Carbon Emissions and Stock Returns: Evidence from the EU Emissions Trading Scheme*

A. Marcel OESTREICH
Brock University
moestreich@brocku.ca

Ilias TSIAKAS
University of Guelph
itsiakas@uoguelph.ca

May 2015

Abstract

This paper provides an empirical investigation of the effect of the European Union's Emissions Trading Scheme on German stock returns. We find that, during the first few years of the scheme, firms that received free carbon emission allowances on average significantly outperformed firms that did not. This suggests the presence of a large and statistically significant "carbon premium," which is mainly explained by the higher cash flows due to the free allocation of carbon emission allowances. A carbon risk factor can also explain part of the cross-sectional variation of stock returns as firms with high carbon emissions have higher exposure to carbon risk and exhibit higher expected returns.

Keywords: European Union Emissions Trading Scheme; Carbon Emission Allowances; Carbon Risk; Stock Returns.

JEL Classification: G12; G18; Q58.

*__Acknowledgements:__ This paper is forthcoming in the *Journal of Banking and Finance*. The authors are grateful for constructive comments to the Associate Editor, two anonymous referees, Ujjayant Chakravorty, Zhuo Chen, Marc Gronwald, Anthony Heyes, René Kirkegaard, John Livernois, Andrea Lu, Erin Mansur, Alex Maynard, Angelo Melino and Brandon Schaufele as well as to participants at the 2012 RCEF Conference in Toronto, the 2013 PhD Workshop in Environmental Economics in Ottawa, the 2013 CEA Meetings in Montreal, the 2013 IFABS Conference in Nottingham, the 2013 CRETE Conference in Naxos and the 2013 NFA Conference in Quebec City. *Corresponding author*: Ilias Tsiakas, Department of Economics and Finance, University of Guelph, Guelph, Ontario N1G 2W1, Canada. Tel: 519-824-4120 ext. 53054. Fax: 519-763-8497. Email: itsiakas@uoguelph.ca.

Electronic copy available at: http://ssrn.com/abstract=2189497

1 Introduction

Since the introduction of the European Union's Emissions Trading Scheme (EU ETS), carbon emissions in Europe are capped, traded and priced. The EU ETS has created a new financial market for trading carbon emission allowances that give firms the right to emit carbon dioxide. During the initial two phases of the scheme, beginning in 2005 and ending in 2012, carbon emission allowances were granted to European firms predominantly free of charge. Firms that chose to pollute more than the allowances they received had to purchase extra allowances in the open market from firms that used less allowances than they received. This has lead to the emergence of the largest multinational carbon market in the world (World Bank, 2014).

This paper is at the cross-section of environmental economics and finance. As the emergence of the European carbon market is a recent phenomenon, there is little work on how environmental regulation on carbon emissions can affect the financial performance of firms. This paper fills this gap in the literature by providing a comprehensive empirical investigation of the effect of the EU ETS on stock returns. Our empirical analysis uses data on monthly stock returns from Germany as well as manually collected data on the number of carbon emission allowances received by each firm in the sample. We focus on Germany because it is by far the largest national market for carbon emissions and accounts for a quarter of Europe's total carbon emissions. For robustness, we also examine data from the UK.

To be more specific, the main question of our empirical analysis is the following: did the free allocation of carbon emission allowances during the initial two phases of the EU ETS generate a "carbon premium" in stock returns? We address this question empirically by designing three carbon portfolios: the "dirty", "medium" and "clean" portfolios. The dirty portfolio is a portfolio of firms that received a high number of free carbon emission allowances, the medium portfolio comprises firms that received a lower number of free allowances, and the clean portfolio includes all firms in the sample that did not receive any allowances. We then define the carbon premium as the abnormal excess return (alpha) of the "dirty-minus-clean" portfolio, which is assessed relative to the CAPM, the Fama and French (1993) three-factor model and the Carhart (1997) four-factor model.

Our empirical analysis relies on an economic mechanism that attributes the carbon premium to two effects: the cash flow effect and the "carbon risk" effect. In terms of the cash flow effect, we show that the free allocation of carbon allowances can generate significant

Electronic copy available at: http://ssrn.com/abstract=2189497

profits to carbon emitting firms. We use the framework of Goulder, Hafstead and Dworsky (2010) to demonstrate that a cap-and-trade system increases the marginal cost of production since the free carbon allowances constitute an opportunity cost to the firm. Firms tend to respond to the higher marginal cost by increasing output prices, reducing production so that less carbon allowances are used up, switching to less carbon-intensive production technologies or a combination of these options. This is the primary mechanism that justifies the carbon premium as it implies that the free allocation of carbon allowances can lead to large windfall firm profits.

