of policy makers in the stabilisation of the carbon market, in addition to regulation transparencies and international co-ordination between the host and domestic policy makers.

1.2 Chapter 2

The EU ETS covers the period from 2005 to 2012. The situation of policy uncertainty beyond 2012 contributes to an already existing tough challenge for policy makers in reducing emissions levels. Ignoring the behavioural aspect of decision under uncertainty might make this challenge even tougher and sometimes unachievable. I propose that uncertainty with regard to future rule of free permits allocation beyond 2012 contributes to such challenge by encouraging strategic behaviour that favours current polluters (the Ratchet effect).

In this chapter I analyse the effect of information uncertainty on the output decision of installations that are subject to the carbon cap and trade framework of the ETS. The aim of the EU cap and trade policy is to reduce total emissions below the emissions levels of 1990. In most EU member states, individual free allocation of permits to installations is based on their past emissions, a practice known as grandfathering. In order to reduce the possible Ratchet effect, where installations have an incentive to increase their current output to gain a larger share in future allocation, past emissions are taken from the period prior to the implementation of the Scheme. It seems that the assumption of the policy maker is that this method of allocation eliminates the Ratchet effect. However, this assumption does not hold when one considers that the policy should continue into the future. If grandfathering continues beyond 2012, then it is possible that current emissions would be considered in future allocations. This may encourage firms to act strategically and increase their current output to receive a larger share of free permits in the future.

To investigate the impact of unknown future rule of free permits allocation on the output of installations, I divide my analysis into two parts: firstly, I demonstrate that there is a distinction between the effects of uncertainty and ambiguity on the current output in the market. Secondly, I show that ignoring uncertainty by the policy maker leads to incorrect policy design.

I start my analysis by assuming that the current policy design ignores the uncertainty in the market. I have labelled it the Benchmark case. This is a simple two period model, which correspond to the two phases of EU ETS. I then release the certainty assumption and extend the model to three periods. The third period policy is assumed not to be known to the firms. I analyse two possible scenarios. One scenario is when the installations are uncertain as to the policy that governs in the third period. Another, more realistic, scenario is when the installations are ambiguous as to the policy that governs in the third period. Ambiguity is a particular type of uncertainty where the agent does not attach probabilistic measures. I apply the maxmin solution concept of Schmeidler and Gilboa (1998) to investigate the impact of ambiguity in future environmental policy on the total output of the market.

I find that, with comparison to the output in the Benchmark case, the output increases both in uncertainty and ambiguity cases. The model, however, points out that in the presence of ambiguity, current output of the firms increases even more than in the case of uncertainty. I show that in the presence of ambiguity, unlike uncertainty, policy makers can reduce the current output and achieve pollution abatement through ambiguity reduction. I suggest that this can be done in several ways. One way would be to gradually diminish the free allocation of permits in the future and adopt a mechanism of auctions. Higher proportion of auctioned permits in the future would diminish the Ratchet effect and, as a result, diminish the output. Another way is to encourage investments in clean technology. This could attribute to the diminishing sensitivity of future allocations, as the companies would give less consideration the future allocation of carbon permits. And finally, future policy transparency is another way which could diminish the installations' ambiguity and decrease their current output.

1.3 Chapter 3

The two Phases of ETS run from 2005 to 2007 and from 2008 to 2012. As a result of the banking ban on permits between two Phases, at the beginning of each Phase, the market is characterised by high information uncertainty about the real state of the market. The participants are uncertain as to whether the market is in a deficit or in a surplus of permits. The real state of the market becomes clear by the end of April, when the submission process of permits is over and the European High Commissioner publishes the verified figures of emissions for the previous year. During this period the market tends to be highly volatile. For instance, the highest drop in the price of the carbon permit was during April 2006, when market participants understood that there was a surplus of permits in the market.

The aim of this chapter is to study how such institutional constraints affect the pricing mechanism of carbon permits during the First and Second Phases of the ETS. Firstly, I study whether the price dynamic is a factor of the Disposition effect, a well-documented anomaly in financial markets. Secondly, I analyse the effect of the institutional constraints on Disposition magnitude in the market.

To construct a variable that detects the Disposition effect, I follow the method proposed by Grinblatt and Han (2005). I show robust evidence for the increased Disposition effect at the beginning of both the First and the Second Phases. In addition, my results indicate that the first compliance event of each Phase is crucial in decreasing and stabilising the Disposition in the market. This evidence points to the harmful effect of institutional constraints on the evolution of the carbon price at the beginning of a Phase.

In the light of these results, I suggest increasing the frequency and transparency of the publications of the verified emissions figures to decrease the Disposition effect which distorts the efficiency of the carbon market.

1.4 Final Word

On 6 April 2009 the EU Commissioner published a draft of the ETS for the Third Phase. There are several propositions that attempt to increase the efficiency of the Scheme. Among those propositions are measures that increase the number of permits to be auctioned and to lift the ban on the inter-Phase banking of permits.

These propositions are in line with the suggestions I make in my thesis. I believe those measures would serve the environmental policy in a way that would reduce, as I suggest, the effect of behavioural anomalies. This in turn could make the Scheme more efficient and contribute to the final goal of a carbon emissions reduction.

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Chapter 1: Evaluation with dynamic reference-Sustainable investment

Abstract

The Prospect Theory proposes to assess outcomes relative to a reference point (or benchmark). Although the literature recognises the relevance of dynamic benchmarks, most of the applications of Prospect Theory employ static reference points (or a status quo). This paper aims to develop a Prospect Theory framework for investment under uncertainty subject to a dynamic reference point, within the context of environmental policy making, where the distinction between a dynamic and a static frameworks is crucial. I evince that, in contrast to the static framework, in a dynamic framework the investor measures not only the absolute but also the relative risk premium (Sharpe ratio) of the investment opportunity, incorporating the risks and returns of a reference portfolio. I propose that there exists a relation between static and dynamic frameworks. Using the dynamic framework, I argue that in the environmental context international co-operation is the key to a successful environmental policy.

2 Introduction

Supply of a growing energy demand in the developling world without compromising sustainable development, the ability to supply the needs of the current generation without compromising the ability of future genrations to meet their own needs, is one of the challenging tasks that we are facing today (WCED, 1983). The introduction of new market-based mechanisms by the Kyoto Protocol, such as the Clean Development Mechanism enable to transfer and implement a valuable emission-reduction technology (aka. sustainable investment) in the developing countries that assist them, among other things, to meet growing demand for energy and enterpreneurs meet the targets set by the Protocol . Such mechanisms pose a new challenge to industry and policy makers. Such sustainable investment projects allow there entrepreneurs earn saleable certified emission reduction credits by reducing emissions in developing countries as a cheaper alternative to domestic emissions reductions. These opportunities are, however, characterised by high risks (Springer, 2003) in comparison to the riskiness of the carbon credits price. Therefore, the issue of the valuation method of this investment opportunity becomes relevant.

The importance of the valuation of an outcome relative to a single reference point, as it is proposed by Prospect Theory, has been well established in the economic literature since Kahneman and Tversky (1979). However, the authors argue that there may be situations in which gains and losses are measured in relation to levels different from the status quo. In such situations that inability to adapt to another reference level may encourage agents to take risks which would not otherwise be acceptable. The following example demonstrates the main idea behind the proposition.

Let's take as an example a decision maker who invests in a project. Consider the initial value of the project to be the status quo. Assume the new value of the project to be below the initial value. The adjustment to a new reference level may be due to unpredictable losses the agent has recently incurred to sustain the project. In addition, the decision maker is assumed to exhibit the Disposition effect.[3] The agent realises the gains by liquidating the

[3]In the empirical literature there is extensive evidence of the Disposition effect (see, among others Dyl 1977, Ferris *et al.* 1988, Goetzmann *et al.* 2008, Grinblatt *et al.* 2005 and more)

project and postpones the realisation of losses by keeping the project. I denote the new reference as Y' and the status quo as Y, where $Y' < Y$. When the value of the project is above Y (gain) the risk compensation is not enough for a Disposition-prone agent to keep the project. The agent, therefore, chooses to liquidate it as soon as possible. On the other hand, if the value of the project is below Y', which is also below Y (loss) by definition, the agent chooses to keep the project rather than liquidating it. This holds even if the agent fails to adjust the reference level. However, if the project's value is in between Y and Y', there is a clear difference between agents who accept the new reference $Y\prime$ and those who fail to do so. In the case where the agent fails to adjust the reference to Y', the value of the project is negative, and the agent prefers to postpone the realisation of losses rather than to liquidate the project. However, if the agent adjusts the reference to Y', the value of the project becomes positive, and the agent chooses to liquidate the project.

Recent empirical evidence recognises that the notion of a dynamic reference and its location are important factors in predicting the behaviour of an agent exhibiting risk aversion as suggested by the Prospect Theory. Gooding *et al.* (1996) evince that in the context of firms, their risk-taking behaviour depends upon the location of the reference point rather than merely the relative position of a firm to the reference point. They also find that the reference point moves in both directions, as a function of some sample estimate of the population properties (e.g. mean, max, median). Heath *et al.* (1999) show that the agent's decision to exercise a stock option depends on its maximum level attained during the past year. Ivkovic *et al.* (2007) find that an investment made by individual investors, both returns relative to the market and absolute performance matter in determining stock sales.

New information is constantly arriving in the carbon market, thus changing the price of carbon credits. The distinction, therefore, between static and dynamic evaluation is crucial. In this sense, an application of the dynamic reference in predicting the behaviour of a decision maker who holds a sustainable project seems natural. Failure to incorporate the dynamic reference may entail the wrong prediction of an agent's behaviour and in turn an inadequate policy design. In what follows I will consider a decision maker who invests in a CDM project to get extra credits to cover for its expected emission levels. Such an investor has an opportunity to purchase extra credits in the carbon market or by initiating CDM investment which can potentially award the investor with Certified Emission Reductions credits (CERs).[4] The evaluation of such projects is a function of the number of expected issued Certified Emission Reductions (CERs) credits by the end of the project and their price in the carbon market. The number of issued CERs is uncertain and depends on the actual emission reduction that will be generated. The profitability of such an investment opportunity is made against the price of credit allowances that can be purchased at one of the trading platforms over the counter (Schneider, 2008). I consider the initial value of the CDM project to be the expected number of issued CERs times their value in the carbon market, and the reference value for such a project is the equivalent value of carbon credits allowances.

Prospect Theory value function applied to investment decisions helps to explain an anomaly such as the Disposition effect (Kyle *et al.*, 2006). The authors, however, restrict their analytical framework only to one static reference level. The aim of this paper is to extend the

[4]For more details on the process of issuance visit the UNFCC cdm.unfc c.int

static framework into a dynamic one and suggest a generalised prediction of the behaviour of an agent under any reference, both static and dynamic. Unlike the static model, I assume that the reference level is an additional stochastic process. I define a new 'reference sensitive' project value Q, which is sensitive to the value of the reference project. I also show that there is a relation between the dynamic and static valuation frameworks. Specifically, the extended model detects that a decision maker who evaluates absolute performance can also evaluate the relative performance of the investment opportunity. This can explain different findings in the empirical literature regarding the location of a reference. As expected, in the extended model the liquidation decision depends on the relative risk and the returns of the reference portfolio with respect to risk and returns of the investment opportunity. Application of the extended framework to sustainable investments evinces that international co-operation and structured policy are the key to an efficient environmental policy.

The rest of the paper is organised as follows: Section 2 describes the dynamic model and its solution. The first part shows the evolution of the model and three behavioural strategies of a decision maker with dynamic reference, where one of the strategies is consistent with the relative Disposition effect. The second part presents a link between relative and absolute Disposition effects. In section 3, I demonstrate an application of the extended model to a risk averse agent in the environmental framework and discuss the implications of the model on policy analysis. Section 4 offers some conclusions; the appendix contains the proofs and developments.

3 The Model

I extend the Status Quo model to allow for a dynamic reference level in the liquidation decision. In contrast with the model of Kyle et al. (2006), I account for the dynamics in the reference level. I also account for the fact that the same relative gain/loss is evaluated differently at different reference levels. For instance, if the reference is 1 and the gain is 10, the relative gain is 10-1=9. However, in case the reference is 101 and the absolute gain is 110 the relative gain is also 9 (110-101), but the same gain is perceived differently at two reference levels. To account for this, I therefore construct a reference sensitive valuation. I define a new 'reference sensitive' project value $Q_t \equiv \frac{P_t}{R_t}$, where P_t is the value of a sustainable project which depends upon the number of CERs issued and their spot price in the carbon market, and R_t is the reference value of the project in which the agent breaks even. The reference value depends on the spot price of the emissions allowances instead. Both spot prices can be obtained at one of the environmental trading platforms. One of the most liquid platform for carbon trade is Blue Next.[5]

The agent receives the value P_t of the project upon its liquidation at time $\tau = min\,[\tau_1, \tau_2]$. The liquidation of the project is either voluntary at time τ_2 or at natural liquidation at time τ_1. Natural liquidation follows a Poisson distribution with arrival rate λ. A rejection of a CDM project's baseline and/or methodoligy can be considered as a natural liquidation event in the context of this framework.

I assume that the value of a sustainable project follows a Brownian motion $dP_t/P_t = \mu_P dt + \sigma_P dZ_t$ with constant parameters of drift μ_p and variance σ_p. The introduction of

[5] For details visit the website of Blue Next: http://www.bluenext.fr

a reference requires an additional structure. In the empirical literature there are several alternative measures for a dynamic reference. For instance, Heath *et al.* (1999) and Gooding *et al.* (1996) base the reference on limited past data of the population properties (e.g. mean, max or median). The author suggests that one year is an appropriate time period for the survival of the reference.[6] Ivkovic *et al.* (2007), on the other hand, measure the performance of the stock relative to its market performance since the purchase. In all of the mentioned studies, the reference adjusts throughout time. To capture the dynamics of the reference, I assume that its evolution follows a geometric Brownian motion $dR_t/R_t = \mu_R dt + \sigma_R dW_t$ with constant parameters of drift μ_R and variance σ_R. The assumption of the evolution of reference is general enough to nest all of the mentioned alternative measures of the reference. I assume that there exists a correlation between two Wiener processes, specifically, $corr(dZ_t, dW_t) = \rho$.

Upon the liquidation of the project agent realises his/her utility. Similarly to Kyle *et al.* (2006), I impose a piecewise exponential value function to evaluate the project:

$$u(Q_t) = \begin{cases} (1 - e^{-\gamma_1(\ln Q_t)}) \text{ if } Q_t \geq 1 \\ \phi_2(e^{\gamma_1(\ln Q_t)} - 1) \text{ if } 0 < Q_t < 1 \end{cases} \quad (1)$$

The value function (1) satisfies the following assumptions:

A1 An index of loss aversion $\phi_2 > 1$;

A2 Local absolute risk aversion is $\gamma_1 > 1$;

A3 $u'(1+) < u'(1-)$ so that $\gamma_1 < \phi_2\gamma_1$;[7]

[6]In some cases, however, the whole historical data is taken, for example in the case of high watermarks where the hedge fund manager receives an incentive fee when the fund value is above the previous maximum.

[7]See Kobberling and Wakker (2005) for a detailed interpretation of parameter ϕ_2, which can represent

A4 Value function is smooth in the continuation region.[8]

Assumption $A1$ ensures that the value function has a steeper curve in the region of gains. Assumptions $A2$, together with $A3$, ensure that the value function satisfies the properties of the Prospect Theory value function, with more sensitivity to losses than to gains, in addition to convexity below the reference. Using Ito's Lemma, the dynamic path of Q_t is:

$$dQ = \{\sigma_P dZ - \sigma_R dW + (\mu_P - \mu_R + \sigma_R^2 - \sigma_P \sigma_R \rho)dt\}Q_t \tag{2}$$

The drift of process Q_t is:

$$\mu_Q \equiv \mu_P - \mu_R + \sigma_R^2 - \sigma_P \sigma_R \rho$$

and the variance of process Q_t is:

$$\sigma_Q \equiv (\sigma_P^2 + \sigma_R^2 - 2\sigma_P \sigma_R \rho) \tag{3}$$

To maximise (1), agents choose an optimal liquidation time τ_2 that maximises the expected value function:

$$V(Q_t) = \max_{Q_t} \mathbb{E}[u(Q_t)]$$

Following the static framework of Kyle *et al.* (2006), I set the time discount rate in the value function to zero. The optimal stopping time problem above can be written as:

$$V(Q_t) = \max_{Q} \{u(Q_t),\ \lambda dt[u(Q_t) - V(Q_t)] + \mathbb{E}[V(Q_t + dQ) \mid Q_t]\} \tag{4}$$

the risk aversion at the reference and set equal to $\phi_2 = \frac{u'_+(1)}{u'_-(1)}$.

[8]It is possible due to the fact that the value function is a transformation of smooth functional form, both below and above the reference level.

The function represented by Equation (4) is the maximisation between the value from liquidating immediately $u(Q_t)$, and the value of postponing the liquidation $\lambda dt[u(Q_t) - V(Q_t)] + \mathbb{E}[V(Q_t + dQ) \mid Q_t]$. $A4$ assures that $V(Q_t)$ is a smooth function. I use Ito's Lemma to derive the differential equation of $V(Q_t)$. First, I evaluate the value function $V(Q_t)$ over the period of $(t,\, t + dt)$ by Taylor expansion:

$$\mathbb{E}(dV) = V_Q Q \mu_Q dt + \frac{1}{2} V_{QQ} Q^2 \sigma_Q dt \tag{5}$$

I denote F_x to be derivative of function F with respect to a variable x. If the project is not liquidated voluntarily, putting together (5) and (4) I get the following expression:

$$V_Q Q \mu_Q + \frac{1}{2} V_{QQ} Q^2 \sigma_Q - \lambda V + \lambda u = 0 \tag{6}$$

I can identify that (6) consists of a *homogeneous* part $V_Q Q \mu_Q + \frac{1}{2} V_{QQ} Q^2 \sigma_Q - \lambda V$ and a *non-homogenous* part λu. First, I solve its homogeneous part.

$$V_Q Q \mu_Q + \frac{1}{2} V_{QQ} Q^2 \sigma_Q - \lambda V = 0 \tag{7}$$

The solution of (7) has the following form:

$$V^+(Q_t) = A_1 Q_t^{\alpha_1} + B_1 Q_t^{\alpha_2} \tag{8}$$

$$V^-(Q_t) = A_2 Q_t^{\alpha_1} + B_2 Q_t^{\alpha_2} \tag{9}$$

where V^+ stands for the value function above and V^- below the reference, and

$$\alpha_1 = \frac{\frac{1}{2}\sigma_Q - \mu_Q + \sqrt{(\mu_Q - \frac{1}{2}\sigma_Q^2)^2 + 2\lambda\sigma_Q}}{\sigma_Q^2} > 0,$$

$$\alpha_2 = \frac{\frac{1}{2}\sigma_Q - \mu_Q - \sqrt{(\mu_Q - \frac{1}{2}\sigma_Q^2)^2 + 2\lambda\sigma_Q}}{\sigma_Q^2} < 0.$$

In order to find the solution to the value function $V(Q_t)$, I proceed to the specific solution of a non-homogenous part.

3.1 Solution of a non-homogeneous part

Proposition 1 *Denote by* $S \equiv \frac{\mu_Q}{\sigma_Q^2}$ *the relative Sharpe ratio of the project. Under (1),*

$$(a)\ \textit{If}\ Q_t \geq 1,\ \mathbb{E}(du(Q_t)) = \begin{cases} \geq 0 & \textit{if}\ \ S > \frac{1}{2}\gamma_1 + \frac{1}{2} \\ < 0 & \textit{otherwise.} \end{cases}$$

$$(b)\ \textit{If}\ 0 < Q_t < 1,\ \mathbb{E}(du(Q_t)) = \begin{cases} \geq 0 & \textit{if}\ \ S > -\frac{1}{2}\gamma_1 + \frac{1}{2} \\ < 0 & \textit{otherwise.} \end{cases}$$

The implication of the proposition is that if the value function is expected to increase over time, an agent would never liquidate the project voluntarily. However, if the value function is expected to decrease, an agent would liquidate the project immediately as the value of holding the project is decreasing.