There is also a secondary mechanism that explains the carbon premium based on the carbon risk effect. According to this effect, carbon emitting firms will be subject to carbon risk due to uncertainty about the future price for carbon allowances, which in turn generates uncertainty about future cash flows. For example, a volatile price for carbon allowances will affect the cash flows of firms. Furthermore, an institutional change in the EU ETS, such as a change in the law that initially gives carbon allowances for free but subsequently makes them available in auctions will also affect future cash flows. Finally, recent contributions by Weitzman (2009), Litterman (2013) and Pindyck (2013) suggest that carbon emitting firms are exposed to carbon risk because they might face a higher price for carbon allowances in the future as a result of catastrophic climate change. In short, therefore, carbon risk is based on uncertainty about the future price for carbon emissions. As a result, carbon emitting firms will require higher expected returns relative to firms with no carbon emissions.

Our main empirical finding is that there is a large and statistically significant carbon premium in stock returns, which can be as high as 17% per year. We show that this result holds for the sample period that ranges from November 2003 to March 2009. This sample period begins with the passing of an EU law establishing the initial two phases of the ETS that offered carbon allowances to firms for free. It ends with the passing of another EU law establishing the third phase of the ETS during which carbon allowances are predominantly sold in auctions from 2013 onwards. Hence this is the period over which the market knew with certainty that carbon emitting firms will be receiving free carbon allowances. Our evidence clearly indicates that after March 2009 the carbon premium largely disappears. The timing of the carbon premium based on German data is also confirmed by the UK data. Note that our main sample extends to December 2012, which is the end of the second phase of the EU ETS.

In addition to the free allocation of carbon allowances, another explanation for the large carbon premium over the relevant sample period is the effect of carbon risk on expected stock returns. We assess this effect by constructing the "dirty-minus-clean" (DMC) risk factor, which is a zero-investment portfolio defined as the expected return on a portfolio of dirty stocks minus the expected return on a portfolio of clean stocks. Then, we implement Fama and MacBeth (1973) regressions to show that there is a positive price of carbon risk since dirty firms that have higher exposure to carbon risk exhibit higher expected returns. Overall, for the sample period of November 2003 to March 2009, carbon risk can explain a large part of the cross-sectional variation in stock returns. For this sample period, the significance of the carbon risk factor is robust to the inclusion of a large set of control variables. In short, therefore, a combination of the cash flow effect and the carbon risk effect can provide a basis for explaining the high carbon premium in German stock returns over the relevant period.

In assessing robustness, we find that the carbon premium tends to be higher the dirtier the portfolio, i.e., the higher the number of allowances received by firms included in the dirty portfolio. Furthermore, the carbon premium is not diminished when we condition on changes in the price for carbon allowances and changes in the price of energy indexes such as oil, natural gas, coal and electricity.

The empirical finding that the carbon premium is present for a specific time period indicates that it may have been a one-off event that lasted for as long as the law stipulated that carbon allowances will be given for free. Specifically, this period commences about one year before the beginning of Phase I and disappears about one year into Phase II. At the same time, it is worth noting that the EU ETS is arguably the most significant multinational initiative ever taken to mobilize markets to protect the environment. As such, it has a profound impact on the development and implementation of other emission trading schemes. Over the past few years, many countries or regions have followed the EU in establishing similar cap-and-trade schemes or are currently in the process of doing so. Therefore, even if the carbon premium is a one-off event in Europe, our analysis makes an important contribution to the current environmental policy debate because it informs policy-makers and investors about the design and implications of similar cap-and-trade environmental regulation implemented elsewhere.[1]

[1] There is a number of existing, emerging and potential emissions trading schemes around the world. For example, some of the existing emissions trading schemes include Switzerland, Australia, New Zealand, Kazakhstan, California, several north-east and mid-atlantic US states, Quebec, several provinces of China and some cities in Japan. For more details, see World Bank (2014).

The remainder of the paper is organized as follows. In the next two sections we review the relevant literature and the institutional details of the EU ETS. Section 4 discusses the theoretical arguments suggesting a relation between carbon emissions and stock returns. In Section 5 we describe the data used in the empirical analysis. Section 6 provides a framework for measuring the carbon premium in stock returns and discusses the main empirical results. In Section 7 we present empirical evidence on the price of carbon risk. Section 8 reports our findings on robustness and Section 9 extends our analysis by providing empirical evidence on the UK. Finally, Section 10 concludes.

2 Literature Review

This paper is related to three distinct lines of research that focus on different aspects of the EU ETS. One line of research evaluates the effect of movements in the price for carbon allowances on the returns of different sets of European electrical power companies. For example, Oberndorfer (2009) and Veith, Werner and Zimmermann (2009) use data from Phase I (2005 to 2007), whereas Koch and Bassen (2013) extend their sample to 2010. These studies estimate the sensitivity of stock returns to changes in the price for carbon allowances, while also conditioning on other energy factors such as price changes in oil, gas, coal and electricity. Overall, this line of research establishes a positive relation between movements in the price of carbon allowances and movements in stock prices in the European power sector.

A second line of research uses an event study methodology to isolate the effect of the sharp decline in the price of carbon allowances that took place in April 2006 on the stock returns of carbon-intensive European firms. These studies include Bushnell, Chong and Mansur (2013) and Jong, Couwenberg and Woerdman (2014). They find that the drastic drop in carbon prices over a three-day window had a negative impact on the stock returns of carbon-intensive firms. This indicates that carbon regulation plays a significant role in determining the profits of dirty firms.

Finally, a third line of research is based on a simulation methodology that makes assumptions about the technology underlying coal-generated and gas-generated power. This analysis is adopted by Sijm, Neuhoff and Chen (2006) and Smale, Hartley, Hepburn, Ward and Grubb (2006), who show that the introduction of the EU ETS allows power companies to realize substantial windfall profits.

A common thread across this body of research is that the main focus is to estimate the sensitivity (i.e., the beta) of stock returns to changes in carbon prices. In contrast, our empirical analysis is primarily concerned with the extent to which the abnormal excess return (i.e., the alpha) of a portfolio of dirty firms is higher than that of a portfolio of clean firms. Compared to the literature, we also adopt a different approach based on an asset pricing methodology applied on portfolios for a large set of stocks from many different industry sectors and for a longer sample. In the end, we make a distinct contribution to the literature by quantifying the effect of carbon regulation on German stock returns and the benefits to investors of holding carbon portfolios for the period when carbon allowances were granted for free.

3 The EU Emissions Trading Scheme

The EU ETS is the world's first and largest multinational cap-and-trade program for carbon dioxide (CO_2). It covers about half of CO_2 emissions in all EU member states, 40% of total greenhouse emissions, and involves about 11,500 factory installations that together emit 2 billion tonnes of CO_2 emissions annually. For more information on the EU ETS see Ellerman, Convery and de Perthuis (2010) and World Bank (2014).

The EU ETS works as follows. First, it sets an annual cap on the overall emissions to be allowed. Second, it allocates allowances to emitters such that the sum of the allowances does not exceed the cap. The units in which allocations are measured are called the European Union Allowances (EUAs), which give polluters the right to emit one tonne of CO_2. Note that the EUAs are given to individual installations (i.e., at the plant level, not the firm level). Third, the emitters choose how much to pollute. If they pollute more than the EUAs they have received, they must purchase extra EUAs from those who used less EUAs than they received, and vice versa. This system creates incentives to polluters to reduce emissions (e.g., through technological innovations) so they can sell the surplus EUAs for profit.

As seen in the timeline presented in Table 1, the EU ETS has been implemented in three separate phases. Phase I ran from January 2005 to December 2007, Phase II from January 2008 to December 2012, and Phase III currently runs from January 2013 to December 2019. For the first two phases, the EUAs were predominantly given to installations free of charge. Note that Phase I allowances could not be banked in Phase II and hence lost their value if unused. In the third phase, the majority of the EUAs are sold in auctions. Installations receive annual allowances in March of every year which, if used, must be surrendered by the end of April of the following year. The penalty for noncompliance is €40 per EUA not surrendered in Phase I and €100 in Phase II. The end of April is also the date when externally verified emissions are made public for each EU country. The EUAs can be traded in several trading platforms, notably the European Climate Exchange (ECX) in London, the European Energy Exchange (EEX) in Leipzig, and Nord Pool in Norway.

4 Cash Flows, Expected Returns and the EU ETS

It is well known that changes in current stock returns reflect changes in future cash flows and changes in expected returns (e.g., Campbell and Shiller, 1988). This section discusses the effect of the EU ETS on firms' cash flows (the primary effect) and expected returns (the secondary effect).

4.1 The Effect on Cash Flows

We begin with a discussion of how a cap-and-trade system with a free allocation of carbon allowances can generate significant additional profits for carbon emitting firms. The first step in the mechanism is to recognize that a cap-and-trade system increases the marginal cost of production for the affected firms. The increase is equal to the market value of the EUAs required to produce one unit of output. Note that this is the case regardless of whether the EUAs are bought in the open market (an actual cost to the firm) or are received for free (an opportunity cost to the firm). In other words, for every unit of carbon allowances the firm uses, either it has to purchase this unit or it has to forego one unit from the surplus allowances it can sell.

Following Goulder, Hafstead and Dworsky (2010), we use the simple demand and supply diagram in Figure 1 to illustrate the effect of carbon allowances on the profits of a perfectly competitive industry.[2] In the absence of carbon regulation, the initial equilibrium price and quantity are given by p_0 and X_0 respectively. When we introduce a cap-and-trade scheme for carbon emissions with a free allocation of carbon allowances, the supply curve shifts up for two reasons: (i) the higher marginal cost due to the actual or opportunity cost of the

[2] The perfectly competitive firms are assumed to have constant emission rates (emissions per unit of output). See Bushnell, Chong and Mansur (2013) for an analysis of imperfectly competitive firms with emission rates that depend on the level of output. Since the main intuition remains the same for perfect and imperfect competition, we focus on the case of perfect competition.

carbon allowances required per unit of output, denoted by r; and (ii) the higher marginal cost associated with a less carbon-intensive technology, denoted by c (fuel-switching costs). In the new equilibrium, production X_1 is lower and the price p_C consumers pay is higher exceeding the original marginal supply cost by $c + r$.