In order to analyse the optimal strategy I adopt a similar method presented by Kyle *et al.* (2006). First, I restrict the value function to be smooth when $Q_t = 1$. Imposing this condition I achieve that at each reference, the agent is indifferent about whether to liquidate or not liquidate the project. This assists me in determining the optimal behaviour of an agent. I set the value function from never liquidating to the expected value function u:

$$V_0(Q_t) = \mathbb{E}[u(Q_{t+\tau_1})] \tag{10}$$

Function V_0 indicates that an agent holding the project would not liquidate it voluntary, unless the expected value from holding the projected is expected to decrease in the future. For tractability of the proof I impose that at each reference point the value function has a value of zero. It is a simplifying assumption to make the calculation easier. Formally I impose

$$\lim u(1) = 0$$

This can be interpreted as the condition where the agent derives no utility from the project. Unlike the static framework, a liquidation decision of a project in a dynamic framework not only depends on the project's statistical values but also on the values of the reference and its correlation with the value of the project ρ. These additional parameters are an important addition to the static framework. It is possible to verify that the dynamic framework works down to the static framework if the reference is set to a constant parameter, specifically, $R = 1$. In the following analysis of an agent's liquidation strategy there are 3 different cases to consider. Prior to each case specification, I summarise it in proposition.

Proposition 2 *If the Sharpe ratio is* $S > \frac{1}{2}\gamma_1 + \frac{1}{2}$ *and* $V_0(1) > u(1) = 0$, *then* $V(Q_t)$ *is increasing in* Q_t *and represented by:*

$$V_0(Q_t) = \begin{cases} \frac{\phi_2 C_2 \gamma_1 - C_1\gamma_1 - \phi_2(C_2-1)\alpha_1 - (C_1-1)\alpha_1}{\alpha_2-\alpha_1} Q_t^{\alpha_2} + 1 - C_1 e^{-\gamma_1(\ln Q_t)} & \text{if } Q_t \geq 1 \\ \frac{\phi_2 C_2 \gamma_1 - C_1\gamma_1 - \phi_2(C_2-1)\alpha_2 - (C_1-1)\alpha_2}{\alpha_2-\alpha_1} Q_t^{\alpha_1} + \phi_2(C_2 e^{\gamma_1(\ln Q_t)} - 1) & \text{if } 0 < Q_t < 1 \end{cases} \tag{11}$$

where

$$\begin{aligned} C_1 &= \frac{\lambda}{\gamma_1\mu_Q - \frac{1}{2}(\gamma_1^2 + \gamma_1)\sigma_Q + \lambda} \\ C_2 &= \frac{\lambda}{\lambda - \{\gamma_1\mu_Q + \frac{1}{2}(\gamma_1^2 - \gamma_1)\sigma_Q\}} \end{aligned}$$

Case 1: According to proposition 1, the relative Sharpe ratio of the project is high enough to compensate the agent for the risk for any relative value Q_t of the project. In addition, the value function (10)is expected to increase over time. In this case an agent has no incentive to liquidate the project voluntarily. When the relative value of the project is $Q_t = 1$ (where the project breaks even), the value of keeping the project ($V_0(1)$)is higher than liquidating it ($u(1)$). Therefore, the agent is better off by keeping the project and (11) >) is the value function from never liquidating the project voluntarily.

Proposition 3 *If the Sharpe ratio is $S > \frac{1}{2}\gamma_1 + \frac{1}{2}$ and $V_0(1) < u(1) = 0$, then $V(Q_t)$ is increasing in Q_t and represented by:*

$$V(Q_t) = \begin{cases} -(1-C_1)Q_t^{\alpha_2} + 1 - C_1 e^{-\gamma_1(\ln Q_t)} \text{ if } Q_t \geq 1 \\ -\phi_2(C_2-1)Q_t^{\alpha_1} + \phi_2(C_2 e^{\gamma_1(\ln Q_t)} - 1) \text{ if } 0 < Q_t < 1. \end{cases} \tag{12}$$

and

$$V_Q^+(1) - V_Q^-(1) = (\alpha_1 - \alpha_2)V_0(1) < 0 \tag{13}$$

Case 2: According to proposition 1, and similarly to case 1, the relative Sharpe ratio is high enough to compensate the agent for the risk for any value of $Q_t \neq 1$ ((the project does not break even). However, if the project's relative value of the project is $Q_t = 1$ the agent would choose to liquidate the project as the sensitivity of the agent toward losses is higher than to gains around the reference. The latter conclusion results from the difference between slopes around reference ($Q_t = 1$) and represented by (13).

Proposition 4 *If the Shrape ratio is $-\frac{1}{2}\gamma_1 + \frac{1}{2} < S \leq \frac{1}{2}\gamma_1 + \frac{1}{2}$ and $V_0(1) < u(1) = 0$, then*

$V(Q_t)$ is increasing in Q_t and represented by:

$$V(Q_t) = \begin{cases} 1 - e^{-\gamma_1(\ln Q_t)} \; \textit{if} \; Q_t \geq 1 \\ -\phi_2(C_2 - 1)Q_t^{\alpha_1} + \phi_2(C_2 e^{\gamma_1(\ln Q_t)} - 1) \; \textit{if} \; Q_t < 1. \end{cases} \tag{14}$$

and

$$V_Q^-(1) - V_Q^+(1) = (\alpha_2 - \alpha_1)V_0(1) > 0 \tag{15}$$

Case 3: According to proposition 1, the relative Sharpe ratio of the project is not high enough to compensate the agent for the risk if its relative value is $Q_t \geq 1.$. The agent would, therefore, choose to liquidate the project. Otherwise, the agent would choose to keep the project until its relative value is set to $Q_t = 1$. As (15) points out, the sensitivity of the agent towards gains is higher than to losses around the reference, therefore, the agent would liquidate the project when it breaks even.

3.2 Absolute and relative dispositions

Financial literature provides strong evidence supporting the Prospect Theory valuation and the Disposition effect. There is, however, no consensus among scholars regarding what the appropriate reference should be. Odean (1998) presents evidence of the Disposition effect based on absolute returns. Godding *et al.* (1996), on the other hand, find strong evidence for a dynamic reference and reject the existence of any fixed reference in the context of firms' risk taking behaviour. Heath *et al.* (1999), find evidence for a dynamic reference in the context of exercising stock options. Ivkovic *et al.* (2005), however, find that stock purchases made by individual investors are driven by both absolute and relative valuations. In light of this extensive evidence, I argue that there exists a relation between the two frameworks.

To do so, I draw attention to Proposition 4. It states that under certain conditions an agent exhibits a relative Disposition effect. In particular, agents choose to liquidate the project when it has relative gains and postpone the liquidation if it has relative losses. I argue that if agents exhibit an absolute Disposition on the project and its reference, then they would also exhibit a relative Disposition effect. I summarise it in the following proposition:

Proposition 5 *Denote by* $v_P \equiv \frac{\mu_P}{\sigma_P^2}$ *and* $v_R \equiv \frac{\mu_R}{\sigma_R^2}$ *absolute Sharpe ratios of a project and its reference, respectively. If under (1),* $-\frac{1}{2}\gamma_1 + \frac{1}{2} < \nu_P < \frac{1}{2}\gamma_1 + .\frac{1}{2}$; $-\frac{1}{2}\gamma_1 + \frac{1}{2} < \nu_P < \frac{1}{2}\gamma_1 + .\frac{1}{2}$ *and* $\rho \leq 0$, *then* $-\frac{1}{2}\gamma_1 + \frac{1}{2} < S \leq \frac{1}{2}\gamma_1 + \frac{1}{2}$.

The proposition suggests that there might be cases of absolute, relative and combined Disposition effects. It can, therefore, explain the variety of empirical evidence which is not conclusive of what the appropriate reference should be. Although the conditions of Proposition 5 are restricted to the case where projects and their references complement investment opportunities, the result is very important in understanding the risk perception of decision makers under valuation with reference.

4 Disposition and sustainable development

Insley (2003) suggests that the riskiness of sustainable projects plays a vital role in the incentives of undertaking emissions reduction projects. Furthermore, Schneider (2008) argues that the profitability of a sustainable project, such as the Clean Development Mechanism, is evaluated against the profitability of holding carbon allowances. In addition, an empirical analysis presented in part 3 of this thesis points to the evidence of a dynamic disposition effect which affects the spot price of carbon alowances. The analysis there is based on the intra-daily data of carbon spot prices which are obtained at the BlueNext environmental exchange platform.[9]

The later evidence together with the fact that the value of carbon allowances and sustainable projects are in constant shift, makes application of the above relative valuation framework suitable for the analysis of such investment opportunities. Among all the results provided in the previous section, Proposition 4 seems the most suitable for such an analysis, as it detects the well-documented Disposition effect. Conducting such analysis could lead policy makers to a better understanding of decision-making dynamics in the context of sustainable development projects. This analysis would improve the efficiency of environmental policies and give a more accurate guidance to policy makers about measures to be taken to create incentives in favour of sustainable projects. In what follows, I discuss firstly the way that the Disposition effect is eliminated using the framework of Proposition 4, where I detect such an effect. Secondly, I apply this framework to the analysis of decision-making dynamics in the context of sustainable development projects, such as the CDM.

4.1 How to eliminate disposition

According to Proposition 4, decision makers who exhibit relative Disposition evaluate the profitability of holding a project according to the following inequality

[9]For more details see part 3 of the thesis.

$$\mu_P - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 \;\leq\; \mu_R - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 - \gamma_1\sigma_P\sigma_R\rho \tag{16}$$

$$\mu_P - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 \;>\; \mu_R - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 + \gamma_1\sigma_P\sigma_R\rho \tag{17}$$

where P and R are the values of a project and its reference portfolio, respectively. By assumption **A2**, $(-\frac{1}{2}\gamma_1 + \frac{1}{2}) < 0$ and $(\frac{1}{2}\gamma_1 + \frac{1}{2}) > 0$. Conditions of (16) therefore, suggest that it is not enough to reduce the risk of the project (σ_P^2) to eliminate the Disposition effect. To do so, one should reduce the risk of the project so that its risk would be relatively lower than the risk of the reference portfolio. Technically, the inequalities (16) should become

$$\mu_P - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 > \mu_R - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 - \gamma_1\sigma_P\sigma_R\rho \tag{18}$$

Inequality (18) satisfies Proposition 3, which gives decision makers an incentive to keep the project rather than liquidating it. Proposition 5, however, points to an additional difficulty. It is possible that decision makers holding the project exhibit both relative and absolute Disposition effects. In this case, it is not enough to reduce the relative riskiness of the project. It is also necessary to ensure that the riskiness of a project is low enough to eliminate both relative and absolute Disposition effects.

4.2 Application

As I mention above, a sustainable project (such as the CDM project) is evaluated against the profitability of holding carbon allowances. In what follows, I, therefore, denote sustainable project and carbon portfolio absolute values to be P and R, respectively. The desired goal of eliminating the Disposition effect in the context of sustainable projects can be achieved in two ways. One is to reduce the absolute risk of the project, σ_P^2, by the CDM host country. Another is to reduce the riskiness of the reference portfolio, σ_R^2, by the domestic policy maker. In order to do that, the policy maker should understand the source of such risks.

Schneidler (2008) suggests that agents' incentives of holding sustainable projects lie within the riskiness of these projects. These projects are often characterised by high risks and uncertainties. Springer (2003) outlines the potential sources of the risks involved in such projects. Among them:

Technological risk: The final allocation of credits to the entrepreneur is a function of the actual emission reduction in the host country. Delays or actual output reduction of factories in the host country, therefore, result in fewer emissions reductions than actually planed. As a result, the entrepreneurs receive fewer credits than was originally planned.

Economic risk: In addition to the technological risks, the entrepreneur is exposed to the economic factors that affect any investment opportunity. Interest rates, exchange rates and the price of foreign land are among the factors that can have a major impact on the riskiness of the sustainable project.

Political risk: The Kyoto protocol restricts the CDM mechanism to be implemented in developing countries. These countries are often characterised by restrictive regulations and political instability. These factors contribute to the already existing uncertainty surrounding these projects and have the potential of increasing the riskiness of such projects.

Investment opportunities usually incorporate some sort of risk. Technological risks are among them. Therefore, it is up to the entrepreneur of such projects to deal with these risks by all means available. One of the accustomed ways of reducing riskiness of investment is by a way of diversification. Enterpreneurs wanting to achieve a cheaper alternative to domestic emission reductions should face the risk as any entrepreneur undertaking a risky investment opportunity. Political risk, however, is the real market failure that may hinder involvement of the private sector in the emission reduction investments. These are risks that private entrepreneurs cannot change by their own behavior and fully diversify. Policy makers should aim at eliminating those unnecessary risks.

The risk classification above is not a clear cut and there are areas in which the categories can overlap. For instance, economic risk can be viewed differently by enterpreneurs and policy makers. For example, as shown by Springer (2003), the profitabilty of a CDM project that aims to increase efficieny in the electricity sector in a host country is affected by the demand for energy in the host country. However, the demand for energy also depends on the regulation in the sector in the host country. Whereas the entrepreneur can view the later as a political risk, the policy maker, on the other hand would classify such risk as an economic risk. In such a scenario, no actions should be taken by the policy maker as this is the kind of risk that international entrepreneurs are faced with.

It is worth noting at this point that emissions reduction projects, such as CDMs, should not be classified as a pure financial investments, as they bring with elements that are outside pure economic benefits but also benefits to the society in a way of promoting a sustainable development and technologic spillovers, that would not happen otherwise. In such framing it is not clear whether policy makers should remain indifferent players in the face of economic risks. In what follows I describe the way the policy makers could address these issues.

The carbon concentration in the atmosphere is a global problem and not restricted by geographical borders. It is, therefore, in the global interest to encourage measures that have the potential for reducing emissions in areas where such measures are likely to contribute more on a marginal basis. Clean Development Mechanism, have a direct impact of achieving the efficient reduction of carbon emissions globally through economic incentives and contributing to valuable technology transfer through investments in sustainable projects in developing countries by foreign entrepreneurs. In the long term CDM projects are changing the course of development in the host countries through a valuable technology transfer and potential spillovers. These factors have the potential of reducing the current carbon footprint in the developing world and also contribute to sustainable development in the future.[10] As of April 2010 UNFCC reports that more than 4,200 projects are in the pipeline. These projects could potentially generate more than 2,900 millions of CERs by 2012. Out of them 2,128 project are currently registered and 72 projects requesting registration by the CDM Executive Board. So far, there are 399,861,040 of issued CERs and 406,752,157 requesting an issuance. Many of the projects will continue to operate well beyond 2012 and are expected to generate an estimated of 6,484,807 GtonCO_2 by 2030. The methodology that prevails in the CDM is the energy industry constituing 27.62% of the approved methodology by scope. As of March 2010 Hydro Power and Wind Power are the leading sources for the total number of CDM projects registration with 561 and 296, respectively. However, judging from the scope of total emission reductions, HFC reductions and N_2O decomposition are responsible for the majority of emission reductions with 484,567 and 252,268 GtonCO_2 emission reductions,

[10]For discussion on the sustainable effect of CDM projects see Olsen, 2007.

respectively. [11][12]

It is evident that structured regulations are one of the ways of eliminating unnecessary risks. Empirical evidence shows that host countries which have structured regulations on Kyoto-related institutions, attract most of the investment from the developed countries (Oleschak et al., 2007). Countries such as China, India, Brazil and Mexico so far have registered 36.97%, 23.39%, 8.03% and 5.64% of total registered CDM projects. Also in terms of expected annual average of CERs the situation is similar. China, India and Brazil are leading with 59.42%, 11.98% and 5.96% of total annual reduction from CDM projects. Structured regulations can contribute to boosting local sustainable technology and reducing substantively the emissions in those regions. Fast growing economies, such as those of China and India, are also rapidly increasing their carbon footprint. It is, therefore, not enough to adhere to the targets set up by the developed countries, such as those in the EU, to eliminate the potential threat of global warming. More structured measures, involving international co-operation, should be implemented.

Another aspect of the successful emissions reduction is in international co-operation. International co-operation is the key to the successful implementation of any sustainable policy. Separate actions of host and domestic countries of the entrepreneurs require substantial effort from both sides to achieve emissions reduction targets. This important factor could, potentially, create a situation similar to the prisoner's dilemma, where neither side would be willing to reduce domestic emissions. This is very similar to the current situation, where

[11] Much of the critism was pointed on the sustainability of CERs originated from Hydroplants and HCF CDM projetcs. For an example of the criticism on the HFC methodology see Schwank, 2004.

[12] For more details visit: http://www.iges.or.jp/cdm/report_cdm.html

developing countries are not willing to reduce their emissions; whereas developed countries are reluctant to credit the investors for potential emissions reduction in host countries and investors are, therefore, not willing to invest. This scenario is not desirable. International co-operation can eliminate these obstacles more effectively. Co-operative efforts can eliminate the riskiness of the projects. According to my framework above, these steps would diminish Disposition both by incurring lower costs and using the comparative advantage of each economy in tackling this issue. As changes in regulation have an effect on the risk structure in the market (Grout *et al.*, 2006), the transparency of domestic (Nondek *et al.*, 2005) and foreign policies is the way of reducing the riskiness of these investment opportunities (IPCC, 2000).

5 Conclusion

This paper extends the static framework of liquidation decisions, first presented by Kyle *et al.*, 2006. I have constructed a new relative valuation which is reference sensitive. I have incorporated dynamics of reference in the decision and show that in this framework, decision makers can also exhibit the Disposition effect, found in many empirical studies. I have showed that there is a relation between the Disposition decision in static and dynamic frameworks. I have applied a decision making under dynamic reference to the liquidation decision of sustainable projects, such as the CDM. I have showed that the behavioural pattern with dynamic reference can play a major role in the implementation of the environmental policy. I have evinced that dynamic reference can play a role in the investment decisions and thus has to be taken into account by policy makers in implementing policy in constantly changing settings such as environmental projects. I have argued that international co-operation is the key to the successful implementation of sustainable developments. This argument is in line with a proposition made by Barret (2007). Barrat argues that successful provision of global public goods such as environmental protection cannot be acheived by the sole, even powerfull country. According to the author, countries need to cooperate on implementing mechanisms such as CDMs. The key issue in success of such mechanism is in the enforcement. Strong enforcement can only be acheived, according to the author, by incentive oriented international cooperation.

A possible extension to the framework would be to incorporate different types of risk aversion at different reference levels. So far, the literature deals with a single reference. However, introducing dynamics to the reference can pose some doubt as to the assumption of unified risk aversion at the reference. Köbberling and Wakker (2005) assumed that risk aversion at the reference set equal to $\frac{u'_+(1)}{u'_-(1)}$, which is the ratio of marginal utilities around reference. However, one could think of different risk aversion at different reference. It is similar to the situation of different valuation of the equal absolute gain/loss. For instance, when considering reference of 10 and 1000 it is not necessary that $\frac{u'_+(10)}{u'_-(10)} = \frac{u'_+(1000)}{u'_-(1000)}$, as the decision maker would be more sensitive to changes in gain/loss around reference of 10 than to the same change around reference of 1000. Although it is an interesting idea, it is beyond the scope of this paper. It shows, however, a promising way of extending the current framework of decision making under dynamic valuation.

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6 Appendix A

Appendix A.1 Derivations

A.1.1 Properties of a piecewise function (1)

First, I derive the shape of the value function when $Q_t \geq 1$:

$u_Q = \gamma_1 \frac{1}{Q_t} e^{-\gamma_1(\ln Q_t)} > 0$

$u_{QQ} = \gamma_1(-\frac{1}{Q_t^2} e^{-\gamma_1(\ln Q_t)} - \frac{1}{Q_t^2}\gamma_1 e^{-\gamma_1(\ln Q_t)}) < 0.$

satisfying the properties of a concave function.

The shape of the value function when $0 < Q_t < 1$:

$u_Q = \phi_2 \gamma_1 \frac{1}{Q_t} e^{\gamma_1(\ln Q_t)} > 0$

$u_{QQ} = \phi_2\gamma_1(-\frac{1}{Q_t^2} e^{\gamma_1(\ln Q_t)} + \frac{1}{Q_t^2}\gamma_1 e^{\gamma_1(\ln Q_t)}) > 0$

$iff\ \gamma_1 > 1.$

satisfying the properties of a convex function.

A.1.2 The dynamics of (2)

First I define the partial derivatives of Q with respect to P_t and R_t:

$$Q_P = \frac{1}{R}; Q_R = -\frac{P}{R^2}; Q_{PR} = -\frac{1}{R^2}; Q_{PP} = 0; Q_{RR} = \frac{2P}{R^3} \tag{19}$$

using Ito's Lemma, I derive the evolution of Q

$$dQ = Q_P dP + Q_R dR + 1/2 Q_{PP} d^2P + 1/2 Q_{RR} d^2 R + Q_{PR} dPdR \tag{20}$$

putting together (19) and (20) results in:

$$= Q_P(\mu_P dt + \sigma_P dZ_t)P + Q_R(\mu_R dt + \sigma_R dW_t)R + 1/2 Q_{PP} P^2 {\sigma^2}_P dt + 1/2 Q_{RR} R^2 {\sigma^2}_R dt + Q_{PR} PR \sigma_P \sigma_R \rho dt \tag{21}$$

- putting together (19) and (21) results in:

$$= \frac{1}{R}P\sigma_P dZ_t - \frac{P}{R^2}R\sigma_R dW_t + (\frac{1}{R}P\mu_P - \frac{P}{R^2}R\mu_R + 1/2\frac{2P}{R^3}R^2\sigma^2{}_R - \frac{1}{R^2}PR\sigma_P\sigma_R\rho)dt$$

rearranging

$$= \{\sigma_P dZ - \sigma_R dW + (\mu_P - \mu_R + \sigma_R^2 - \sigma_P\sigma_R\rho)dt\}Q$$

A.1.3 The optimal stopping of (4)

$$\begin{aligned} V(Q_t) &= \max_{Q_t}\{u(Q_t),\ \lambda u(Q_t)dt + (1-\lambda dt)\mathbb{E}[V(Q_t+dQ) \mid Q_t]\} \\ &= \max_{Q_t}\{u(Q_t),\ \lambda u(Q_t)dt - \lambda dt\mathbb{E}[V(Q_t+dQ) \mid Q_t] + \mathbb{E}[V(Q_t+dQ) \mid Q_t]\} \\ &= \max_{Q_t}\{u(Q_t),\ \lambda dt[u(Q_t) - V(Q_t)] + \mathbb{E}[V(Q_t+dQ) \mid Q_t]\} \end{aligned}$$

A.1.4 The Taylor expansion of (5)

$$\begin{aligned} E(dV) &= \mathbb{E}\left\{V_Q dQ + \frac{1}{2}V_{QQ}(dQ)^2\right\} \\ &= \mathbb{E}\left\{V_Q[Q\sigma_P dZ - Q\sigma_R dW + Q\mu_Q dt] + \frac{1}{2}V_{QQ}(Q\sigma_P dZ - Q\sigma_R dW)^2\right\} \\ &= V_Q Q\mu_Q dt + \frac{1}{2}V_{QQ}Q^2(\sigma_P^2 + \sigma_R^2 - 2\sigma_P\sigma_R\rho)dt \end{aligned}$$

A.1.5 Solution of the homogeneous part of (7)

Noting that (7) has a standard solution of the $V(Q_t) = AQ_t^\alpha$ form, I define its derivatives in the following fashion:

$$\begin{aligned} V_Q &= A\alpha Q^{\alpha-1} \qquad (22) \\ V_{QQ} &= A\alpha(\alpha-1)Q^{\alpha-2} \end{aligned}$$

putting together (22) and (7) results in:

$$\frac{1}{2}(\sigma_Q^2)Q_t^2 A\alpha(\alpha-1)Q_t^{\alpha-2} + \mu_Q Q_t A\alpha Q_t^{\alpha-1} - \lambda A Q_t^{\alpha} = 0$$

dividing both sides by AQ^{α} gives way to:

$$\frac{1}{2}\sigma_Q^2\alpha(\alpha-1) + (\mu_Q)\alpha - \lambda = 0 \tag{23}$$

The solutions to $(A5)$ are:

$$\begin{aligned}
\alpha_1 &= \frac{\frac{1}{2}\sigma_Q^2 - \mu_Q + \sqrt{(\mu_Q - \frac{1}{2}\sigma_Q^2)^2 + 2\lambda\sigma_Q^2}}{\sigma_Q^2} > 0, \\
\alpha_2 &= \frac{\frac{1}{2}\sigma_Q^2 - \mu_Q - \sqrt{(\mu_Q - \frac{1}{2}\sigma_Q^2)^2 + 2\lambda\sigma_Q^2}}{\sigma_Q^2} < 0.
\end{aligned}$$

Appendix A.2 Proofs

B.1 Proof of Proposition 1

(a) First and second order derivatives of $u(Q_t)$:

$$u_Q = \gamma_1 \frac{1}{Q_t} e^{-\gamma_1(\ln Q_t)};\ u_{QQ} = (-\gamma_1^2 \frac{1}{{Q_t}^2} - \gamma_1 \frac{1}{{Q_t}^2})e^{-\gamma_1(\ln Q_t)} \tag{24}$$

using Ito's Lemma:

$$\mathbb{E}(du(Q_t)) = \mathbb{E}\{u_Q dQ_t + \frac{1}{2}u_{QQ} d^2 Q_t\} \tag{25}$$

putting together (24) and (25):

$$= \{\gamma_1 \frac{1}{Q_t} Q_t \mu_Q + \frac{1}{2}[-\gamma_1^2 \frac{1}{Q_t^2} - \gamma_1 \frac{1}{Q_t^2}] {Q_t}^2 \sigma_Q^2\} e^{-\gamma_1(\ln Q_t)} dt$$

then rearranging:

$$\mathbb{E}(du(Q_t)) = \gamma_1 \{\mu_Q - \frac{1}{2}\gamma_1 \sigma_Q^2 - \frac{1}{2}\sigma_Q^2\} e^{-\gamma_1(\ln Q_t)} dt.$$

(b) In a similar fashion:

$$u_Q = \phi_2 \gamma_1 \frac{1}{Q_t} e^{\gamma_1(\ln Q_t)}; u_{QQ} = (\phi_2 \gamma_1 \frac{1}{Q_t^2} - \phi_2 \gamma_1 \frac{1}{Q_t^2}) e^{\gamma_1(\ln Q_t)} \tag{26}$$

putting together (25) and (26):

$$= \{\phi_2 \gamma_1 \frac{1}{Q_t} Q_t \mu_Q + \frac{1}{2}[\phi_2 \gamma_1 \frac{1}{Q_t^2} - \phi_2 \gamma_1 \frac{1}{Q_t^2}] {Q_t}^2 \sigma_Q^2\} e^{\gamma_1(\ln Q_t)} dt$$

then rearranging:

$$\mathbb{E}(du(Q_t)) = \phi_2 \gamma_1 \{\mu_Q + \frac{1}{2}\gamma_1 \sigma_Q^2 - \frac{1}{2}\sigma_Q^2\} e^{\gamma_1(\ln Q_t)} dt$$

A.2.1 Proof of Proposition 2

I impose on the value function $V(Q_t)$ to satisfy the following boundary conditions: (a) $\lim V_{Q\to\infty}(Q_t) = 1$ and (b) $\lim V_{Q\to 0}(Q_t) = -\phi_2$. These conditions assure that the value function is

bounded. I also impose on $V(Q_t)$ to have a smooth and continuous passing at each reference. Mathematically, I impose (c) $\lim V^+(1) = \lim V^-(1)$ and (d) $\lim V_Q^+(1) = \lim V_Q^-(1)$.

Therefore the following must hold:

$$\text{(a) } \lim V(\infty) = 1 \Rightarrow A_1 = 0 \tag{27}$$

$$\text{(b) } \lim V(0) = -\phi_2 \Rightarrow B_2 = 0$$

$$\begin{aligned} \text{(c) } \lim V^+(1) &= \lim V^-(1) \\ B_1 Q_t^{\alpha_2} + 1 - C_1 e^{-\gamma_1(\ln Q_t)} &= A_2 Q_t^{\alpha_1} + \phi_2(C_2 e^{\gamma_1(\ln Q_t)} - 1) \\ B_1 + 1 - C_1 &= A_2 + \phi_2(C_2 - 1) \\ B_1 &= A_2 + \phi_2(C_2 - 1) + C_1 - 1 \end{aligned} \tag{28}$$

$$\text{(d) } \lim V_Q^+(1) = \lim V_Q^-(1)$$

which is equivalent to:

$$\frac{B_1 \alpha_2 Q_t^{\alpha_2} + C_1 \gamma_1 e^{-\gamma_1(\ln Q_t)}}{Q_t} = \frac{A_2 \alpha_1 Q_t^{\alpha_1} + \phi_2 \gamma_1 C_2 e^{\gamma_1(\ln Q_t)}}{Q_t} \tag{29}$$

when $Q_t = 1$, (29) becomes:

$$B_1 \alpha_2 + \gamma_1 C_1 = A_2 \alpha_1 + \phi_2 \gamma_1 C_2$$

putting together (28) and (29):

$$(A_2 + \phi_2(C_2 - 1) + C_1 - 1)\alpha_2 + \gamma_1 C_1 = A_2 \alpha_1 + \phi_2 \gamma_1 C_2 \tag{30}$$

rearranging (30)

$$A_2 = \frac{\phi_2 C_2 \gamma_1 - C_1 \gamma_1 - \phi_2(C_2 - 1)\alpha_2 - (C_1 - 1)\alpha_2}{\alpha_2 - \alpha_1}$$

In a similar fashion:

$$B_1 = \frac{\phi_2 C_2 \gamma_1 - C_1\gamma_1 - \phi_2(C_2-1)\alpha_1 - (C_1-1)\alpha_1}{\alpha_2 - \alpha_1}$$

Proof of Proposition 3

I impose on the value function $V(Q_t)$ to satisfy the following boundary conditions: (a) $\lim V(\infty) = 1$ and (b) $\lim V(0) = -\phi_2$. These conditions assure that the value function is bounded. Therefore, (27) must hold. I also impose on $V(Q_t)$ to be continuous. Mathematically, I impose (c) $\lim V^+(1) = \lim V^-(1) = 0$. Then,

$$\begin{aligned} V^+(1) &= B_1 Q^{\alpha_2} + 1 - C_1 e^{-\gamma_1(\ln Q)} = 0 \\ B_1 &= -(1-C_1) \end{aligned} \tag{31}$$

and

$$\begin{aligned} V^-(1) &= B_2 Q^{\alpha_1} + \phi_2(C_2 e^{\gamma_1(\ln Q)} - 1) = 0 \\ B_2 &= \phi_2(1-C_2); \end{aligned} \tag{32}$$

The derivative of $V(Q)$ with respect to Q :

$$\begin{aligned} V_Q^+(1) &= \frac{-(1-C_1)\alpha_2 Q^{\alpha_2} + C_1\gamma_1 e^{-\gamma_1(\ln Q)}}{Q} \\ V_Q^-(1) &= \frac{-\phi_2(C_2-1)\alpha_1 Q^{\alpha_1} + \phi_2 C_2 \gamma_1 e^{-\gamma_1(\ln Q)}}{Q} \end{aligned} \tag{33}$$

when $Q = 1$, (33) becomes

$$\begin{aligned} V_Q^+(1) &= -(1-C_1)\alpha_2 + C_1\gamma_1 \\ V_Q^-(1) &= -\phi_2(C_2-1)\alpha_1 + \phi_2 C_2 \gamma_1 \end{aligned}$$

and their difference is

$$V_Q^+(1) - V_Q^-(1) = -(1 - C_1)\alpha_2 + C_1\gamma_1 + \phi_2(C_2 - 1)\alpha_1 - \phi_2 C_2\gamma_1 = (\alpha_1 - \alpha_2)V_0(1) < 0$$

Proof of Proposition 4

I impose on the value function $V(Q)$ to satisfy the following boundary conditions (a) $\lim V(0) = -\phi_2$. This condition assures that the value function is

bounded.

$$\lim V(0) = -\phi_2 \Rightarrow A_2 = 0;$$

I also impose on $V(Q)$ to be continuous. Mathematically, I impose (c) $\lim V^+(1) = \lim V^-(1) = 0$. Therefore, (32) is satisfied. In addition, the derivative of $V(Q)$ with respect to Q:

$$\begin{aligned} V_Q^+(Q_t) &= \gamma_1 e^{-\gamma_1(\ln Q_t)} \\ V_Q^-(Q_t) &= \frac{-\phi_2(C_2 - 1)\alpha_1 Q_t^{\alpha_1} + \phi_2 C_2 \gamma_1 e^{-\gamma_1(\ln Q_t)}}{Q_t} \end{aligned} \tag{34}$$

when $Q_t \doteq 1$, (34) becomes

$$\begin{aligned} V_Q^+(Q_t) &= \gamma_1 \\ V_Q^-(1) &= -\phi_2(C_2 - 1)\alpha_1 + \phi_2 C_2 \gamma_1 \end{aligned}$$

and their difference is

$$V_Q^+(1) - V_Q^-(1) = -\phi_2(C_2 - 1)\alpha_1 + \phi_2 C_2\gamma_1 - \gamma_1 = (\alpha_2 - \alpha_1)(V_0) > 0$$

Proof of proposition 5

Under static reference the Disposition conditions of the project P and reference R are:

$$-\frac{1}{2}\gamma_1 + \frac{1}{2} < \nu_P < \frac{1}{2}\gamma_1 + \cdot\frac{1}{2} \quad (35)$$

$$-\frac{1}{2}\gamma_1 + \frac{1}{2} < \nu_P < \frac{1}{2}\gamma_1 + \cdot\frac{1}{2} \quad (36)$$

rearranging (36):

$$\mu_P - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 < 0 \quad (37)$$
$$\mu_P - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 > 0$$

rearranging (36):

$$\mu_R - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 < 0 \quad (38)$$
$$\mu_R - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 > 0$$

taking together (37) and (38):

$$\mu_P - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 < \mu_R - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 \quad (39)$$
$$\mu_P - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 > \mu_R - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2$$

under the assumption that $\rho \leq 0$ (39) is equivalent to

$$\mu_P - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 \leq \mu_R - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 - \gamma_1\sigma_P\sigma_R\rho$$
$$\mu_P - (-\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_P^2 > \mu_R - (\frac{1}{2}\gamma_1 + \frac{1}{2})\sigma_R^2 + \gamma_1\sigma_P\sigma_R\rho$$

alternatively, condition (39) becomes

$$-\frac{1}{2}\gamma_1 + \frac{1}{2} < \frac{\mu_P - \mu_R + \sigma_R^2}{\sigma_P^2 + \sigma_R^2} < \frac{1}{2}\gamma_1 + \frac{1}{2}.$$

which is equivalent to

$$-\frac{1}{2}\gamma_1 + \frac{1}{2} < S \leq \frac{1}{2}\gamma_1 + \frac{1}{2}$$

Chapter 2: Environmental policy under ambiguity

Abstract

In 1997, in Kyoto, Japan, industrialised countries signed a protocol, agreeing to reduce their collective GHG emissions. The protocol establishes flexible mechanisms for reducing the industrial carbon footprint, mainly through economic incentives. One of the first implementations of the protocol within a framework of cap and trade is the EU Environmental Trading System (ETS). Recent evidence, however, points out that there are serious flaws and inefficiencies in the way the Scheme operates. For instance, instead of an expected decrease, several industrialised EU members are experiencing an increased emissions–to-cap ratio (total emissions relative to allocated permits). In addition, some suggest that spot price volatility in the carbon market has a profound impact on long-term investment risk and in turn affects the efficiency of the market. It seems, therefore, that there are some factors that policy makers have neglected in the design of the environmental policy. The main contribution of my work is to suggest that behavioural anomalies are the cause for the inefficiencies in the environmental policy.

7 Introduction

The aim of the EU's environmental policy is to gradually reduce total emissions below the emissions levels of 1990. The EU Emissions Trading Scheme (EU ETS) aims to reach this goal in the most economically efficient manner. The essence of the EU ETS is to cap the total emissions of the economy and assign individual installations with allowances, so that the total number of permits does not exceed the cap. To create incentives to reduce the emissions, the ETS allows emissions permits to be freely traded. In most EU member states, individual allocation is based on historical emissions, a practice known as grandfathering. In order to reduce the possible Ratchet effect, where the installations have an incentive to increase their current production to gain a larger share in free future allocation, historical emissions from the period prior to the implementation of the EU ETS is taken. For instance, in the National Allocation Plan (NAP) of the UK it is said explicitly that historical emissions prior to the ETS implementation is taken; otherwise, it might create incentives in some sectors to emit more.[13]

Post-Kyoto negotiations are currently taking place and there exists a draft of the policy for the years 2012-2020. Although the draft specifies that free allocation would gradually diminish, it does not specify how the remaining free allocation would take place. This uncertainty in policy contributes to an already existing tough challenge for policy makers to reduce emissions levels in a constantly growing global economy where demand for energy is rising. Ignoring the behavioural aspect of the problem might make this challenge even tougher and sometimes impossible to achieve.[14]

Despite the interaction between companies' strategy and market uncertainty, very little discussion has been dedicated to the analysis of companies' behaviour under policy uncertainty. The aim of my paper is to extend existing literature on the allocation of carbon permits. I investigate how uncertainty and ambiguity resulting from the lack of an envi-

[13] Section 3.5 in the UK NAP for the Second Phase (2008-2012).

[14] Stern (2006) mentions ambiguity as a possible method in the analysis of appropriate reaction of society to climate change.

ronmental policy impact production. I show that there is a clear distinction between the impacts of uncertainty and ambiguity on the total production in the market. Moreover, I demonstrate that ignoring the lack of information in the carbon market might lead to incorrect policy design.

In order to conduct the analysis, first, I present the literature that deals with the allocation of permits and uncertainty. Then, I lay down the model which is based on the UK model of NAP regarding carbon permits. Later, I investigate how the lack of a post-Kyoto environmental policy impacts the total output of the market. In addition, I extend the basic theoretical framework by incorporating ambiguity into the model. Finally, I compare the changes in the output that are driven by ambiguity and uncertainty.

In order to investigate the effect of uncertainty, I adopt a mean-preserving spread technique. To study the impact of ambiguity, however, I use the accepted method of the Choquet integral. To conduct this analysis I use an output-based allocation model in the Cournot Oligopoly. To get an empirically related analysis I use the UK NAP for the years 2008-12 (Second Phase) which has been approved by the EU Commission on 29 November 2006, as a case study. I will put forward some policy recommendations in the concluding section of the paper.

8 Literature review

The optimal allocation rule of carbon permits has been one of the main issues for a debate in the policy design for the First (2005-2007) and the Second (2008-2012) Phases in the implementation of the Kyoto protocol. There has been extensive research on the efficiency of different methods of allocation. Several alternative policies have been analysed: auctioning (Cramton and Kerr, 2002), pollution taxes (Baldursson *et al.*, 2004, Haucap *et al.*, 2003), free and output-based allocation (see Fischer 2001; Haucap and Kirstein, 2003; Neuhoff, Grubb and Keats, 2005).[15]

Most of the EU member states choose to distribute their available permits based on historic output and/or emissions levels, a method called grandfathering. In the NAP of the UK, Germany and Austria,[16] allocation of permits to the existing companies is determined according to their share in the historic emissions prior to the First Phase. One of the main justifications for using historical data on emissions/output, beside the practical difficulties of collecting updated data, is that this method eliminates companies' strategic behaviour. Adopting a more recent emissions/output may encourage high productivity and reward less efficient firms for continuing to emit at higher levels. (Ahman *et al.*, 2005; Fischer, 2003).

Two additional issues concern policy makers: the allocation of permits to new entrants and the closure of existing companies. These issues are beyond the scope of this paper. It is worth mentioning, however, that most EU member states choose to set aside some permits for new entrants at the New Entrant Reserve (NER).[17] New entrants receive their permits from the NER according to a benchmark level of emissions, which is the estimated emissions projection for each sector.[18]

[15]Most EU member states (Germany, Austria, Netherlands, Poland, etc.) choose to allocate the majority of available emission permits and auction only a small part of them.

[16]These are the only NAPs available in English.

[17]I refer the readers to the UK NAP section 1.15 for Second Phase, for detailed view of the methods and incentives behind the allocation plan. It can be found on the following website: http://www.defra.gov.uk/environment/climatechange/trading/eu/index.htm

[18]Appendix D1 UK NAP. The same benchmark spreadsheet is used to determine the relevant emission for

Despite a rigorous analysis of the optimal allocation of carbon permits, most of the research conducted in this area ignores the important fact that there is no detailed policy on free allocations after the Kyoto protocol expires in 2012. This fact creates uncertainty in which companies that are subject to emissions cap and trade of permits will have to consider a variety of future policies. Although they can anticipate possible scenarios, it is highly unlikely that they can anticipate their exact probability distribution. Therefore, their lack of information creates a special sort of uncertainty, often referred to as ambiguity. In the presence of ambiguity, no matter how much more information companies gather to calculate their optimal behaviour, they will remain uncertain as to the correct probability distribution of possible policy scenarios. In the organisational context, where management faces dispersed knowledge, the distinction between ambiguity and uncertainty is of great importance (Becker, 2001).