In this setup, the introduction of a cap-and-trade system with a free allocation of carbon allowances can generate significant profits to carbon emitting firms. Specifically, the gain in producer surplus is represented by the shaded rectangular area A (or area $p_C aef$), which is equal to $r \times X_1$. Note that, had the allowances been sold at auctions, area A would reflect the revenue to government. In the figure, area A appears much larger than the loss in producer surplus represented by the shaded trapezoidal area B (or area $p_0 bdp_S$). If the difference of area A minus area B is positive, we can conclude that the free allocation of carbon allowances provides the firm with higher profits in the presence of carbon regulation. The size of areas A and B depends on the extent to which firms can shift to consumers the increase in marginal cost through higher output prices.

In summary, Figure 1 provides a simple but effective framework for showing the two direct effects on firm profits of the cap-and-trade scheme for carbon emissions. First, firms face higher marginal costs, which to a large extent are passed through to consumers through higher output prices, thus increasing firm revenue. Second, output falls and, since carbon allowances are allocated freely, the allowances not used in production can be sold for a profit. The combination of the two direct effects provides a mechanism that leads to substantial additional profits for carbon emitting firms.[3]

It is important to note that in the early stages of the EU ETS, there was considerable uncertainty regarding several aspects of its implementation. For example, as shown in the timeline in Table 1, the number of allowances given to each firm was made public in April 2006, which is more than two years after the EU ETS became law in November 2003. The price of the EUAs fluctuated considerably over time. There were other unknowns as well: the degree to which the opportunity cost of the allowances was incorporated into prices and the degree to which firms invested in alternative less carbon-intensive technologies. These examples indicate that, although the actual effect of the ETS on firm cash flows is expected to be positive, its exact magnitude was initially uncertain as information gradually became

[3]The graphical illustration of Figure 1 presents a static analysis. Goulder, Hafstead and Dworsky (2010) also propose an intertemporal general equilibrium model that delivers similar results. For related theoretical studies of the effect of the EU ETS on firm profits see Sijm, Neuhoff and Chen (2006), Smale, Hartley, Hepburn, Ward and Grubb (2006), and Demailly and Quirion (2009).

available over time. This is consistent with the insights of Pastor and Veronesi (2012), who study the effect of uncertainty about government policy on stock prices and identify impact uncertainty as the uncertainty about the impact of a new government policy on firms' profitability.

Overall, this analysis informs the following testing hypothesis:

<u>*Hypothesis 1*</u> *(H1)*: *Other things being equal, firms receiving free carbon allowances will on average experience higher cash flows and therefore higher returns. In other words, there is a carbon premium in stock returns.*

4.2 The Effect on Expected Returns

In addition to the primary effect of the free allocation of carbon allowances, there is a secondary effect based on "carbon risk". In particular, firms that require carbon allowances are subject to carbon risk due to uncertainty about the future price for the allowances, which also generates uncertainty about future cash flows. For example, the EUA price has fluctuated considerably over time and will likely continue to remain volatile in the future. This can have an effect on future cash flows.

Furthermore, an institutional change in the EU ETS, such as a change in the law that initially gives carbon allowances for free but subsequently makes them available in auctions has a profound effect on the market's expectation of future cash flows.

Finally, recent contributions by Weitzman (2009), Litterman (2013) and Pindyck (2013) suggest that carbon emitting firms are exposed to carbon risk because they might face a higher price for carbon allowances in the future as a result of catastrophic climate change. This is because the price of carbon allowances reflects the present value of damages from emitting one tonne of CO_2, which is often referred to as the social cost of carbon.[4] According to Litterman (2013), carbon risk is non-diversifiable and hence will command a risk premium determined by societal risk aversion. It is true that assessing the social cost of carbon is difficult because there is great uncertainty today about: the size of future economic damages related to climate change; the probability with which they may occur; the timing of when they may occur; and the discount rate to be used in computing their present value. Given this uncertainty, as long as we cannot rule out that a climate-related economic catastrophe

[4] For example, Pindyck (2013) argues that if there is a reasonable possibility that a catastrophic climate change might occur, then the social cost of carbon in the US could reach a price of $200. This is about ten times higher than the EUA price in our sample period.

may happen in the future, dirty firms will be subject to carbon risk.

In short, therefore, carbon risk in our context reflects the uncertainty about the future price for carbon allowances. As carbon emitting firms are exposed to carbon risk, they will require higher expected returns relative to firms with no carbon emissions. This argument informs our second testing hypothesis:

Hypothesis 2 (*H2*): *Other things being equal, carbon emitting firms are exposed to carbon risk and hence require higher expected returns relative to firms with no carbon emissions. This is a further reason why there is a carbon premium in stock returns.*

5 Data on Carbon Emissions and Stock Returns

5.1 Sample Period

The sample period used in our analysis ranges from November 2003 to December 2012. This period begins with the passing of an EU law establishing the initial two phases of the EU ETS. It ends with the expiration of Phase II and, therefore, covers only the period during which carbon allowances were given to firms for free. Note that this sample period commences 14 months before the beginning of Phase I, which runs from January 2005 to December 2007, and covers the full span of Phase II, which runs from January 2008 to December 2012.

Throughout our analysis, we also consider a shorter sample period, which also begins in November 2003 but ends earlier in March 2009. The end date of the shorter period coincides with the passing of an EU law establishing Phase III of the EU ETS beginning in 2013 during which carbon allowances are mainly sold in auctions. Hence the shorter period captures the period over which the law stipulated the free allocation of carbon allowances. Hence during this period there was no uncertainty to firms about whether they would receive free allowances or not. A detailed timeline of events is shown in Table 1.[5]

5.2 Stock Returns

Our empirical analysis uses an extensive data set of monthly stock returns from Germany, which is the largest economy in the EU and is responsible for one quarter of EU carbon emissions. We focus on the 80 firms currently trading on the Frankfurt Stock Exchange, which are included in the two main German stock indexes: the DAX (30 large caps) and

[5] The first EU law was passed on October 13, 2003: Directive 2003/87/EC. The second EU law was passed on April 23, 2009: Directive 2009/29/EC.

the MDAX (50 mid caps). Together the DAX and MDAX companies comprise more than 95% of the German stock market capitalization, which is indicative of the high degree of concentration in the German economy.

Our main analysis excludes 15 of the 80 firms for which we do not have monthly return observations for the full sample period. Hence we employ data for the remaining 65 firms. In the robustness section, we show that using the full cross-section of 80 firms does not affect our main findings. Monthly stock returns are calculated as $r_{j,t+1} = \ln(P_{j,t+1}) - \ln(P_{j,t})$, where $P_{j,t}$ is the total return index (that accounts for dividend reinvestment) of stock j at time t obtained from *Datastream*. The market value of equity (ME) is also taken from *Datastream*.

The return to the market portfolio is proxied by the DAX stock index return taken from *Datastream*. Our proxy for the monthly risk-free rate is the one-month money market rate reported by Deutsche Bundesbank. The Fama-French (1993) size and value factors and the Carhart (1997) momentum factor are provided by the Centre for Financial Research at the University of Cologne. These factors are especially constructed for the German economy (see, Artmann, Finter, Kempf, Koch and Theissen, 2012). Note that these factors are available until December 2012, which covers our full sample. This set of Fama-French factors for Germany has recently been studied in detail by Bruckner, Lehmann, Schmidt and Stehle (2014), who assess the factor construction and the underlying data and conclude that these factors are highly reliable. This is especially true for our sample period that begins in 2003.

5.3 Carbon Emission Allowances

We manually collect information on the number of carbon emission allowances given for free to each firm using the *Community Independent Transaction Log* (CITL), which is a source of verified carbon emission information set up by the European Commission. Note that the CITL emission allowances are allocated by the member state's National Allocation Plan for each individual installation of each firm. We match each installation to the firm it belongs to and aggregate across installations for each firm to determine the total number of free EUAs issued to each firm. Overall, the companies included in our analysis received about one third of the total amount of EUAs allocated in Germany. This is because a considerable proportion of the allowances were granted to utilities that are partly state-owned (hence are not public) or trade infrequently outside of the main stock indexes.

5.4 Descriptive Statistics

Table 2 reports monthly descriptive statistics for the 65 German stocks over the two sample periods of November 2003 to March 2009 and November 2003 to December 2012. The table indicates that firms belong to a wide range of industries effectively capturing every aspect of the German economy. Of the 65 firms, 24 received carbon emission allowances (the "dirty" firms), whereas 41 firms did not (the "clean" firms). The number of annual allowances issued to each firm ranges from 5,000 to 109 million. 14 firms received more than 100,000 annual allowances and eight firms received more than one million annual allowances. In general, the number of Phase I allowances tends to be higher than that of Phase II, especially for large polluters.

The table also reports firm size measured by the average market value of equity (ME) as well as the annualized mean return, standard deviation and Sharpe ratio for each firm. Overall, the sample of 65 firms represents a high proportion of the German stock market capitalization, while capturing a wide distribution of firms across industries, size, performance and use of carbon emission allowances.

6 The Carbon Premium in Stock Returns

Our empirical analysis provides a framework for investigating whether firms that received carbon emission allowances significantly outperformed firms that did not. In particular, we are interested in whether on average "dirty" firms exhibit abnormal excess returns relative to "clean" firms. In other words, our main question is whether there is a carbon premium in stock returns.

6.1 A Portfolio Approach

We address this question by designing three carbon portfolios: the "dirty", "medium" and "clean" portfolios. The dirty portfolio is a portfolio of firms, which during the initial two phases of the EU ETS have received annually more than one million free EUAs. The medium portfolio is a portfolio of firms, which for the same period have received annually more than zero but less than one million free EUAs. The clean portfolio is a portfolio of firms, which have not received any EUAs. Throughout our analysis we also form the "dirty-minus-clean" portfolio, which is equivalent to going long on the dirty portfolio and short on the clean portfolio. This difference portfolio allows us to better understand the role of carbon allowances in determining financial performance. All portfolios are formed with equal weights.[6] Note that the composition of the three carbon portfolios does not change over time since it is the same firms that each year satisfy the criteria for inclusion in the portfolios. Therefore, there is no portfolio rebalancing.