The distinction between uncertainty and ambiguity in the decision maker's (DM) state of mind is well defined in the economic literature (see for example Ellsberg, 1961; Mukerji, 1997). Schmidler and Gilboa (1989) have developed an axiomatic representation of decision, in which they distinguish between situations where the DM is aware of the objective probabilities of underlying scenarios and where he/she is not. The former is regarded as uncertainty and the latter as ambiguity. In the case of uncertainty one may use a standard approach of expected values, whereas in the case of ambiguity one cannot. The main reason is that ambiguity cannot be represented by an additive probability distribution. In the presence of ambiguity the DM's subjective beliefs are represented by a convex non-additive probability

incumbent firms.

k, sometimes referred to as Knightian probability or capacity. To deal with this special case of uncertainty, the Choquet integral is accepted as the main tool for evaluating the expected value (Scmeidler, 1989; Sarin and Wakker, 1992). Schmidler and Gimlboa (1989) show that given a convex non-additive probability k, the Choquet integral is a simple minimum of all possible values. Putting it another way, I find the most pessimistic expected value.[19]

One recent application of ambiguity aversion is made in the context of a company's irreversible investment decision (Nishimura *et al.*, 2007). In that context the authors find that the effect of ambiguity is drastically different from that of traditional uncertainty. Given these results it seems natural to extend existing literature on emissions allocation, incorporating ambiguity into the production decision of companies. It would be interesting to compare companies' decisions under these two sorts of uncertainties. In order to make the proposed model more realistic, I choose to base it on one of the EU states' NAP. Due to the relative simplicity of the UK NAP's method of allocation, I adopt it as our case study.

9 The Model

9.1 Preliminaries of the model

According to the UK NAP, carbon permits are allocated on the sectorial level (i.e., permits are allocated first to the whole market and then divided among sectors of the market). Therefore, I choose to focus my analysis on each sector individually. First, I derive results assuming that companies know the exact probability distribution of potential future policies

[19]For an example of how to use the Choquet integral see Dow *et al.*, (1992)

(Uncertainty Case). Then, I release the later assumption and analyse a scenario in which companies do not know the exact distribution but rather hold a set of possible probability distributions of potential future policies (Ambiguity Case).

T-defined as a time horizon of the model. $t \in T$ can be any natural number between $(0, \infty)$. I restrict our model to three periods only, $t \leq 3$. First, I derive results from a two-periods model. Next, I extend the two-periods model to incorporate the third period as well. In the three-periods model I assume that companies are not aware of the allocation method that governs in period $t = 3$.

N- is the total number of companies in the sector, s.t. $i \in N = (0, \infty)$.[20]

q_i^t- is an output that each company i produces in period t. I assume that companies choose their level of production at the beginning of each period t.

Q^t- is a total output in the sector in period t.

E^t- is a total of issued permits for distribution in the sector in period t. The policy maker (in our case, the UK government) sets the cap of total permits to emit Greenhouse Gases (GHG) in order to comply with its obligation to reduce its national emissions level. Each permit allows the emission of one metric tonne of CO_2.

e_i^t - is verified emissions of company i in period t. I assume that actual emissions are expressed as a linear function of companies' output, where $\delta^t = (0, \infty)$ is the marginal rate of emissions in period t. For simplicity, I assume that companies in the same sector have an identical marginal rate of emissions δ^t.[21] Although it is a strong assumption which is not

[20] It is also possible to assume a different number of firm operating in each period t. However, the assumption that in each period there is an identical number of firms will not affect the qualitative result.

[21] It is a reasonable assumption since I am dealing with companies in the same sector. A similar assumption

supported in reality, it does not change the qualitative result of this paper. The only place where this assumption is implimented is when I derive the relative allocation based on the historic benchmark of the company. To avoid using this assumption, one could analyse the output-based allocation (a different variation of the grandfathering rule), instead, and would get to an equivalent result.

Therefore, the actual emissions levels of a company in the sector can be expressed as

$$e_i^t = \delta^t q_i^t$$

Although such a constuction of the model sugests that emissions can be reduced only by reducing the output, another way of reducing emissions would be through reducing the rate of emissions δ^t through R&D in a cleaner technology, for instance. I will discuss this point toward the end of the paper, in the policy recomendation section.

m- is a market price to buy or sell permits to emit 1 tonne of GHG. The price of permits is established in the permits market. One of the largest trading platforms for carbon permits is the European Energy Exchange. Due to the large number of participants in the daily trade, the price of permits is assumed to be exogenous to the companies.[22]

d- a discount factor between two adjusting periods. I assume that $d = (0, 1)$

9.2 Allocation rule

Grandfathering is an allocation rule where permits are distributed based on historical emission levels. The allocation to each incumbent installation is done according to the following

is made by Hepburn *et al.* (2006)

[22] Website of European Energy Exchange:http://www.eex.com/en/

formula:[23]

$$\text{Total incumbent allocation} = \frac{\text{Incumbent's relevant emissions}}{\text{Sum of relevant emissions of all incumbents in the sector}} E^t \quad (40)$$

First, I am introducing a two-period model. In section 3.3 I will extend the model to three periods.

9.3 Two-period Oligopoly-Benchmark case

I denote the inverse demand that companies face in the market for their product

$$P(Q^t) = \alpha - bQ^t$$

c_i- is the marginal cost of company i to produce one additional unit of output q_i^t.

π_i^t-is the profit function of company i in period t.

In the UK NAP, historic emissions are relevant to the allocation of permits. The policy which is adopted in the Second Phase of the UK NAP (2008-2012) is that of a rolling over of historic emissions benchmark (i.e. emissions of years 1998-1999 are relevant for permits allocation in the First Phase; in the Second Phase the relevant emissions level is rolled over to years 2000-2003. To follow this methodology I say that emissions in period $(t-2)$ determine the allocation of permits to the incumbent in period t. For example, if I want to determine the relevant allocation for the incumbent in period $t = 2$, I take its historic emissions level in period $t = 0$.

[23]Section 3.2 in the UK NAP

The profit function π_i^t can be expressed:

$$\pi_i^t = [\alpha - bQ^t]q_i^t - c_i q_i^t - m[\delta^t q_i^t - \frac{q_i^{t-2}}{Q^{t-2}}E^t]$$

The expression $\delta^t q_i^t - \frac{q_i^{t-2}}{Q^{t-2}}E^t$ the difference between the allocated permits $\frac{q_i^{t-2}}{Q^{t-2}}E^t$ and the company's emissions to produce q_i^t.

The difference between the company's actual allocation and actual emissions results in a surplus/deficit of its permits. On one hand, if a company has a surplus of permits it will sell them for the price of m. The revenue from selling the permits is a profit to the company that outperforms and reduces its emissions level below the initial allocation. On the other hand, if the company does not hold enough permits to cover its actual emissions, it can purchase additional permits for the price of m. The cost of purchasing additional permits is a 'tax' to the company that emits more that its initial allocation.

Π_i^t- is the total profit of company i in period t. I can express the total profit Π_i^t as a discounted sum of all its profits from period $t = 1$ to $t = T$

$$\Pi_i^t \equiv \sum_1 d^{t-1}\pi_i^t$$

I analyse my problem as a game between N companies. Technically I solve the optimisation problem in the Cournot Oligopoly with two periods. I use a standard method of backward induction to find an optimal output in each period t.

9.3.1 Second period

Let me denote $t = 0$ as a relevant period for comany's allocation of permits in period $t = 2$. E^2 is the total number of permits to be distributed among the companies.

The maximisation

$$\arg\max_{q_i^2} \pi_i^2 = [\alpha - bQ^2]q_i^2 - c_i q_i^2 - m[\delta^2 q_i^2 - \frac{q_i^0}{Q^0}E^2]. \tag{41}$$

First order condition:

$$\frac{d\pi_i^2}{dq_i^2} = \alpha - b(Q^2) - bq_i^2 - c_i - m\delta^2 = 0 \tag{42}$$

Summing up N first order conditions, as the number of companies in the sector, I get:

$$N\alpha - (N+1)b(Q^2) - \Sigma c_i - Nm\delta^2 = 0 \tag{43}$$

Optimal total output in the sector in $t = 2$, I solve Equation (43) for $(Q^2)^*$:

$$(Q^2)^* = \frac{N\alpha - \Sigma c_i - Nm\delta^2}{(N+1)b} \tag{44}$$

I see that optimal total output is not affected by the future allocation of permits. I derive the second order condition to verify the optimal condition for $(Q^2)^*$.

Second order condition:

$$\frac{d^2\pi_i^2}{d^2 q_i^2} = -2b < 0 \tag{45}$$

The second order condition is satisfied, insuring that Equation (44) is the optimal total output that maximises total profit in period $t = 2$.[24]

[24] As the number of firms in the market increases, the conditions in the market approach the competitive

9.3.2 First period

I use the method of backward induction to find the optimal output in period $t = 1$. I add the discounted profit π_i^2 to the profit π_i^1 which results in total profit Π_i^1 of company i in period $t = 1$. I denote period $t = -1$ as a relevant period for allocation of permits to company in period $t = 1$. The maximisation is

$$\arg\max_{q_i^1} \Pi_i^1 = [\alpha - bQ^1]q_i^1 - c_i q_i^1 - m[\delta^1 q_i^2 - \frac{q_i^{-1}}{Q^{-1}} E^1] + d\pi_i^2 \tag{47}$$

Profit function π_i^2 does not depend on q_i^1. Therefore first order condition is

$$\frac{d\Pi_i^1}{dq_i^1} = \alpha - b(Q^1) - bq_i^1 - c_i - m\delta^1 = 0 \tag{48}$$

Summing up N first order conditions and solving for the optimal output in period $t = 1$, I get that Q^1 is identical to Q.

The optimal output in period $t = 2$:[25]

$$(Q^1)^* = \frac{N\alpha - \sum c_i - Nm\delta^1}{(N+1)b} \tag{49}$$

equilibrium. The output in the market approaches the competitive output. To find the competitive output I have to assume that $\lim_{N\to\infty}(\frac{\sum C_i}{(N+1)b}) = C$ is a constant. Otherwise the equation explodes and tends to infinity:

$$\lim_{N\to\infty} Q^2 = \frac{\alpha - m\delta}{b} - C \tag{46}$$

[25] For the S.O.C please check the solution for the first Second period-Oligopoly. The condition is represented by Equation (45).

I denote:

$$\overline{Q^1} \equiv (Q^1)^* \quad (50)$$

$$\overline{Q^2} = (Q^2)^* \quad (51)$$

To sum up, in the two-period model companies have no incentive to increase their output to receive a larger share of permits in the future allocation. Therefore, in the benchmark case, a revision cap policy $(E^t)\})$ to achieve the target of reducing emissions level can be implemented (i.e. as the total production in the sector does not depend on the future policy and future cap, a policy maker can revise the cap at each phase individually and set E in a way that achieves the desired emissions in the economy in period t). It is done based on the emissions projection in that period which is derived from the total estimated output Q^t. I should note, however, that the former argument is restricted only to myopic companies that consider their actions for the nearest future. In the above case there are only two periods. For instance, the policy maker in period $t = 1$ would ideally set up the cap of E^1 to satisfy the following equality

$$E^1 = \delta^1 \overline{Q^1} = \lambda(\delta^1 Q_{BAU})$$

rearranging I get that

$$\overline{Q^1} = \lambda Q_{BAU}$$

where $\lambda \in (0, 1)$ is the parameter indicating the commitment of the policy maker to reduce the emissions level, such that $\lambda = 0$ would represent the policy maker who is committed to reduce the emissions by 100 per cent. Furthermore, Q_{BAU} is the production in the "business as usual scenario", which stands for production if there is no cap on the emission. The same rule would apply to the cap of period $t = 2$.

However, companies are not acting myopically and consider their action with respect to horizons that are beyond two periods. Two questions naturally arise in this context: 1) What happens to total output if one considers a framework of more than two periods? 2) Does the UK NAP still fulfil its purpose of eliminating the incentives of companies to act strategically? In the following section I address these questions.

9.4 Three-period oligopoly: uncertainty case

Although the EU Council adopted a revised ETS plan for the post-Kyoto period in which the free allocations are gradually reduced, there is no clear directive on how free allocation would be implemented. From now on, therefore, I assume that companies face an uncertain allocation rule beyond 2012. I show the effect of uncertainty on total output. To do so, I first extend the benchmark model to three periods. Next, I state what the most probable allocation policies are for the third period. I also assign probabilities to possible allocation scenarios as they are perceived by companies. To conclude this section I compare total output under uncertainty with total output under the benchmark model.

Third period - uncertainty case To analyse the effect of uncertainty on the total output in the market I assume that companies consider only two policies of free allocation. On one hand, the policy maker continues with rolling over the relevant historic emissions. This is a reasonable assumption. In period t=3 emissions level of period $t = 1$ are available and show a more updated measure of historic emissions than emissions level of period $t = 0$.

On the other hand, the policy maker might adopt more recent emissions levels. Historic emissions of period $t = 2$ would become relevant emissions for the allocation of permits in period $t = 3$. A reasonable justification for that can be that the policy maker might try to diminish companies' incentives to adjust their behaviour in period $t = 1$ to receive a larger share of permits in period $t = 3$.[26] I denote p^t as a probability that the policy maker assigns relevant historic emissions to be in period t such that

$$\sum p^t = 1.$$

The maximisation is

$$\arg\max_{q_i^3} \pi_i^3 = [\alpha - bQ^3]q_i^3 - c_i q_i^3 - m[\delta^3 q_i^3 - \{p^1 \frac{q_i^1}{Q^1} + p^2 \frac{q_i^2}{Q^2}\}E^3] \tag{52}$$

First order condition:

$$\frac{d\pi_i^3}{dq_i^3} = \alpha - b(Q^3) - bq_i^3 - c_i - m\delta^3 = 0 \tag{53}$$

Summing up N f.o.c. I get that the total output in period $t = 3$ equals

$$Q^3 = \frac{N\alpha - \sum c_i - Nm\delta^3}{(N+1)b} \tag{54}$$

To find what the total output is in periods $t = 1, 2$ I proceed, as before, using the standard method of backward induction.

Lemma 6 *Let's denote Q_U^t as the total output in period t when companies consider an uncertain future policy in period $t = 3$ and the policy is uncertain. Total output in periods*

[26] I can also assume that companies can assign probabilities to a policy that assign relevant emissions to $t = 0$. However, it will not affect qualitative results, as this option will be discarded in the first order condition. I therefore ignore this scenario and concentrate on the two aforementioned scenarios.

$t < 3$ increases, so that

$$Q_U^t = \frac{\overline{Q^t}}{2} + \sqrt{\frac{(\overline{Q^t})^2}{4} + d^{T-t}\frac{m(N-1)E^3p^t}{(N+1)b}} > \overline{Q}.$$

Second period-Uncertainty Case **Proof.** See Appendix B.1.1 ■

First period-Uncertainty Case **Proof.** See Appendix B.1.2 ■

I conclude that in the presence of uncertainty, total output in the sector increases in both periods $t = 1$ and$t = 2$. This result suggests that companies who consider longer horizons policies tend to overproduce to receive a larger share of future permits' allocation - the Ratchet Effect. Unlike the benchmark case, the output in the current period ($t = 1$) is a positive function of future allocation E^3. Therefore, a policy maker who ignores that effect may find it hard to achieve its goal of reducing emissions levels. Only considering short-term policy would underestimate the production levels Q^1 in the economy and consequently miss the emissions reduction targets. At this point it is worth mentioning that emission targets and CAP should not necessarily coincide. The market for carbon permits is considered as an open market. There, the traders from different localities can trade their permits by purchasing additional credits at the carbon market (Mackenzie et al., 2008). Therefore, the restriction imposed by the domestic policy maker on the emissions CAP does not necessarily apply to the domestic companies in the market, as additional credits could be purchased in the carbon market and/or reslut fom the market-mechanisms such as CDMs and JIs. Therefore, there are situations in which the CAP is not violated, however the emissions target set by the policy maker is missed.

9.5 Ambiguity vs. uncertainty

In the previous section I assumed only two scenarios, in which their probabilities were known to the companies and the probabilities summing up to one. In reality it is highly unlikely that companies know the exact probability distribution of possible future policies. This situation of uncertainty is called ambiguity. In ambiguity both possible future policies and their expected values are uncertain. In order to study the effect of ambiguity on total output, I use a solution method proposed by Schmeidler and Gilboa (1989). However, first I briefly introduce the notion of capacity and the Choquet expected value.

9.5.1 Capacity

In contrast to standard assumptions on probabilities, capacities (Knightian probabilities) assign non-additive weights to possible scenarios. Capacity can be formally represented by a real function k which satisfies the following properties (Schmeidler, 1989):

(a) for two events A,$B \in \Omega$ s.t $A \subseteq B \Longrightarrow k(A) \leq k(B)$

(b) $k(\varnothing) = 0$;

(c) $k(\Omega) = 1$.

Capacity is convex if it satisfies: $k(A) + k(B) \leq k(A \cup B) + k(A \cap B)$. In this paper I will concentrate on convex capacities. According to Scmeidler and Gilboa (1989) a core 'C' of k, where $\Delta(\Omega)$ is the set of all additive probability measures on Ω:

$$C(k) = \{p \in \Delta(\Omega) \mid p(A) \geq k(A) \ \forall A \subseteq \Omega\}$$

meaning that $C(k)$ is the set of all the plausible probabilities that companies may assign to future policies. Therefore, $k(A) = \min_{p \in C(k)} p(A)$. In the presence of ambiguity I assume that companies assign Knightian, non-additive probabilities k^1 and k^2 to the same policies as they did in the uncertainty case. Non-additive property of convex capacities ($\sum k^t < 1$) reflects ambiguity of the DM. The measure of ambiguity aversion can be represented by

$$AA = 1 - k^1 - k^2.$$

The higher the value of AA, the higher the ambiguity aversion of the DM (Dow *et* al., 1992). Next, I introduce the concept of ε-contamination to show the effect of an increase in ambiguity.

9.5.2 ε-contamination

The behavioural foundation for ε-contamination can be found in Nishimura *et al.* (2006) and its application to a discrete time search in Nishimura *et al.* (2004). The concept of ε-contamination is usually used in the context of Bayesian uncertainty. To deal with Bayesian uncertainty a new set of priors is introduced by contaminating one single hypothetical prior (Nishimura *et al.*, 2004). This procedure is often referred to as ε-contamination. I also follow this technique by contaminating the prior distribution (p^1, p^2) which I assume in the uncertainty case.

In the previous section I defined capacity as $k(A) = \min_{p \in C(k)} p(A)$. I contaminate priors (p^1, p^2) and set the core to be in the range of $C(k) = (p^t - \varepsilon,\ p^t + \varepsilon)$, where $\varepsilon > 0$ is a small number. An increase in ε can be seen as an increase of ambiguity. An increase in ε leads to an increase of AA as k^t decrease. Companies become more ambiguous regarding the future policy, and as a consequence tend to decrease their output.

9.5.3 Choquet expected value

The Choquet integral is accepted as the main tool to evaluate the expected value in case of non-additive probabilities (Scmeidler, 1989; Sarin and Wakker, 1992). Schmidler and Gimlboa (1989) show that given a convex non-additive probability k, the Choquet expected value is a simple minimum of all possible values. In my model companies simply choose the lowest possible value for the allocation of permits according to the following formula:

$$\mathbb{CE} = \left(\begin{matrix} \min \\ p \in C(k) \end{matrix}\right) \sum_{t=1}^{t=2} p \frac{q_i^t}{Q^t}$$

where $\frac{q_i^t}{Q^t}$ is the relevant output ratio for the allocation in period $t = 3$. To find out the explicit expression for the Choquet expected value I consider two cases:

Case 1 For companies whose relative production in period $t = 1$ is higher than in period $t = 2$ ($\frac{q_i^1}{Q^1} > \frac{q_i^2}{Q^2}$), the Choquet expected value ($\mathbb{CE}$) is

$$\mathbb{CE} = k^1\left(\frac{q_i^1}{Q^1} - \frac{q_i^2}{Q^2}\right) + \frac{q_i^2}{Q^2}$$

Case 2 For companies whose relative production in period $t = 1$ is lower than in period $t = 2$ ($\frac{q_i^1}{Q^1} < \frac{q_i^2}{Q^2}$), the Choquet expected value ($\mathbb{CE}$) is

$$\mathbb{CE} = k^2\left(\frac{q_i^2}{Q^2} - \frac{q_i^1}{Q^1}\right) + \frac{q_i^1}{Q^1}$$

I have to note that unless $\sum k^t < 1$, the two Choquet expected values above coincide.

Third period - ambiguity case I assume that the total number of incumbents in period $t = 3$ who satisfy condition $\frac{q_i^2}{Q^2} < \frac{q_i^1}{Q^1}$ equals G. Assuming that total production in period $t+1$ is higher than in period t, implies the condition $N - G > G$. In light of these assumptions I distinguish between two maximisations of the incumbent in period $t = 3$.