The first criterion for distinguishing between dirty versus clean firms on the basis of whether they have received free carbon allowances is natural. In the context of our data sample, 24 stocks received carbon allowances (belonging to the dirty and medium portfolios), whereas 41 did not (belonging to the clean portfolio). The second criterion for distinguishing between firms receiving a high number of carbon allowances (belonging to the dirty portfolio) and those receiving a low number of carbon allowances (belonging to the medium portfolio) is however ad hoc. Throughout our analysis, we draw the line between the dirty and medium portfolios at one million free EUAs. This implies that eight stocks belong to the dirty portfolio and 16 stocks to the medium portfolio. Note, however, that in the robustness section we comprehensively assess whether changing the composition of the dirty portfolio affects the results.

6.2 Portfolio Returns

Our first empirical finding is illustrated in Figure 2, which plots the cumulative returns of the dirty, clean and dirty-minus-clean portfolios for three sample periods. The first period is the pre-ETS period, which ranges from November 1998 to October 2003, and corresponds to the five years immediately before the ETS was passed into law. The second period ranges from November 2003 to March 2009, which is the period that begins with the passing of the law establishing the EU ETS and ends with the passing of the law that terminates the free allocation of allowances. The third period ranges from April 2009 to March 2014, which corresponds to the five years immediately after the second period.

The figure provides a stark contrast in the performance of the carbon portfolios before (upper graph), during (middle graph) and after (lower graph) the introduction of the EU ETS. In the five years before, the performance of the dirty-minus-clean portfolio revolves

[6] We use equally weighted portfolios because the cross-section of firms is not very large and hence equally weighted portfolios ensure that the performance of the carbon portfolios is not determined primarily by the largest firms. This is important since firm value in the German economy is highly concentrated in few firms. Note, however, that in unreported results we find that value weighted portfolios deliver qualitatively similar results.

around zero. In the second period, the cumulative return of the dirty-minus-clean portfolio increases monotonically and reaches a maximum value of about 100%. Finally, in the five years after the second period, the cumulative return of the dirty-minus-clean portfolios decreases monotonically. In short, this is preliminary evidence suggesting that firms that received carbon allowances substantially outperformed firms that did not for the period of November 2003 to March 2009, but not before or after.

Table 3 corroborates the evidence in Figure 2 by reporting more details on the performance of the carbon portfolios. For example, the dirty-minus-clean portfolio has an annualized mean return of 16.8% for the period of November 2003 to March 2009, which becomes 3.6% for the full sample of November 2003 to December 2012. During Phase I, this value is 19.0% but drops to −8.4% during Phase II. This evidence further confirms the timing and magnitude of the performance of the dirty-minus-clean portfolio.

6.3 Factor Models

Next we turn to the alpha (α) of the carbon portfolios, which is measured as the abnormal excess return relative to three standard factor models. This leads to three time-series regressions. The first regression is based on the Capital Asset Pricing Model (CAPM), which is specified as follows:

$$r_{j,t} - r_{f,t} = \alpha_j + \beta_j \left(r_{M,t} - r_{f,t} \right) + \varepsilon_{j,t}, \tag{1}$$

where $r_{j,t}$ is the monthly return of portfolio j at time t for j being one of the dirty, medium or clean portfolios, $r_{f,t}$ is the monthly riskless rate at time t, $r_{M,t}$ is the monthly return to the market portfolio at time t, and $\varepsilon_{j,t}$ is a normal error term.

The second regression is based on the Fama and French (1993) three-factor model:

$$r_{j,t} - r_{f,t} = \alpha_j + \beta_{j1} \left(r_{M,t} - r_{f,t} \right) + \beta_{j2} SMB_t + \beta_{j3} HML_t + \varepsilon_{j,t}, \tag{2}$$

where SMB_t is the monthly return to the "small-minus-big" size factor, and HML_t is the monthly return to the "high-minus-low" value factor. We term this the $FF3$ model.

The third regression is based on the Carhart (1997) four-factor model:

$$r_{j,t} - r_{f,t} = \alpha_j + \beta_{j1} \left(r_{M,t} - r_{f,t} \right) + \beta_{j2} SMB_t + \beta_{j3} HML_t + \beta_{j4} MOM_t + \varepsilon_{j,t}, \tag{3}$$

where MOM_t is the monthly return to the momentum factor. We term this the $FF4$ model. Note that the SMB_t, HML_t and MOM_t factors are specific to the German economy (see, Artmann, Finter, Kempf, Koch and Theissen, 2012).

6.4 The Carbon Premium

We define the alpha of the dirty-minus-clean portfolio as the carbon premium in stock returns. This is the abnormal excess return of the dirty portfolio over and above that of the clean portfolio. By definition, it is also equal to the difference in alphas between the dirty and the clean portfolios. The size and significance of the carbon premium is the main focus of our empirical analysis.

Consistent with our preliminary analysis, our main finding is that there is a high and significant carbon premium for the sample period that begins in November 2003 and ends in March 2009. This finding is illustrated in Figure 3, which plots a rolling estimate of the carbon premium relative to the CAPM using a three-year rolling window. Statistical significance is assessed by plotting rolling p-values of the alpha based on Newey-West (1987) standard errors. Figure 3 identifies the exact timing of when the dirty-minus-clean portfolio delivers a high and significant alpha. The shaded area in the figure corresponds to the critical sample period of November 2003 to March 2009. The figure reveals that the alpha is high and significant only during this sample period but not immediately before or after. To be more specific, the figure suggests that the good performance of the dirty-minus-clean portfolio: (i) begins around November 2003, which is more than a year before the implementation of Phase I in January 2005; (ii) it then continues during all of Phase I (2005-2008); (iii) it diminishes in the first year of Phase II (2008); and (iv) it disappears afterwards.

These results are further illustrated in Table 3. Specifically, the carbon premium relative to the CAPM is 16.8% and highly significant for the sample period of November 2003 to March 2009, but falls to 2.9% and becomes insignificant when the sample period extends to the end of Phase II in December 2012. It is also interesting to note that in Phase I (2005-2007) the carbon premium is 15.3% and significant, whereas in Phase II (2008-2012) it is -8.2% and insignificant. The results are similar using the FF3 and FF4 factor models.

Overall, this evidence suggests that the carbon premium is present for the period that the market knew with certainty that carbon emitting firms will be receiving allowances for free. This is because: (i) the appearance of the carbon premium coincides with the passing of the EU law establishing the ETS with free allocation of allowances; and (ii) the disappearance of the carbon premium coincides with the passing of an EU law stipulating that allowances will be mainly sold in auctions beginning in 2013. It is therefore likely that the carbon premium may have been a one-off event, which was only present during this particular period as it was driven by the free allocation of carbon allowances and lasted for as long as the law stipulated the allocation will be free.

In conclusion, the presence of a high and significant carbon premium over the sample period identified in Figure 3 is a new and important result. This finding strongly supports the first testing hypothesis (*H1*) implied by the economic mechanism discussed in Section 3. A high and significant carbon premium confirms empirically that carbon emitting firms are substantially overcompensated by receiving free carbon emission allowances as indicated by the theoretical work of Demailly and Quirion (2009) and Goulder, Hafstead and Dworsky (2010) among others. In this context, our analysis contributes to the current environmental policy debate because, in addition to helping us understand the workings of the EU ETS, it informs policy-makers and investors about the design and implications of similar cap-and-trade environmental regulation implemented elsewhere.

7 The Price of Carbon Risk

This section evaluates the effect of carbon risk on the cross-section of expected stock returns. Our empirical analysis is based on Fama and MacBeth (1973) regressions. In line with standard practice in asset pricing, we proxy carbon risk by the "dirty-minus-clean" (DMC) risk factor. This is a zero-investment portfolio defined as the expected return on the equally weighted portfolio of the eight dirty stocks minus the expected return on the equally weighted portfolio of the 41 clean stocks. Note that the DMC factor is the expected return of the dirty-minus-clean portfolio, whereas the carbon premium is the alpha of the same portfolio.

We implement the Fama and MacBeth (1973) procedure in the standard two stages. First, we use time-series regressions to estimate the betas on the CAPM, the three-factor Fama-French (1993) model and the four-factor Carhart (1997) model, while adding the DMC factor to all these specifications. In the second stage, we implement a cross-sectional regression of the average returns of all 65 stocks on their betas. The slopes of the cross-sectional regression deliver the price of risk for each factor.

For robustness, in addition to the standard four factors we also specify an industry factor as well as a series of other factors recently proposed in the asset pricing literature. The industry factor (IND) is generated by grouping the 65 stocks in 10 industry portfolios using the Fama-French industry definitions. Then, we estimate the beta of each stock on the excess return to the equally weighted industry portfolio it belongs to, while also conditioning on the excess return of the market. We use the industry betas as an independent variable in the cross-sectional regressions and we report the price of risk. This captures the cross-sectional variation of the sensitivity to the industry factor.

We also use six additional control variables, which are specified as follows: (i) MAX is the Bali, Cakici and Whitelaw (2011) measure of the maximum daily return within a month for each stock; (ii) ILLIQ is the Amihud (2002) measure of stock illiquidity for each stock defined as the ratio of the absolute stock return to its dollar trading volume. As with the standard factors, we estimate the beta of each stock on MAX and ILLIQ separately, and then use these betas in the cross-sectional regressions; (iii) IVOL is the Ang, Hodrick, Xing and Zhang (2006) measure of idiosyncratic volatility estimated as the standard deviation of the residuals to the three-factor Fama-French (1993) regression for each stock; (iv) COSKEW is the Harvey and Siddique (2000) measure of coskewness measured as the beta on the squared excess market return for each stock, while also conditioning on the excess market return; (v) downside beta is the Ang, Chen and Xing (2006) measure of the CAPM beta using only observations for which the market return is less than its mean; (vi) and, similarly, upside beta is the CAPM beta using only observations for which the market return is greater or equal than its mean. Note that when conditioning on downside beta and upside beta, we remove the full sample beta (denoted by MKT in the table) to avoid multicollinearity.