1) when $\frac{q_i^1}{Q^1} > \frac{q_i^2}{Q^2}$:

$$\arg\max_{q_i^3} \pi_i^3 = [\alpha - bQ^3]q_i^3 - c_i q_i^3 - m[\delta^3 q_i^3 - \{k^1 \frac{q_i^1}{Q_A^1} + (1-k^1)\frac{q_i^2}{Q_A^2}\}E^3] \tag{55}$$

2) when $\frac{q_i^1}{Q^1} < \frac{q_i^2}{Q^2}$:

$$\arg\max_{q_i^3} \pi_i^3 = [\alpha - bQ^3]q_i^3 - c_i q_i^3 - m[\delta^3 q_i^3 - \{(1-k^2)\frac{q_i^1}{Q_A^1} + k^2 \frac{q_i^2}{Q_A^2}\}E^3 \tag{56}$$

Total output in period $t = 3$ equals Q^3 and is represented by Equation (44).

Proof. See above. ■

Using backward induction I calculate the total output in period $t = 2$ and $t = 1$.

Proposition 7 *Let's denote Q_A^t as the total output in period t when companies consider future policy in period $t = 3$. If the policies in period $t = 3$ are ambiguous, the output in period $t = 1$ is higher than in the uncertainty case, such that $Q_A^1 > Q_U^1$, and in period $t = 2$ is lower than in the uncertainty case, such that $Q_A^2 < Q_U^2$*

Second period-Ambiguity Case **Proof.** See Appendix B.2.1 ■

First period-Ambiguity Case **Proof.** See appendix B.2.2 ■

I show that the total output depends on the subjective beliefs of the companies, specifically capacities. Given that $k(A) = \min_{p \in C(k)} p(A)$ and $C(k) = (p^t - \varepsilon, p^t + \varepsilon)$, I conclude that $k^1 = p^1 - \varepsilon$ and $k^2 = p^2 - \varepsilon$. Using the proposition above I see that under our assumption the total output in period $t = 1$, when I assume ambiguity, is higher than in the case where I assume uncertainty. The result shows that production, under the ambiguity case, in period $t = 2$, is smaller than it is under the uncertainty case. It is important to notice, however, that my main interest is output in period $t = 1$.

Given these results, it is clear that under ambiguity the policy maker might find it really difficult to achieve the goals of current emissions reduction if it does not account for the ambiguity aversion. As a result of higher output under the ambiguity case than under the uncertainty case, the emissions are, as a consequence, higher as well. Therefore, as suggested in the previous section, only considering short-term policy would underestimate the production levels Q^1 in the economy and consequently miss the emissions reduction targets. As I explain above, there are situations in which the CAP is not violated, however the emissions target is missed.

10 Analysis: increase in uncertainty vs. increase in ambiguity

The effect of an output-based allocation of emissions permits has been already examined by Fischer (2001). Fischer, in a simple one-period model, finds that an output-based allocation has a smaller impact on the output reduction than a fixed allocation. Similar results were also found in the empirical analysis of emissions in the province of Alberta, Canada (Haites, 2003). However, these results are restricted to one period only. My model presents a more general framework for analysing the impact of output-based allocation on total production. I show in the previous section that ambiguity and uncertainty of future free allocation policy increases the total output in the sector in comparison with lump-sum allocation.

Next, I propose an analysis of total output when companies face an increase in ambiguity and/or uncertainty

Proposition 8 *Whenever companies face an increase of ambiguity of future policy it leads to an increase of current total output, whereas an increase of uncertainty of future policy has no effect on current total output.*

Proof. See Appendix B.3. ■

10.1 Increase of uncertainty

It is accepted to analyse an increase in uncertainty by a mean-preserving spread technique. In my context the new spread preserves the expected value of the expected policy

There are two alternatives for possible historic emissions benchmarks $(\frac{q_i^1}{Q_U^1}, \frac{q_i^2}{Q_U^2})$. The former stands for a policy that considers historical emissions of period $t = 1$, and the latter of period $t = 2$. The spread is $(\frac{q_i^1}{Q_U^1} + \theta, \frac{q_i^2}{Q_U^2} - \frac{p^1}{1-p^1}\theta)$. Parameter θ is interpreted as an additional factor to future policies. For instance, policy makers can change the number of total permits to be distributed in the sector, this way adjusting to updated information regarding the environmental impacts. It can also represent an additional tax or subsidy that policy makers can impose on companies that are subject to cap and trade of emissions permits. Proposition 3 shows that the total output in period $t < 3$ is not affected by an increase of uncertainty. An increase in ambiguity, however, produces a different effect.

10.2 Increase of ambiguity

An increase in ambiguity leads to an increase in total output. By employing the concept of ε-contamination I can show that an increase in ε can be seen as an increase in ambiguity. Companies become more ambiguous regarding the future policy of free allocation. Next, I analyse the scenario where ambiguity aversion (AA) increases because of higher contamination ε in the priors. This setting indicates that total output in period $t = 1$ increases as a result of a high degree of AA.

11 Policy recommendations

In this section I describe some of the policy implications. I show that whenever there is uncertainty in the market regarding the future policy, it tends to affect the total output in the market. Companies tend to increase their output when they face an uncertain future policy. For instance, in the UK alone, emissions to cap ratio has risen from 15 per cent in 2005 to 19.5 per cent in 2007. These figures show that the UK industry increases its emissions beyond the initial allocation. My model can suggest that the rise in the emissions-to-cap ratio is driven by behavioural biases. And if I am right in my predictions, then it seems that the role of the policy maker is to eliminate such behavioural biases. This conclusion corresponds with the environmental literature and the latest draft of the EU ETS. For example, a similar idea is proposed by Baldursson *et al.* (2004). The authors suggest that in the presence of uncertainty in the market, policy makers should favour tax regulations on emissions rather than issuing transferable permits, as the former regime has a smaller effect on companies' behaviour. In other words, policy makers should favour a regime that diminishes behavioural biases of companies. To conclude, I suggest some policy implications.

11.1 Information certainty

When the decision maker's state of mind is ambiguous the choices are made with caution in response to the imprecise knowledge of probability distribution (Mukerji, 1998). Such behaviour creates a bias toward the decision which is based upon the magnitude of certainty of the outcome rather than its magnitude. As I show in my previous analysis, ambiguity of future policy causes the decision maker to to be cautious with respect to future policy and increases current total output in comparison with the lump-sum allocation (Benchmark case), in case the future allocation of pemits is based upon the current output. In addition, I show that an increase in ambiguity tends to increase the total output. One of the possible interpretations of an increase in ambiguity is that there is high information uncertainty regarding the future free allocation rule. The higher the information uncertainty in future policy, the higher the current total output and emissions level. Therefore, the policy maker should try and reveal its long-term policy. This way it contributes to a decrease of total output in the economy and subsequently makes it possible for achieving emission reduction targets.

As I pointed out, companies are not aware of the correct probability distribution of the potential free allocation policy. In other words, companies' state of mind is of ambiguity rather than of uncertainty. Therefore, the policy maker can affect the company's state of mind by reducing the ambiguity of the future policy. This can be done by signalling what the future allocation policy is expected to be. Correct signalling might eliminate strategic behaviour or at least diminish behavioural biases of companies and achieve the desired policy goal.

For instance, if policy makers wanted to encourage lower output in the market, they could release information regarding the future policy that should decrease the contamination ε. According to the model, such signalling decreases total output in the sector.

Frequent press releases that indicate what future policies might be, can decrease companies' ambiguity. Indeed, the EU Commission and member states periodically issue press releases regarding future environmental policies. Such releases include NAPs, guidelines and the goals of future policies.[27] The EU uses signalling as a tool. However, it is not clear whether the use of signalling is aimed to modify beliefs or merely to provide information. It is clear, however, that policy makers could use signalling to produce desirable outcomes. It is especially useful, as I show in the analysis above, when one deals with environmental policies.

However, information revelation by the policy maker can be problematic, as shown by Walker et al. (1977) in the framework of using standard tax system in pollution control. In addition, information release to the market can decrease the ambiguity although it will not eliminate it entirely. New information can be interpreted differently by different decision makers. The effect on the ambiguity decrease will be interpreted differently on different individuals. Therefore, the tool of informartion certainty has a somewhat limited effect on deminishing the output. Next, I discuss additional tools which can have a more profound

[27] http://ec.europa.eu/environment/climat/emission/2nd_phase_ep.htm

effect on diminishing the output and decreasing the ambiguity bias.

11.2 Diminishing allocation

In the model I show that the total output in the sector is a function of the future allocation of permits E^3. In addition to the information disclosure discussed earlier, the policy maker could diminish the effect of the future allocation on present production by reducing the E^3variable. This can be done in two ways. On one hand, policy makers may gradually reduce the number of permits that are distributed for free, namely E^3. One can increase the number of permits for an auction instead of offering them for free distribution. This way the permits are allocated to companies that value them the most. Moreover, the revenue earned from auctioning can be allocated to researching and developing environmentally friendly technologies that can reduce GHG. Similar views are advocated by Bovenberg *et al.* (2005), Quirion (2003) and Hepburn *et al.* (2006). In reality, this corresponds to current trends in the EU's environmental policies. Similar suggestions are found in the EU's climate-energy legislative package from 6 April 2009. In this package the EU sets out to gradually reduce the permits that are distributed for free.

Although there is litterature to support the adoption of auctions instead of free allocations, the mechanism has additional difficulties. In order to construct an efficient auction mechanism, ambiguity aversion of the auction participant should be taken into account as it may arise there as well. As a result, there might be strategic bidding and revenue losses to the participants of the auctions. Where the seller in the auction is ambiguity averse, it may impose loses on the seller, in our case the policy maker, when the seller is ambiguis to the startegic biding of the permit buyer (Turocy, 2008). If the buyers are ambigous as to the valuation of other bidders then the bids tend to be lower, which can achieve a suboptimal price of the permits (Chen *et al.*, 2007).

11.3 Clean technology

The results above indicates that in an ideal scenario policy makers should set up a cap on the emissions that correspond to the optimal production and marginal rate of emissions, formally $E^3 = \delta^3 Q^3$. It seems that another way of diminishing the effect of future policy on current production is by reducing the future marginal rate of emissions, δ^3. This way policy makers should achieve the goals: first, expected growth of production to the future level of Q^3, second, fulfilling its targets of reducing emissions level.

In order to reduce the future marginal rate of emissions policy makers should encourage R&D in cleaner technologies which could potentially provide companies with environmentally friendly production processes.

12 Conclusion

In this paper I analyse the effect of ambiguity on total output. I show that in the presence of ambiguity or uncertainty with output-based allocation, companies tend to increase their production compared to the fixed allocation. Similar results are pointed out by Mackenzie *et al.* (2008). The authors show that in the presence of historical base grandfathering it will generate intertemporal distortion of companies incentive and they tend to produce beyond social optimum. This paper comes as an extension to the results acheived there by showing that by adding ambiguity in the rule governing the permit allocation in the future can potentially increase the production even beyond the production derived under intertemporal grandfathering.

Related literature on the uncertain future abatement tax policy shows that under uncertain times and magnitude of a tax policy can have a dramatic effect on the abatement investment of the pollutors (Frazin et al., 2000). Similarly, in this paper, I pointed out that decreasing ambiguity has a diminishing effect on the total output. In the analysis of these results I point out how the former result can be used by policy makers. They might achieve high rates of productivity and emissions abatement. Despite the generality of my model it has only a few shortcomings, which can be seen as potential subjects for future research. One possible extension would be to account for companies' heterogeneity in ambiguity perception. Some may say that small or new companies are more vulnerable to changes in ambiguity, whereas large companies are less vulnerable. To see the effect of the production on the price structure, one should endogenise the price of permits. While I assumed an identical number of new entrants and closures at each period, one could think of a heterogeneous number of new entrants and closures. Another potential extension can be made by introducing an equilibrium condition for the permits market into the model. I assume that each sector is a price taker. However, if the sector is large enough, this assumption is no longer valid as the sector's demand for permits could potentially affect permits prices. Despite the mentioned shortcoming of the model, it sheds some light on the output determination in the EU ETS. In structural terms, my paper solves the three-period Oligopoly model with ambiguity.

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13 Appendix B

13.1 Proof of Lemma 6

13.1.1 Second period total output

Assuming that I have the value of the total output which maximises the third period profit, I can plug it as given into Π_i^2 (the total profit function of the second period).

Maximisation is

$$\arg\max_{q_i^2} \Pi_i^2 = [\alpha - bQ_U^2]q_i^2 - c_i q_i^2 - m[\delta^2 q_i^2 - \frac{q_i^0}{Q^0}(E^2)] + d\pi_i^3 \tag{57}$$

first order condition equals

$$\frac{d\Pi^2}{dq_i^2} = \alpha - bQ_U^2 - bq_i^2 - c_i - m\delta^2 + dmE^3p^2\frac{Q_U^2 - q_i^2}{(Q_U^2)^2} = 0. \tag{58}$$

summing up N f.o.c., as the number of the companies in the market, sums up to

$$N\alpha - (N+1)bQ_U^2 - \sum c_i - Nm\delta^2 + d\frac{mE^3p^2}{(Q_U^2)'}(N-1) = 0.$$

rearranging

$$Q_U^2 = \frac{\overline{Q^2}}{2} + \sqrt{\frac{(\overline{Q^2})^2}{4} + d\frac{m(N-1)E^3p^2}{(N+1)b}} > \overline{Q} \tag{59}$$

13.1.2 First period total output

Maximisation is

$$\arg\max_{q_i^1} \Pi_i^1 = [\alpha - bQ_U^1]q_i^1 - c_i q_i^1 - m[\delta^1 q_i^1 - \frac{q_i^0}{Q^0}E^1] + d\Pi_i^2 \tag{60}$$

solving for the value of Q_U^1 I get

$$Q_U^1 = \frac{\overline{Q^1}}{2} + \sqrt{\frac{(\overline{Q^1})^2}{4} + d^2\frac{m(N-1)E^3p^1}{(N+1)b}} > \overline{Q} \tag{61}$$

13.2 Choquet expected value ($\mathbb{CE}$)

1.Given that $\frac{q_i^1}{Q^1} > \frac{q_i^2}{Q^2}$, $\mathbb{CE}$ is

$$\begin{aligned}
\mathbb{CE} &= \begin{pmatrix} \min \\ p \in C(k) \end{pmatrix} \sum_{t=1}^{t=2} p\frac{q_i^t}{Q^t} = \begin{pmatrix} \min \\ p^1 \in C(k) \end{pmatrix} (p^1 \frac{q_i^1}{Q_A^1} + (1-p^1)\frac{q_i^2}{Q_A^2}) \\
&= \begin{pmatrix} \min p^1 \\ p^1 \in C(k) \end{pmatrix} (\frac{q_i^1}{Q^1} - \frac{q_i^2}{Q^2}) + \frac{q_i^2}{Q^2} \\
&= k^1(\frac{q_i^1}{Q^1} - \frac{q_i^2}{Q^2}) + \frac{q_i^2}{Q^2}
\end{aligned}$$

2. Given that $\frac{q_i^1}{Q^1} < \frac{q_i^2}{Q^2}$, $\mathbb{CE}$ is

$$\begin{aligned}
\mathbb{CE} &= \begin{pmatrix} \min \\ p \in C(k) \end{pmatrix} \sum_{t=1}^{t=2} p\frac{q_i^t}{Q^t} = \begin{pmatrix} \min \\ p^2 \in C(k) \end{pmatrix} ((1-p^2)\frac{q_i^1}{Q_A^1} + p^2\frac{q_i^2}{Q_A^2}) \\
&= \begin{pmatrix} \min p^2 \\ p^2 \in C(k) \end{pmatrix} (\frac{q_i^2}{Q^2} - \frac{q_i^1}{Q^1}) + \frac{q_i^1}{Q^1} \\
&= k^2(\frac{q_i^2}{Q^2} - \frac{q_i^1}{Q^1}) + \frac{q_i^1}{Q^1}
\end{aligned}$$

13.3 Proof of Proposition 7

13.3.1 Second period total output

Maximisation incumbents is

$$\arg\max_{q_i^2} \Pi_i^2 = [\alpha - bQ_A^2]q_i^2 - c_i q_i^2 - m[\delta^2 q_i^2 - \frac{q_i^0}{Q^{0\prime}} E^2] + d\pi_i^3 \tag{62}$$

first order condition of incumbents which satisfy the condition of $\frac{q_i^1}{Q^1} < \frac{q_i^2}{Q^2}$ is

$$\frac{d\Pi^2}{dq_i^2} = \alpha - b(Q_A^2) - bq_i^2 - c_i - m\delta^2 + dmE^3 k^2 \frac{Q_A^2 - q_i^2}{(Q_A^2)^2} = 0 \tag{63}$$

first order condition of incumbents which satisfy the condition of $\frac{q_i^1}{Q^1} > \frac{q_i^2}{Q^2}$ is

$$\frac{d\Pi^2}{dq_i^2} = \alpha - bQ_A^2 - bq_i^2 - c_i - m\delta^2 + dmE^3(1 - k^1)\frac{Q_A^2 - q_i^2}{{Q_A^2}^2} = 0 \tag{64}$$

Summing up N f.o.c. sums up to

$$N\alpha - (N+1)bQ_A^2 - \sum c_i - Nm\delta^2 + d\frac{mE^3}{(Q_A^2)^2}\{\sum^{N-G}(Q_A^2 - q_i^2)k^2 + \sum^{G}(Q_A^2 - q_i^2)(1-k^1)\} = 0$$

given that $k^1 = \binom{\min p^1}{p^1 \in C(k)} = p^1 - \varepsilon$ and $k^2 = \binom{\min p^2}{p^2 \in C(k)} = p^2 - \varepsilon$ I get

$$N\alpha - (N+1)bQ_A^2 - \sum c_i - Nm\delta^2 + d\frac{mE^3}{(Q_A^2)^2}\{\sum^{N-G}(Q_A^2 - q_i^2)(p^2 - \varepsilon) + \sum^{G}(Q_A^2 - q_i^2)(1 - p^1 + \varepsilon)\} = 0$$

rearranging

$$N\alpha - (N+1)bQ_A^2 - \sum c_i - Nm\delta^2 + d\frac{mE^3}{(Q_A^2)^2}\{\sum^{N-G}(Q_A^2 - q_i^2)(p^2 - \varepsilon) + \sum^{G}(Q_A^2 - q_i^2)(p^2 + \varepsilon)\} = 0$$

if $N - G > G$, I get

$$N\alpha - (N+1)bQ_A^2 - \sum c_i - Nm\delta^2 + d\frac{mE^3}{(Q_A^2)^2}\{(NQ_A^2 - Q_A^2)(p^2) + (\sum^{G}(Q_A^2 - q_i^2) - \sum^{N-G}(Q_A^2 - q_i^2))\varepsilon\} = 0$$

$$N\alpha - (N+1)bQ_A^2 - \sum c_i - Nm\delta^2 + d\frac{mE^3(N-1)p^2}{Q_A^2} > 0, \tag{65}$$

solving Equation (65) I get that Q_A^2 is

$$Q_A^2 < \frac{\overline{Q^2}}{2} + \sqrt{\frac{(\overline{Q^2})^2}{4} + d\frac{m(N-1)E^3p^2}{2(N+1)b}}$$

13.3.2 First period total output

Maximisation of incumbents is

$$\arg\max_{q_i^1} \Pi_i^1 = [\alpha - bQ_A^1]q_i^1 - c_i q_i^1 - m[\delta^1 q_i^1 - \frac{q_i^{-1}}{Q^{-1}}E^1] + d\Pi_i^2 \tag{66}$$

first order condition of companies which satisfy the condition of $\frac{q_i^1}{Q^1} < \frac{q_i^2}{Q^2}$ is

$$\frac{d\Pi^1}{dq_i^1} = \alpha - bQ_A^1 - bq_i^1 - c_i - m\delta^1 + d^2mE^3(1-k^2)\frac{Q_A^1 - q_i^1}{(Q_A^1)^2} = 0 \tag{67}$$

first order condition of comapnies which satisfy the condition of $\frac{q_i^1}{Q^1} > \frac{q_i^2}{Q^2}$ is

$$\frac{d\Pi^1}{dq_i^1} = \alpha - bQ_A^1 - bq_i^1 - c_i - m\delta^1 + d^2mE^3k^1\frac{Q_A^1 - q_i^1}{(Q_A^1)^2} = 0 \tag{68}$$

Summing up N f.o.c. sums up to

$$N\alpha - (N+1)bQ_A^2 - \sum c_i - Nm\delta^1 + d^2\frac{mE^3}{(Q_A^1)^2}\{\sum^{N-G}(Q_A^1 - q_i^1)(1-k^2) + \sum^{G}(Q_A^1 - q_i^1)k^1\} = 0 \tag{69}$$

given that $k^1 = \binom{\min p^1}{p^1 \in C(k)} = p^1 - \varepsilon$ and $k^2 = \binom{\min p^2}{p^2 \in C(k)} = p^2 - \varepsilon$ I get

$$N\alpha-(N+1)bQ_A^2-\sum c_i-Nm\delta^1+d^2\frac{mE^3}{(Q_A^1)^2}\{\sum^{N-G}(Q_A^1-q_i^1)(p^1+\varepsilon)+\sum^{G}(Q_A^1-q_i^1)(p^1-\varepsilon)\}=0 \tag{70}$$

rearranging

$$N\alpha-(N+1)bQ_A^1-\sum c_i-Nm\delta^1+d^2\frac{mE^3(N-1)p^1}{Q_A^1}<0 \tag{71}$$

solving Equation (71) I get that Q_A^1:

$$(Q_A^1)^*>\frac{\overline{Q^1}}{2}+\sqrt{\frac{(\overline{Q^1})^2}{4}+d^2\frac{m(N-1)E^3p^1}{2(N+1)b}}=Q_U^1 \tag{72}$$

13.4 Proof of Proposition 8

Substituting spread allocation with an additional parameter θ to Equation (??) has no effect on the maximisation in period $t=3$, as the parameter θ cancels out. Therefore, an increase of uncertainty has no effect on the total output in the sector. However, in the case of ambiguity, increase of ambiguity has a different effect on total output.

An increase of parameter ε decreases Equation (70) and it becomes even less than Inequality (71)

$$N\alpha-(N+1)bQ_A^1-\sum c_i-Nm\delta^1+d^2\frac{mE^3(N-1)p^1}{Q_A^1}\ll 0$$

as a result the value of Q_A^1 increases beyond its value in Inequality (72)

$$
\begin{aligned}
(Q_A^1)^{**} &\gg \frac{\overline{Q^1}}{2} + \sqrt{\frac{(\overline{Q^1})^2}{4} + d^2 \frac{m(N-1)E^3 p^1}{2(N+1)b}} \\
(Q_A^1)^{**} &> (Q_A^1)^*
\end{aligned}
$$

Therefore, the total effect on Q_A^1 is positive as ε increases.

Chapter 3: Disposition in the carbon market and institutional constraints

Abstract

This chapter investigates the impact of banking and submission constraints, set by the EU Emission Trading Scheme, on the efficiency of the carbon permits spot market using intra-daily data. My aim is to identify whether there is a Disposition effect in the spot market. I will examine a data set that includes spot prices for the First and Second Phases of the Scheme from 24 June 2005 to 07 August 2009. I find that the Disposition effect is significantly high at the beginning of each Phase and decreases close to the first compliance event. In the light of these results I propose a lifting of the ban on banking between Phases and an increased emissions information disclosure in order to increase the efficiency of the Scheme.

14 Introduction

The aim of the European Union Emission Trading Scheme (ETS) is to set up a platform for achieving a target reduction of CO2 emissions in the most efficient way. In order to achieve the emissions target, each installation receives carbon permits on a yearly basis, which can be traded at one of the existing environmental trading platforms. The permits are valid only within the allocated Phase, and banking of permits between phases is not allowed.[28] By the end of March installations are required to submit enough permits to cover their yearly

[28] The First Phase covers the period form 2005 to 2007; the Second Phase covers the period from 2008 to 2012.

emissions. These institutional constraints allow installations to plan their investments and to also neutralise the irregularities of CO2 emission levels within each Phase.

However, such institutional constraints have also a negative effect on the efficiency of the market. Daskalakis *et al.* (2008) suggest that the behaviour of the carbon market is not consistent with weak-form efficiency according to which all the information contained in past prices is reflected in the current price. The authors demonstrate that permit returns are serially predictable and that simple trading strategies can be employed in order to produce substantial profits. The authors argued that one of the reasons that the carbon market is not efficient could be due to the restrictions imposed on permits banking. Spot prices for carbon permits also exhibit high volatility, where the highest decline followed the release of verified emissions in April 2006. Betz *et al.* (2006) suggest that spot price volatility has a profound impact on long-term investment risk and in turn can also affect the efficiency of the carbon market.

These institutional constraints can, therefore, have a potential negative effect on carbon market efficiency. Despite the importance of the topic, there is a scarcity of literature that analyses the role of institutional constraints in price dynamics and carbon market efficiency. Borak *et al.* (2006) find an overall increasing price volatility with an increase in maturity. These surprising results contradict the time to maturity effect that suggests a decline of price volatility as maturity increases. According to the authors these findings suggest that there is a high uncertainty in the market, which can result from the uncertainty with regard to the future allocation of the permits. Daskalakis *et al.* (2009) suggest, without providing empirical evidence, that the prohibition of banking permits between phases can have significant implications on the pricing of permits derivatives. The authors propose to lift the ban on banking in order to decrease the uncertainty in the market. Unrestricted banking, in their opinion, increases efficiency in the market and leads to emissions reduction at the least possible cost. Chevallier *et al.* (2008) show that in the carbon market there is a relation between the institutional constraints and the modification of investors' subjective beliefs. The authors found a significant change in the risk aversion of traders in April 2006, when the actual figures on emissions were first published. However, the above studies do not provide an explanation for how those institutional constraints affect the evolution of the carbon permits price.

It is worth mentioning, however, those few studies that investigate the evolution of the carbon permits price. Bunn and Fezzi (2007) show that the price of permits and the price of energy in the UK have a major role in formulating each others' equilibrium price. The authors indicate that the permits price reacts quickly to shocks in gas prices; however, the pass through of shock in permits price to the electricity market is much slower. Extreme weather conditions are identified as one of the fundamental factors that determine permits price (Mansanet-Bataller *et al.*, 2007). Indeed, extreme temperatures affect the demand for energy. For instance, in cold winters there is an increased demand for heating. As a result, power generators increase their emissions and in turn the demand for permits increases as well. The significant effect of industrial indices on the determination of permits price is demonstrated by Alberola *et al.* (2007). The authors show that the price of permits reacts to the economic activity of the main sectors that are covered by the ETS. They point out that the announcement of the European Commission on verified emissions in 2006 revealed that prior to the announcement, trading had been based more on anticipation rather than the fundamental price mechanism. Benz *et al.* (2009) propose that due to different regimes in carbon price and volatility behaviour of returns, the AR-GARCH model outperforms constant volatility models.

Although the carbon permit is not a pure financial commodity in the usual sense as it expires at the end of each Phase, there seems to be a general consensus that it should be studied as such (among others see Kosobud *et al.*, 2002, Daskalakis *et al.*, 2009, Benz *et al.*, 2009). Explanations of the anomalies in the financial market can, therefore, assist in clarifying the role of the financial institutions' constraints in the context of the carbon market. One of the extensive fields of empirical finance incorporates psychological biases into the analysis of investment decision making. One of the most documented psychological anomalies in financial literature is that of the Disposition effect. Disposition-prone investors tend to hold on to their losing assets, and realise their winning assets (Shefrin *et al.*, 1985). This tendency contradicts the rational behaviour of the market, where investors hold their winning assets and get rid of their losing assets. Another documented anomaly is the tendency of investors not to react to news, which creates a drift in price and return predictability. The risk aversion of the Prospect Theory type (Kahneman and Tversky, 1979) together with mental accounting explains both the Disposition effect (Grinblatt and Han, 2005) and the delayed reaction to news in the market (Frazzini, 2006).

In the light of the existing literature it seems that there is a place to analyse the effect of the Prospect type risk aversion, specifically the Disposition effect, on the pricing mechanism of carbon permits. I will contribute to the existing literature by evaluating the link between institutional constraints and the Disposition effect in the carbon market. I will investigate whether there is a change in the Disposition effect around compliance events of the First and Second Phases and towards the end of the First Phase. To perform my analysis I use a data set of intraday data from the BlueNext exchange platform (BlueNext Spot EUA 05-07, BlueNext Spot EUA 08-12, BlueNext Spot CER) a historical transactions data set recorded since 24 June 2005. Unlike Benz *et al.* (2009) and Chevallier *et al.* (2008) who use the GARCH process, I will use the ARMA process, which delivers estimations without remaining autocorrelation in the residuals. I will also use an additional dummy variable of capital gains that captures the Disposition effect in the market. To construct a capital gains variable I will follow a methodology proposed by Grinblatt and Han (2005). The authors show that disposition behaviour, where investors tend to hold their losing assets, has a predictive power on future returns. The use of high frequency data is necessary for a reasonable approximation of capital gains (Grinblatt and Han, 2005). High frequency data allows me to trace changes in Disposition that occur during the daily trade.

My findings suggest that the Disposition effect holds throughout the two sample periods. I have found that the Disposition effect significantly decreases after April 2006 and 2007, after the publication of verified emissions by the European Commissioner. These findings suggest that the compliance event that occurs between March and April has a significant effect on shaping the behaviour of market participants. Specifically, the availability of information on total emissions contributes to the rational behaviour of the carbon market participants. My findings also show that after the first compliance event of the Second Phase the Disposition effect stabilises and remains constant throughout the rest of the period. These findings strengthen the argument that the first compliance event has a significant effect on the evolution of the carbon spot price and in turn the efficiency of the carbon market. Opposed to the proposition of Daskalakis *et al.* (2009), however, my finding shows no evidence of the effect of banking constraints on the risk perception in the market.

The remainder of the paper is organised as follows: Section 2 outlines the EU ETS structure, the BlueNext exchange platform and the data. Section 3 specifies the econometric model and discusses the results. I will also perform a robustness analysis of the results where various specifications of model and independent variables yield similar qualitative results. In section 4, I will test the relevance of institutional constraints in the context of the carbon market and provide policy recommendations. In Section 5 I present my conclusions.

15 EU ETS and BlueNext

The EU has introduced the Emission Trading Scheme to comply with the international emissions target commitment set by the Kyoto Protocol. The ETS is the first trading scheme to operate on the international scale so as to tackle global warming concerns. Each member state in the EU can achieve its obligations of reducing the total national emissions by using one of the flexible mechanisms set by the Protocol. Permits trading is one among the three mechanisms.[29] The first trade in carbon permits took place in 2005, three years prior to the protocol commitment period. The first three years of the scheme operation, which are usually referred to as First Phase (2005-2007), were aimed at adjusting the market to the

[29] Clean Development Mechanism and Joint Implementation are additional mechanisms that aim to reduce emissions through projects that reduce emissions in foreign countries.

emissions trade and smoothing the transactions of the market to the Protocol commitment period. This corresponds to the Second Phase (2008-2012) of the ETS. Each member state submits, prior to each Phase, its National Allocation Plan for approval by the European High Commissioner. The purpose of a NAP is to describe the allocation rules that govern the initial allocation of permits to installations, and the total of CO_2 that member states are to extract during each Phase. The total of emissions is referred to as a cap.

Most of the states chose to allocate their cap according to a relative historical benchmark, a method often labelled as grandfathering. For instance, according to the UK NAP for the Second Phase, allocation to installations is based on their relative production prior to the Phase, specifically during the period 2003-2005.[30]Each permit allows extracting one tonne of CO2 during the allocated Phase. An allocated permit expires at the end of each Phase, and the owner of the permit cannot bank it to cover emissions that are generated in a different Phase.[31] The member states allocate permits to installations on a yearly basis, and the latter must submit enough permits to cover their yearly emissions. In April, when the submission process is over, the European High Commissioner publishes the verified figures of emissions for the previous year.[32] The trade of the permits is open to the public. However, only a few sectors are covered by the NAPs. Only those installations whose historic production/emissions are above a predetermined threshold have to submit permits to cover

[30]For a detailed description of NAP of the member states please visit the EU website: http://ec.europa.eu/environment/climat/emission_plans.htm.htm

[31]However, banking within the Phase is permitted.

[32]It is evident that the allocation of allowances for the First Phase of EU ETS has been too generous, as it is argued by environmental groups. This argument is debated by Ellerman and Buchner (2008). The authors argue that installations that abate for profit purposes would be considered as being in excess of permits.

their emissions.

There are currently a few trading platforms that allow the trade of emissions permits. Futures, options and Certified Emission Reduction (CER)[33] are among the possible trading opportunities, in addition to the spot market available to traders. BlueNext Spot EUA is one of the leading spot exchanges for EU carbon permits with over 60 per cent of the market share in the spot exchange. It was founded by NYSE Euronext and Caisse des Depots, in December 2007. It consists of 101 members and has a 95 per cent market share. Futures and spots on EU permits as well as CER are traded on BlueNext. Cash held on account earns an interest rate of the Euro Overnight Index Average minus an eighth. The price tick is 0.01 €/t, and the minimum price is 0.01 €/t. The volume tick is 1,000 tons and the minimum volume tick is 1,000 tons. Its trading hours are between 8:00 AM to 5:30 PM (UTC+1), from Monday to Friday. The delivery and settlement operated by BlueNext is in real time. Delivery consists of the transfer of the underlying permits from the seller's account to the buyer's account via a BlueNext transit account in the French registry for the EUA.[34]

15.1 Data description and regression

My data consists of a data set provided by BlueNext. The data set contains data of the spot prices and traded volumes of permits, including information about the date, time of trade and traded volume. The data is an irregular spread in time intra daily closing spot price from 24 June 2005 to 07 August 2009 amounting to total of 40,339 observations. The data set include data on permits for the First (BlueNext Spot EUA 05-07) and Second Phases

[33] For more information on CER please see: http://unfccc.int/2860.php.

[34] The complete description of BlueNext is available at http://www.bluenext.eu/.

(BlueNext Spot EUA 08-12), as well as some observations on CERs. I have divided the data set into two sets with observations related to the First and Second Phases. I do so in order to identify the effect of psychological biases on the price of permits for the First in contrast to the Second Phases. After excluding from the data set observations related to trade of CERs, in order to concentrate only on the price evolution of permits, the total number of observations is 37,924.

I denote P_t to be the spot price of carbon permit observation at time t. The log returns of carbon spot prices at time t is $r_t = log\frac{P_{t+2}}{P_t}$. In order to account for high trading activity during the opening and closure of the market, I consider volatility adjusted returns $\widetilde{r}_t = \frac{r_t}{s_T}$ where s_T denotes standard deviation of returns on the day r_t is observed. This way I construct a time series of standardised returns for the First and Second Phases, where the former consists of 4,927 and the latter of 32,997 observations. Figures 1 and 2 display the series of standardised log returns for both the First and Second Phases, respectfully.

16 Disposition effect

In this section I will test whether in the market for carbon permits there exists a significant Disposition effect on the dynamics of carbon log returns.[35] In what follows, I describe the capital gain specification of Grinblatt and Han (2005) and the statistical model. I conclude this section by performing a robust analysis which shows that my findings are robust to a different sampling, model and variable specification.

[35] For evidence of the effect of psychological bias on the dynamics of prices in emerging markets see, among others, Tan *et al.*, 2008 and Chen *et al.*, 2007.

Table 1 documents the sample mean, standard deviation, minimum, maximum, median, skewness and kurtosis of the standardised log returns variable $\tilde{r}_t$. In the First Phase the log returns variable exhibits a slight deviation from the normal distribution by displaying a slight positive excess kurtosis, due to the high concentration of log returns around zero. In addition, log returns in the First Phase exhibit a slight positive skew. In contrast, in the Second Phase the standardised log returns exhibit a very high positive skew as well as a high kurtosis in comparison to the First phase. This may be due to a higher concentration of positive log returns in the Second Phase. Table 1 also reports a significantly high positive autocorrelation in the first lag for both First and Second Phases. There is no evidence for volatility clustering in the standardised log returns (Figures 1 and 2) in contrast to normal log returns (Figure 3 and 4). The latter suggests that volatility clustering in the log returns is mainly due to different regimes in daily trading activity.

I employ an ARMA specification to account for the autocorrelation in the log returns and unobserved shocks in the market. I will also consider a dummy variable for capital gains, which I will construct using a method similar to the one used by Grinblatt and Han (2005). As in Grinblatt and Han, I will construct a costs basis R_t as a proxy for the reference price of the permits portfolio. However, I lack the information on the real identity of the permit holders. To overcome this obstacle, Grinbaltt and Han suggest that R_t can be approximated by $R_t = \sum_{n=1}^{\infty} \left(V_{t-n} \prod_{\tau=1}^{n-1} [1 - V_{t-n+\tau}] \right) P_{t-n}$, where $V_{t-n} \prod_{\tau=1}^{n-1} [1 - V_{t-n+\tau}]$ is a probability that a permit has been purchased at date $t-n$ and V_t is a turnover ratio. However, unlike Grinbaltt and Han, I propose an alternative proxy for the turnover variable V_t at each point of time t. The proxy that I will use consists of the total number of traded permits the day the observation t is taken and the total number of traded permits at each observation point t. V_t is the proxy for turnover ratio, which represents the probability of buying an additional asset and is expressed in the following manner:

$$V_t = \frac{\text{Total of traded permits at each observation point } t}{\text{Total of traded permits the day observation } t \text{ is taken}}$$

I define capital gains g_t at time t as the log of the spot price of carbon permit P_t and the reference price R_t, which is $g_t = \log \frac{P_t}{R_t}$. Similar to Grinblatt and Han (2005) I employ g_{t-1} instead of g_t in the regression so as to avoid market microstructure effect, such as bid-ask bounce. To evaluate the Disposition effect in the carbon market, I have employed an ARMA(1,1) specification where I include the capital gain proxy variable g_t.This gives way to

$$r_t = +\alpha g_{t-1} + \phi r_{t-1} + \varepsilon_t + \varphi \varepsilon_{t-1} \tag{73}$$

where ε_t is iid. The capital gains coefficient α represents the Disposition effect on the logreturns. According to the theoretical framework of Grinblatt and Han (2005), the Disposition effect prevails in the market if the coefficient $\alpha > 0$.

16.1 Estimation results

I estimate by least-squares Equations (73) for the series of log returns for the First and Second Phases. I report the results in Table 3. I have employed the ARMA(1,1) process, as the latter copes better with autocorrelation in the residuals than the AR(1) process. The Q-statistics of the Ljung-Box test (1978) show that an MA(1) component is necessary to cope with the first order autoregressive structure in the log returns for two Phases. The results of the Ljung-Box test (1978) show no evidence of a remaining autocorrelation in the residuals up to the 13th order. I proceed, therefore, to the analysis of the estimates. All of the coefficients reported in Table 3 are significant.

Table 3 also reports that there is a significant momentum which arises from the strategies that form portfolios from the first autoregressive and moving average components ϕ and φ, respectively. However, the most important result comes from the variable of capital gains. The significant coefficient of α suggests that there is a significant positive effect on the returns coming from the capital gains variable. This is consistent with the Disposition effect reported by Grinblatt and Han (2005). Altogether, my findings indicate that during the First and Second Phases of ETS the price of carbon permits is affected by the Disposition tendency of traders in the market.

16.2 Robustness analysis

To evaluate the sensitivity of my findings I will perform a robustness analysis of the predicted coefficient on capital gains. In particular, I will test whether there are qualitative changes in the coefficient due to variations in the sample period, capital gains variable and model specifications. First, I will divide the data set into five subsamples: 2005, 2006, 2007, 2008 and 2009. The main goal is to show that during all the sub-periods of First and Second Phases of the Scheme capital gains have a significant positive effect on the log returns. Results of the Ljung-Box test (1978) in Table 4 show no evidence for the remaining autocorrelation in the residuals. The capital gains variable is still positive and significant. This suggests that my findings are robust to the sampling of the data. Another interesting feature of the subsample results is that there is a significantly high effect coming from the capital gains at the beginning of the each Phase. These latter findings may suggest that during the first year of each Phase market participants, on average, are more Disposition-prone than during the rest of the Phase. This may be due to the novelty of the market and/or commodity during the First Phase and the lack of information on the commodity price fundamentals during the Second Phase. As the market becomes more mature, the Disposition effect diminishes.

Secondly, I will consider an alternative capital gains variable that tests the sensitivity of my results to a different specification of the capital gains variable. To construct a new reference, instead of using reference R_t, I will set my reference to be a maximum past price (Heath *et al.*, 1999). I will take a maximum of the past 30 observations to be my alternative reference $\widetilde{R_t} = \max(P_{t-30}; P_{t-1})$.The new capital gains variable is, therefore, $\widetilde{g}_t = \log \frac{P_t}{\widetilde{R}_t}$. Table 4 shows that the alternative specification of the capital gains does not affect the qualitative result which suggests that the capital gains variable is positive and significant in both Phases. I, therefore, conclude that the significant predictive power of the capital gains is not an artefact of the way I have constructed it.

Thirdly, I will test whether my results are due to the standardisation of log returns. Table 2 documents the sample mean, standard deviation, minimum, maximum, median, skewness and kurtosis of the log returns variable r_t. The log returns variable exhibits a positive excess kurtosis both in the First and Second Phases, due to the high concentration of log returns around zero. In addition, log returns in the First Phase exhibit negative skew, due to a larger concentration of negative log returns. However, in the Second Phase the log returns exhibit positive skew, due to a larger concentration of positive log returns. Table 2 also reports significantly high positive autocorrelation in the first two lags for First and Second Phases (in addition to the volatility clustering which is evident from Figure 3 and 4). I will, therefore, employ an ARMA(1,1)-GARCH specification to estimate the evolution of carbon spot log returns similar to Benz *et al.*, (2009) who consider AR-GARCH and Borak *et al.*, (2006) who consider MA-GARCH specifications. I will employ an ARMA(1,1)-GARCH(1,1) specification to account for the autoregressive component in addition to volatility clustering in the log returns. As before, I will include the capital gain variable g_t. This gives way to

$$r_t = \alpha_0 + +\alpha_1 g_t + \phi_1 r_{t-1} + \varepsilon_t + \varphi_1 \varepsilon_{t-1} \tag{74}$$

$$\varepsilon_t = u_t \sigma_t \tag{75}$$

$$\sigma_t^2 = \beta_0 + \theta_1 \varepsilon_{t-1}^2 + \theta_2 \sigma_{t-1}^2 \tag{76}$$

where $\varepsilon_t \sim iid(0,1)$. Table 5 reports the estimated coefficients of Equation (74). Although the ARMA-GARCH specification cannot cope with autocorrelation in the residuals, the overall results indicate that there is a significant Disposition effect in the market both in the First and the Second Phases.

To conclude, my results provide robust evidence of the Disposition effect in the carbon market during the First and Second Phases. It is my next task to provide an explanation as to the cause of such an effect and how to diminish it. In the next section I suggest that the institutional constraints of the Scheme are the main cause for increasing the Disposition effect in the market.

17 Institutional Constraints

In this section I will estimate Equation (73) for changes in the capital gains variable due to institutional constraints. The most important institutional features of the ETS are twofold: firstly, there is a statutory obligation for installations to submit their verified emissions by the end of March each year. The installations are obliged to submit enough permits to cover their yearly emissions. By the end of April, actual emissions figures are revealed to the market. The market, however, learns of the actual emissions prior to the publication of the actual emissions when the market is updated with the actual emissions figures. From the demand for permits in the carbon market, the traders can learn whether the market has a surplus or deficit of permits. If there is, therefore, a strong signal in the market of the real value of the permits, it can diminish the effect of psychological biases on the carbon price during and/or after the publication of official figures for the total emissions levels.

Secondly, there is a ban on permits banking between First and Second Phases.[36] There is an argument in the literature that the banking prohibition has an effect on the efficiency of the carbon market (Daskalakis et al., 2008). This effect, however, has not been tested so far and no direct evidence points to that. The argument in favour of abandoning the ban is that during the transition period between Phases, there is a loss of installations' flexibility to adhere to the emissions limitation and the ban on banking can increase inefficiency towards the end of each Phase. This constraint, in turn, affects the efficiency of the trade (Schleich et al., 2006). In addition, at the beginning of each Phase market participants have to re-establish their expectations and learn the new commodity mechanism. This in turn creates

[36] Banking is suggested for the Third Phase of ETS.

uncertainty and may increase psychological biases at the beginning of each Phase.

In order to detect how these institutional constraints affect the price evolution in the market, I will conduct a two-step analysis. Firstly, I will trace the evolution of estimates for the capital gains coefficient throughout the First and Second Phases. Figures 5 and 6 provide a plot of α for the capital gains estimator for both First and Second Phases, respectively. Figure 5 shows a dramatic jump downwards which indicates a structural break in the data during the first compliance event in April 2006. This coincides with the release of official figures for total emissions. These results are in line with findings reported by Chevallier *et al.* (2008) who detected a dramatic change in the market perception of risk during the 2006 compliance event. After the first compliance event the coefficient slightly increased up until the second compliance event in April 2007, and decreased toward the end of the First Phase. Figure 6 shows no dramatic changes occurred in the Second Phase. The plot of α coefficient, however, stabilised after the first compliance event in April 2008. In addition, Figure 5 and 6 indicate that at the beginning of each Phase the α coefficients were significantly higher than during the rest of the Phase and decreasing toward the first compliance event.

Secondly, I will divide the data set into three subsamples categories: Jan-Feb, Mar-Apr and the rest of the year. The first two subsamples detect changes in the Disposition effect before and during the submission of verified emissions, respectively. Whereas the latter subsample distinguishes the magnitude of Disposition during the rest of the year from the two submission periods, Tables 6 and 7 report the results. It is evident from the results that during the Mar-Apr subsamples for the First and Second Phases capital gains variables are significantly lower than during the preceding year subsamples. This coincides with the results of the two plots of α coefficient.

These findings suggest that, whereas banking prohibition increases Disposition in the market at the beginning of each phase, the first compliance events significantly diminish it and contribute to the stabilisation of market expectations. Such behaviour of the capital gains coefficient can be attributed to the degree of information uncertainty in the market. The literature recognises that psychological biases are increasing under conditions of higher information uncertainty (Hirshleifer, 2001; Daniel *et al.*, 2001 and Zhang, 2006). When the market learns its real position, fewer participants are subject to psychological biases. This explanation is also in line with the framework proposed by Grinblatt and Han (2005). According to the authors, the smaller the number of investors who are subject to Disposition, the smaller their effect on the market price.

These results validate the proposition that institutional structure has an effect on the efficiency of the carbon market, which is transformed to a high Disposition effect, as I have reported above. The results point out that Disposition in the carbon market is a factor of information uncertainty, especially during the first year of each Phase. In addition, the above results indicate that the first compliance event has a vital role in shaping the expectations in the market, by stabilising and/or diminishing the Disposition in the market. The question that arises is how to eliminate, or at the very least diminish, the Disposition in the market. The purpose of the next section is to address these questions.

17.1 Discussion and analysis

In previous sections I have demonstrated that the price trend in the market for carbon permits can be explained by assuming psychological biases, specifically, the Disposition effect. It is not surprising to find the Disposition effect in the market of carbon permits in light of extensive evidence, which tracks this phenomenon in financial markets. In the context of the carbon market, however, these results should receive major attention. The policy designer should seek and eliminate the Disposition that affects trade of carbon permits. Identifying the source of the Disposition effect in the institutional structure of the Scheme should allow the policy maker to diminish its effect and increase the efficiency of the carbon market.

As I have pointed out in the previous section, institutional constraints on the installation during the First and Second Phases of the Scheme operation, such as yearly submission and a ban on banking of permits, are the main drivers of the Disposition effect. Policy makers who wish to achieve emissions abatement in the most efficient manner should, therefore, not disregard these findings. These results point out that the carbon market, which should create an efficient environment for trade of carbon permits, is not efficient due to those constraints. Similar results have already been pointed out by Daskalakis *et al.* (2008) and Chevallier *et al.* (2008).

The above results indicate that before the first compliance event the Disposition effect is higher than during the rest of the year. As I suggested above, this could be due to information uncertainty. One suggestion that may reduce the Disposition in the market is to make the information on the emissions level public. Installations that trade carbon permits should reveal their emissions intensity and make it publicly accessible throughout the year rather than once a year. A similar method is already practiced in the stock exchange market where publicly traded companies are required to make their information public on a regular basis. It seems reasonable to make emissions levels publicly known as the benefit would be in the highly efficient carbon trading platform, which would benefit both the installations, for having an efficient trading platform, and the public, in the way of an efficient abatement system.

Another way of reducing the information uncertainty as to the market position with respect to the carbon permits would be by engaging installations to submit permits to cover their emissions more frequently than once a year (a frequency that is suggested by current practice). This way the information gets to the market more frequently. This may eliminate such dramatic changes in the market expectations as were evident during the First Phase. It may also reduce the uncertainty in the market and in turn reduce the effect of psychological biases on the carbon price in a more consistent way, without creating unnecessary shocks to the system. The information uncertainty is to be diminished to make way for the efficient market of carbon permits. Reducing the uncertainty by revealing the information may reduce the psychological biases of the traders and create a more efficient market. These suggestions are in line with a proposition made by Seifert *et al.* (2008). The authors argue that in immature markets, such as the carbon market, expectation building is not working well. In such conditions frequent publication of emissions would improve expectation building in the market.

The results of the previous section also point to another flaw of the Scheme, which is the ban on banking between Phases. The results show that this constraint increases the

Disposition effect at the beginning of each Phase. This flaw is addressed by the literature (among others see, Schleich *et al.*, 2006 and Alberola *et al.*, 2009). Indeed, in the proposal for the Third Phase of ETS, the banking ban is dropped. This proposition could contribute to the efficiency of the carbon market. The installations would not have to face the lack of information during the beginning of each Phase, and would be rewarded for carbon intensity, which could be planned for the future and not limited to only one Phase.

18 Conclusions

There is a scarcity of literature dealing with the fundamentals of the carbon price. My contribution to this literature is in presenting the first evidence of the Disposition effect in the carbon market, based on the spot price of carbon permits on the BlueNext trading platform from 24 June 2005 to 07 August 2009. The sample covers for the First and Second Phases of the EU Emissions Trading Scheme.

In the paper I presented evidence for the Disposition effect, which increases as a result of the institutional constraints, specifically the ban on banking and the yearly submission of the verified emissions. The estimated results indicate that the carbon price evolution is affected by the Disposition effect during the first year of each Phase. I assert that the main factor that drives the Disposition effect in the carbon market is information uncertainty. I have found that these results are robust by using an alternative method of tracing the Disposition effect. My results are in line with the previous evidence of the efficiency of the carbon market and findings that the Disposition has a positive effect on the evolution of price in the market.

I have suggested possible alternatives to resolve uncertainty in the market. Specifically, I have suggested revealing the information on the actual emissions level throughout the year and not only once a year. In addition, I suggest that more frequent submission of the verified emissions could reduce the Disposition effect in the market and make it more efficient. My finding also point out that the banking ban increases the psychological effect during the first year of each Phase.

It is worth mentioning, however, besides the possible policy implications outlined above that these new results have an important implication for portfolio construction and risk management. For further research it would be interesting to follow the evolution of the carbon price during the rest of the Second Phase and see whether there are changes in the market due to the alternations of institutional constraints in the Third Phase of the Scheme. Although I present evidence on one of the well-documented behavioural anomalies in the financial markets, there is place to extend current research and analyse the market for another source of inefficiency in the market. Detailed information on the identity of traders could potentially contribute to more accurate analysis and policy recommendations.

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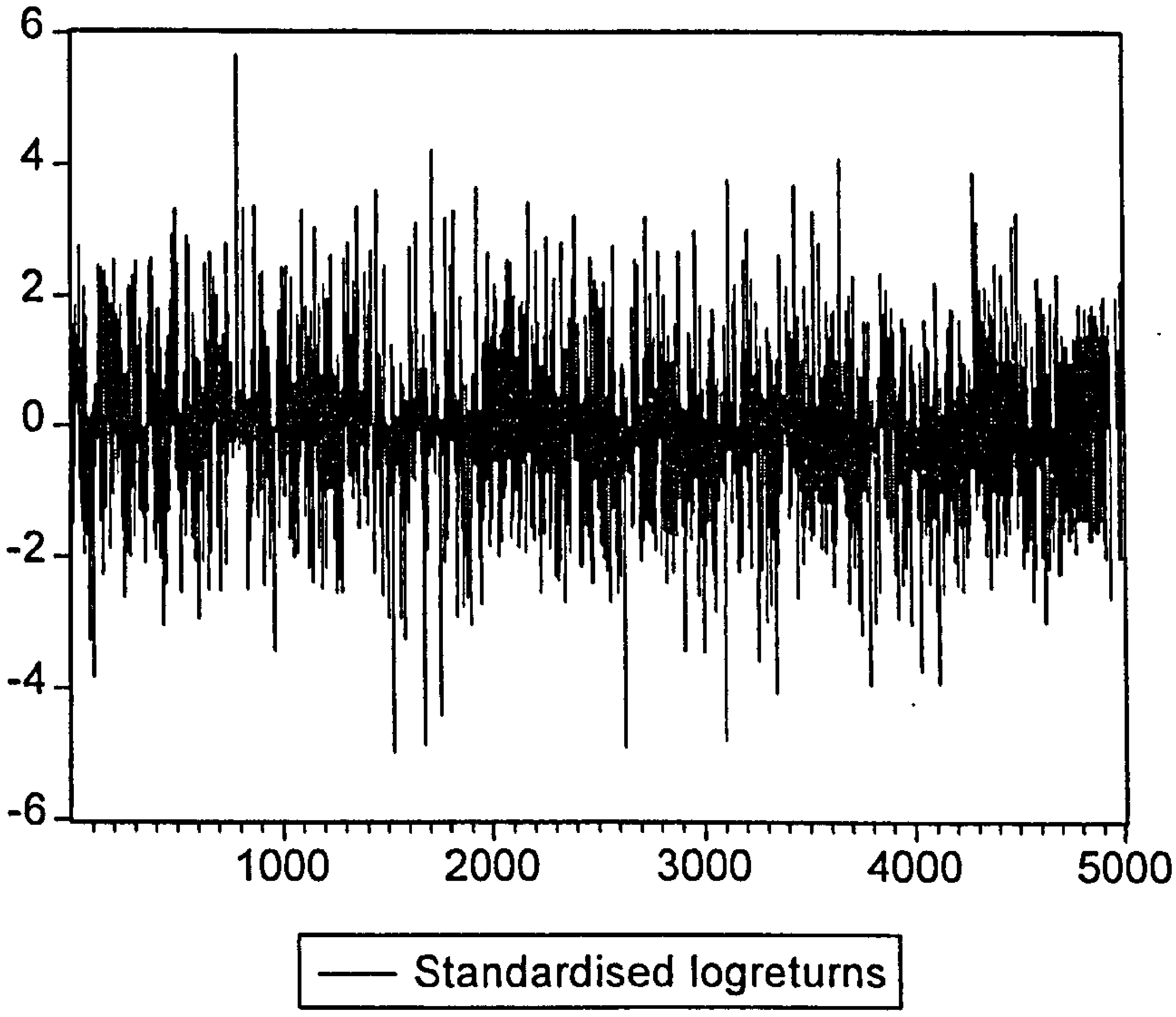

Figure 1: Standardised log returns of carbon permit prices for the First Phase

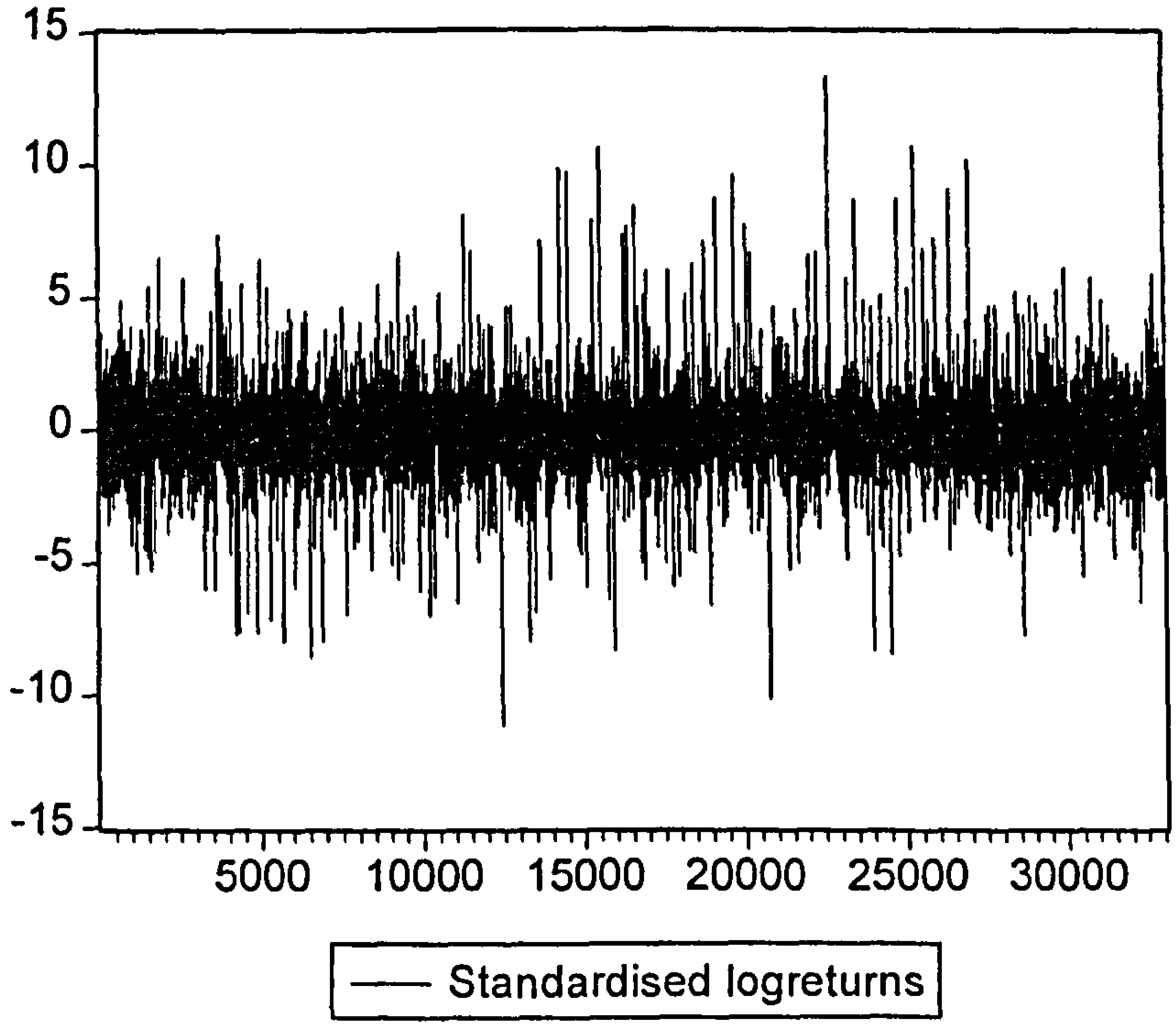

Figure 2: Standardised log returns of carbon permit prices for the Second Phase.

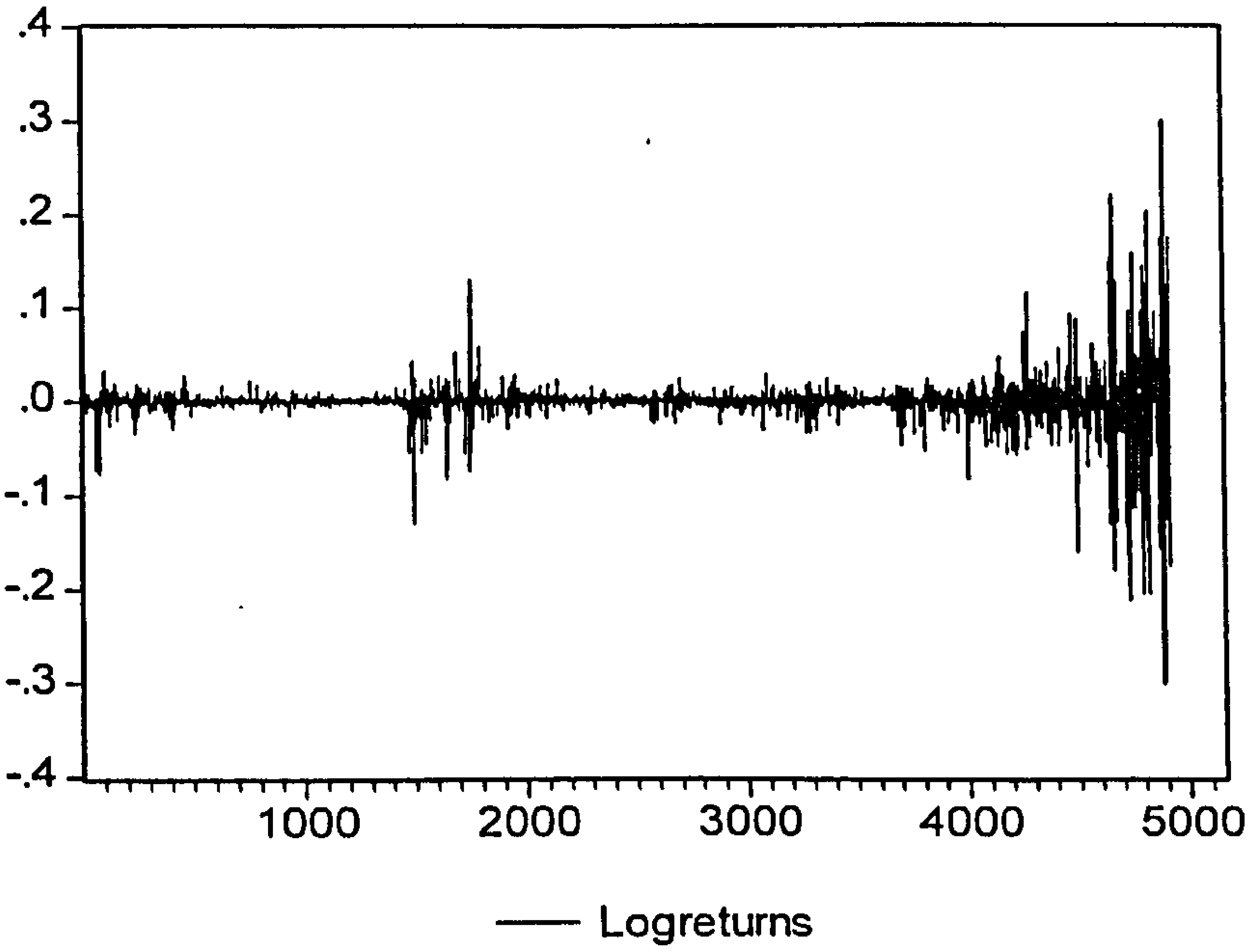

Figure 3: Log returns of carbon permit prices for the First Phase

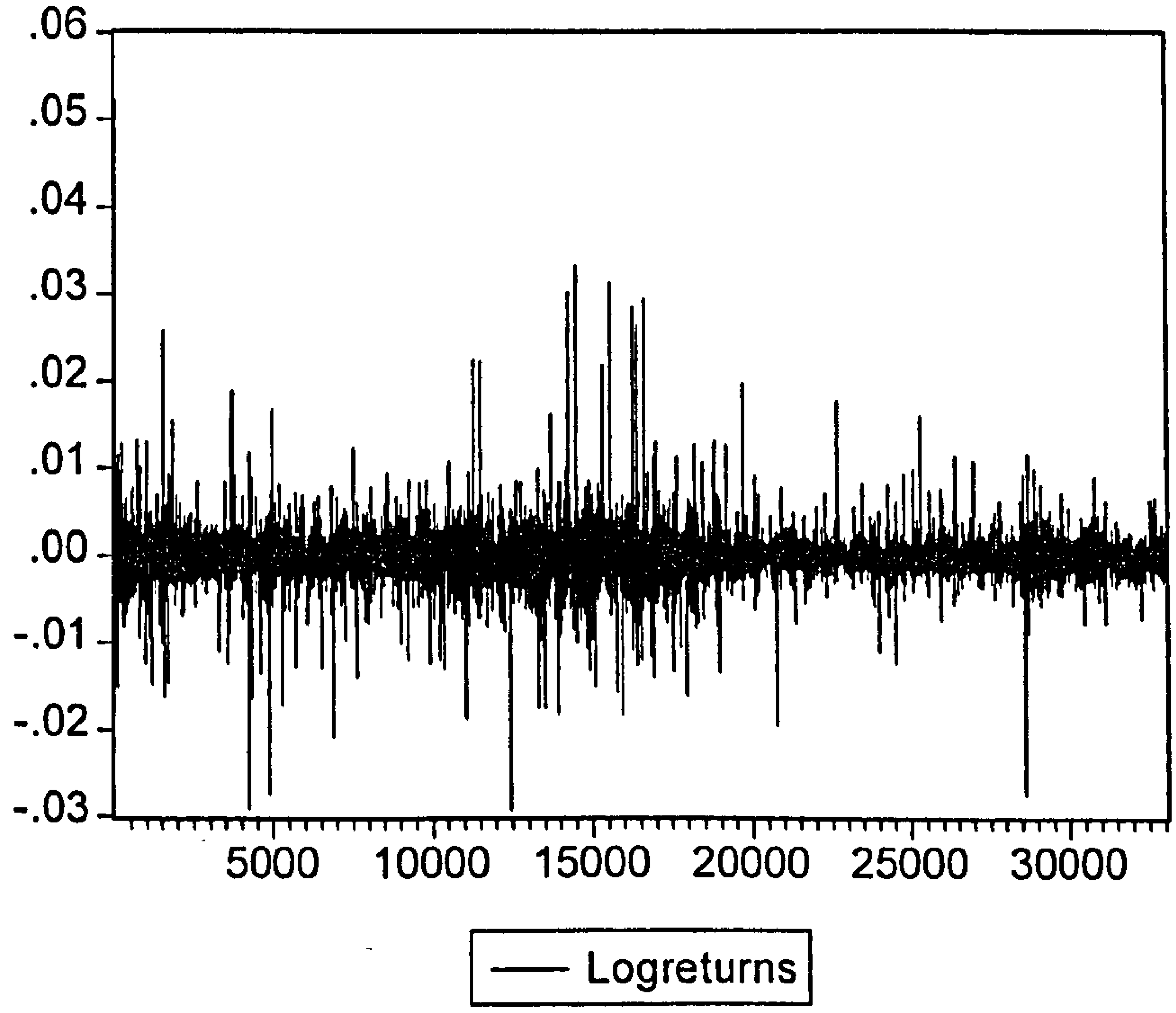

Figure 4: Log returns of carbon permit prices for the Second Phase

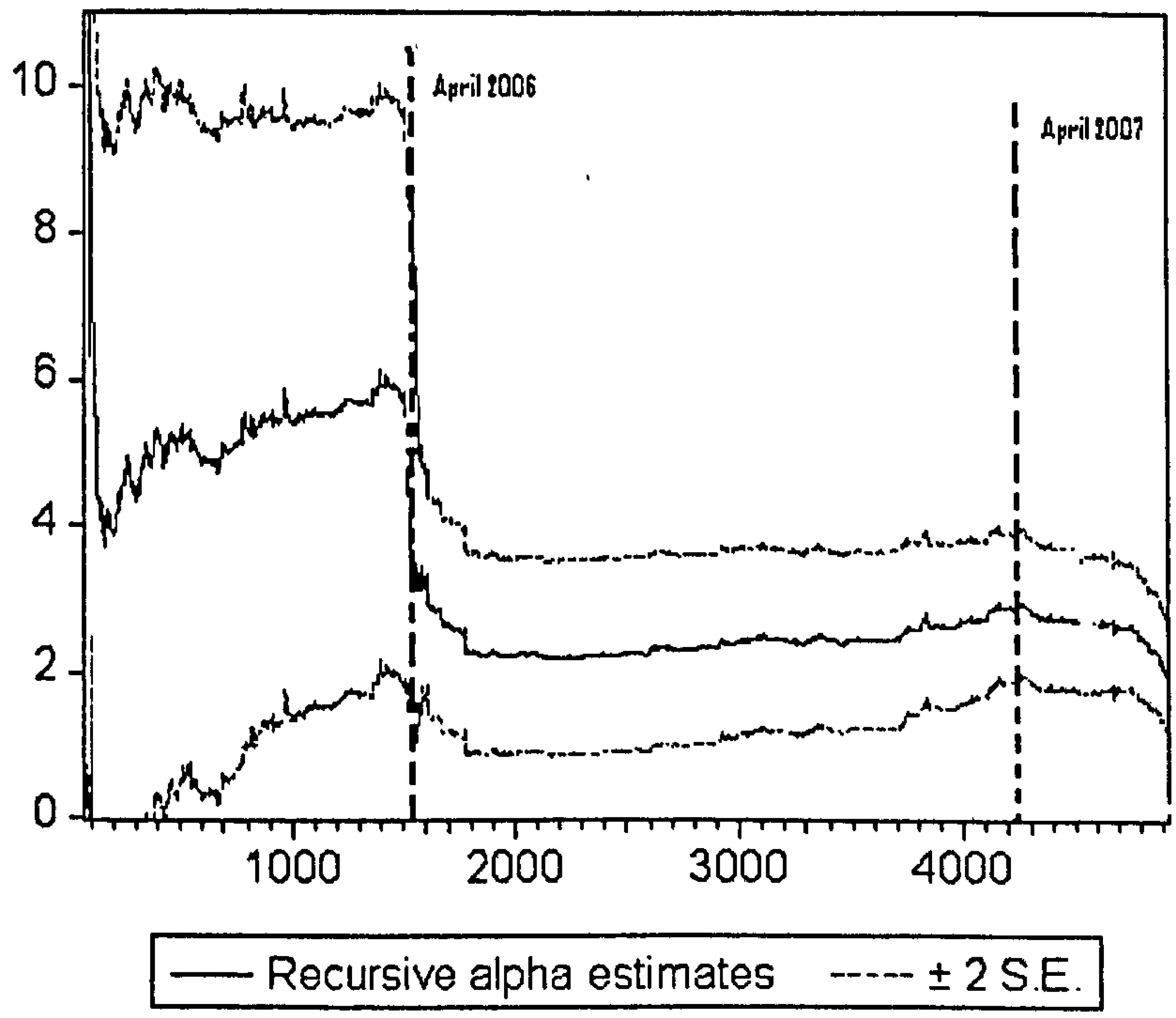

Figure 5: Evolution of alpha coefficient for the First Phase.

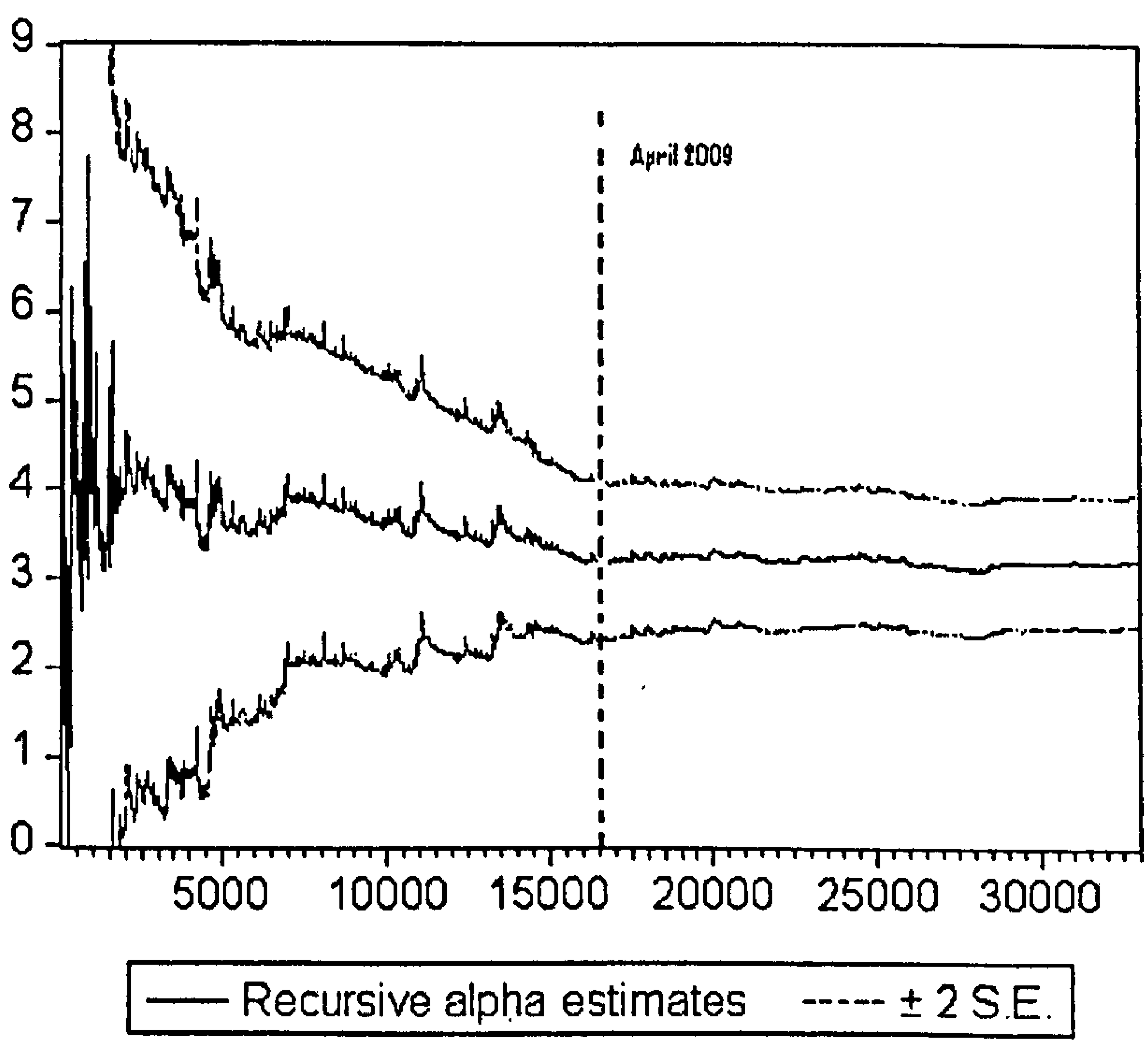

Figure 6: Evolution of alpha coefficient for the Second Phase.

Table 1: Descriptive statistics for the series of standardised log returns

The two sample period run from 24 June 2005 to 13 August 2009. I excluding from the data set observations related to trade of CERs, in order to concentrate only on the price evolution of EUAs. I compute the log returns and standardise them by the standard deviation for the day the log returns are computed. The total of observations is 37,924.

	First Phase	Second Phase
sample mean	-0.031	-0.004
sample median	0.000	0.000
sample maximum	5.671	13.341
sample minimum	-4.968	-11.127
sample standard deviation	0.999	1.000
sample skewness	0.036	0.389
sample kurtosis	5.001	18.017
number of observations	4,927	32,997
nth order autocorrelation		
n=1	0.456	0.472
n=2	-0.002	-0.011
n=3	0.021	0.022
n=4	0.012	0.018
n=5	0.011	0.009
n=6	0.018	0.010
n=8	0.020	0.011
n=10	0.016	0.010

Table 2: Descriptive statistics for the series of logreturns

The two sample period run from 24 June 2005 to 13 August 2009. I exclude from the data set observations related to trade of CERs, in order to concentrate only on the price evolution of EUAs. The total of observations is 37,924.

	First Phase	Second Phase
sample mean	-0.001	0.000
sample median	0.000	0.000
sample maximum	0.301	0.043
sample minimum	-0.301	-0.029
sample standard deviation	0.022	0.001
sample skewness	-1.558	0.781
sample kurtosis	52.502	51.274
number of observations	4,927	32,997
nth order autocorrelation		
n=1	0.433	-0.015
n=2	-0.099	-0.489
n=3	-0.089	0.021
n=4	-0.078	0.000
n=5	-0.019	-0.006
n=6	-0.017	-0.001
n=8	-0.009	-0.005
n=10	0.012	0.007
n=11	0.043	0.010
n=13	0.012	-0.002

Table 3: Estimation results

I estimate by least squares the AR(1) and ARMA(1,1) models in Equation (81) for the First and Second Phases, with period that runs from 24 June 2005 to 07 August 2009, including all together 37,914 observations. For each parameter estimate, the figures within parenthesis refer to the White's (1980) robust t-statistics. The row Q-stat. reports Q-statistics of Ljung-Box's test (1979) for autocorrelation in the residuals up to order 13. The row sample size reports the number of observations.

	First Phase		Second Phase	
	ARMA(1,1)	AR(1)	ARMA(1,1)	AR(1)
α	2.036 (5.922)	0.465 (1.397)	3.220 (9.493)	0.305 (0.807)
ϕ	−0.037 (−1.706)	0.457 (43.867)	−0.046 (−4.384)	0.472 (39.173)
φ	0.730 (24.229)		0.869 (58.932)	
R^2_{Adj}	0.322	0.208	0.401	0.222
Q-stat.	0.367	0.000	0.367	0.000
sample size	4,914	4,915	32,997	32,997

Table 4: Robustness analysis: Sub-sampling and specification

I estimate by least squares ARMA(1,1) model in Equation (81) for the period that runs from 24 June 2005 to 07 August 2009, including all together 37,914 observations. The columns of 'subsample estimations' consider yearly subsamples and columns of 'alternative specification' consider capital gains variable with alternative reference. For each parameter estimate, the figures within parenthesis refer to the White's (1980) t-statistics. The row Q-stat. reports Q-statistics of Ljung-Box's test (1979) for autocorrelation in the residuals up to order 13. The row sample size reports the number of observations.

	sub-sample estimations					altrenative specifcation	
	2005	2006	2007	2008	2009	First Phase	Second Phase
α	11.192 (4.355)	3.969 (4.662)	1.774 (3.045)	9.499 (6.693)	4.710 (6.775)	1.926 (5.125)	17.566 (14.098)
ϕ	0.021 (0.333)	−0.040 (−1.476)	−0.006 (−1.522)	−0.072 (−3.829)	−0.043 (−3.410)	−0.041 (−2.064)	−0.045 (−4.244)
φ	0.669 (15.883)	0.747 (49.503)	0.726 (25.091)	0.847 (102.828)	0.881 (184.344)	0.734 (53.251)	0.868 (203.151)
R^2_{Adj}	0.324	0.335	0.288	0.376	0.412	0.326	0.404
Q-stat.	0.933	0.691	0.187	0.920	0.673	0.978	0.367
sample size	628	3,055	1,240	9,543	23,454	4,697	32,970

Table 5: Robustness analysis: ARMA-GARCH

I estimate by maximum likelihood the ARMA(1,1)-GARCH(1,1) models in Equations (82) and (84) for the First and Second Phases, with period that runs from 24 June 2005 to 07 August 2009 , including all together 37,914 observations. For each parameter estimate, the figures within parenthesis refer to the t-statistics. The row Q-stat. reports Q-statistics of Ljung-Box's test (1979). The row ARCH LM reports the p-value of Engle's (1982) LM test for autoregressive conditional heteroskedasticity up to order 13. The row sample size reports the number of observations.

	First Phase	Second Phase
α_1	0.074 (11.304)	0.005 (5.745)
ϕ_1	−0.011 (−0.687)	−0.085 (−6.262)
φ_1	0.963 (277.728)	0.997 (837324.2)
β_0	0.000 (33.231	0.000 (5.103)
θ_1	0.094 (52.991)	0.262 (7.501)
θ_2	0.927 (772.548)	0.640 (19.781)
R^2_{Adj}	0.444	0.482
Q-stat.	0.023	0.000
ARCH LM	0.999	0.999
sample size	4,915	32,984

Table 6: Estimation results for Disposition effect in the First Phase

I estimate by least squares the ARMA(1,1) model in Equation (81) for the First Phase, with data for the period that runs from 24 June 2005 to 27 February 2008, including all together 4,925 observations. For each parameter estimate, the figures within parenthesis refer to the White's (1980) robust t-statistics. The row Q-stat. reports Q-statistics of Ljung-Box's test (1979) for autocorrelation in the residuals up to order 13. The row sample size reports the number of observations.

	Panel A Jul-Dec '05	Panel B Jan-Feb '06	Panel C Mar-Apr '06	Panel D May-Dec '06	Panel E Jan-Feb '07	Panel F Mar-Apr '07	Panel G May-Dec '07
α	11.192 (4.252)	20.931 (3.098)	3.640 (4.072)	3.657 (3.875)	5.523 (4.916)	0.834 (0.474)	0.523 (0.734)
ϕ	0.021 (0.445)	−0.009 (−0.163)	−0.043 (−0.745)	−0.045 (−1.665)	−0.044 (−0.956)	−0.053 (−0.671)	−0.153 (−2.044)
φ	0.669 (17.261)	0.735 (15.785)	0.771 (18.259)	0.746 (36.567)	0.815 (28.158)	0.648 (9.138)	0.710 (12.107)
R^2_{Adj}	0.324	0.335	0.346	0.329	0.356	0.255	0.228
Q-stat.	0.933	0.375	0.885	0.944	0.850	0.631	0.499
sample size	628	422	500	2133	614	321	305

Table 7: Estimation results for Disposition effect in the Second Phase

I estimate by least squares the ARMA(1,1) model in Equation (81) for the Second Phase, with data for the period that runs from 08 April 2008 to 07 August 2009, including all together 32,997 observations. For each parameter estimate, the figures within parenthesis refer to the White's (1980) robust t-statistics. The row Q-stat. reports Q-statistics of Ljung-Box's test (1979) for autocorrelation in the residuals up to order 13. The row sample size reports the number of observations.

	Panel A	Panel B	Panel C	Panel D
	April-Dec '08	Jan-Feb '09	Mar-Apr '09	May-Aug '09
α	9.499 (6.693)	3.492 (3.492)	5.686 (4.023)	7.511 (4.579)
ϕ	−0.072 (−3.829)	−0.017 (−0.851)	−0.033 (−1.389)	−0.062 (−3.068)
φ	0.847 (102.828)	0.913 (169.302)	0.871 (96.261)	0.873 (105.969)
R^2_{Adj}	0.376	0.444	0.411	0.396
Q-stat.	0.920	0.745	0.885470	0.894
sample size	9,543	6,394	6,722	10,388