Table 4 presents the results, which can be summarized in the following four findings: (i) for the shorter sample of November 2003 to March 2009, the DMC factor has a positive price of risk, which is highly significant in all cases. This implies that the higher a firm's exposure to carbon risk, the higher the expected return, even when conditioning on a large number of control variables; (ii) for this sample, the DMC factor alone accounts for one-third of the cross-sectional variation of stock returns; (iii) however, when using the longer sample of November 2003 to December 2012, the explanatory power of the carbon risk factor diminishes and becomes insignificant; and (iv) overall the model specification that conditions on all control variables accounts for more than 90% of the cross-sectional variation of stock returns in either sample.

These results indicate that carbon risk can explain a large part of the variation of stock returns for the sample period of November 2003 to March 2009. For this sample, therefore, firms that have a high exposure to carbon risk (i.e., dirty firms) require higher expected returns. This provides direct empirical support for the second testing hypothesis (*H2*) for the period that the market knew for sure that carbon emitting firms will be receiving free carbon allowances.

8 Robustness and Further Analysis

This section extends the empirical analysis in several directions in order to assess the robustness of our main finding on the carbon premium.

8.1 The Carbon Premium, the EUA Price and Energy Factors

First, we provide an empirical examination of whether the carbon premium can be explained by conditioning on the price for carbon allowances and the price of energy indexes such as electricity, oil, natural gas and coal.

In line with Daskalakis, Psychoyios and Markellos (2009) and Koch and Bassen (2013), for the price of carbon allowances we consider monthly settlement prices of EUA futures contracts traded on the Intercontinental Exchange (ICE), which owns the European Climate Exchange (ECX). We construct a continuous price series that combines a series of contracts as follows. In Phase I, the EUA price series is equal to the price of the December 2008 contract. In Phase II, the EUA price series uses the December 2009 contract until its last trading day, then switches to the December 2010 contract until its last trading day, and so on until December 2012. Figure 4 plots the EUA futures price in euros.[7]

Following prior literature (e.g., Oberndorfer, 2009, and Koch and Bassen, 2013), for oil, gas and coal prices we use the following one-month futures contracts: the Brent crude oil front-month forward from Independent Commodity Information Services (ICIS); the front-month natural gas forward from the ICE; and the one-month ahead New York Mercantile Exchange (NYMEX) futures contract for coal converted to euros. Note that the European counterpart to this contract (i.e., the one-month ahead API 2 coal futures contract delivered to Amsterdam, Rotterdam and Antwerp) is not available for the full sample but the correlation in the two series is about 90%. Finally, for electricity prices, we use the Phelix Month Base from the EEX in Leipzig as in Oberndorfer (2009). All these data are taken

[7] The sharp decline in the EUA price around the end of April 2006 is the focus of Hintermann (2010), Bushnell, Chong and Mansur (2013) and Jong, Couwenberg and Woerdman (2014). These papers argue that the decline was primarily due to the release of information about aggregate EU emissions indicating an unanticipated surplus in available EUAs. For studies on the time-series behavior of EUA prices, see also Paolella and Taschini (2008), Benz and Truck (2009), and Daskalakis, Psychoyios and Markellos (2009).

from *Datastream*.

In all cases, we use the price data to generate a time series for the return to each variable. For example, we compute the return to the EUA as: $r_{EUA,t} = ln(P_{EUA,t}) - ln(P_{EUA,t-1})$, where $P_{EUA,t}$ is the EUA price series at time t. Similarly, we compute $r_{oil,t}$, $r_{gas,t}$, $r_{coal,t}$, and $r_{elec,t}$. We then use the dirty-minus-clean portfolio returns to estimate the CAPM with these additional explanatory variables. This allows us to assess the significance of these additional factors ($r_{EUA,t}$, $r_{oil,t}$, $r_{gas,t}$, $r_{coal,t}$, $r_{elec,t}$) and the extent to which they can affect the alpha of the regression (i.e., the carbon premium).

Table 5 reports results for two sample periods: one period ranges from May 2005 to March 2009; and the second one from May 2005 to December 2012. Note that, for this table only, we begin the regressions in May 2005 because EUA trading begins in April 2005 and hence the first observation for $r_{EUA,t}$ is available in May 2005.

We find that the sensitivity (beta) of the EUA, oil, gas and coal returns is positive, whereas for electricity returns it is negative. However, in all cases, the betas are insignificant. More importantly, when conditioning on these additional variables, the alpha (i.e., the carbon premium) remains largely unaffected as it is still high (about 18%) and statistically significant for the sample period that ends in March 2009. Therefore, for this sample period the carbon premium remains intact even after we account for movements in the EUA price and energy factor prices.

8.2 The Carbon Premium and the Number of Carbon Allowances

The carbon premium depends crucially on how the dirty portfolio is defined. Our main analysis places in the dirty portfolio the eight firms which received annually more than one million free EUAs. We assess the sensitivity of the carbon premium to the composition of the dirty portfolio with two robustness checks. For both checks, we focus on the sample period of November 2003 to March 2009, when the carbon premium is found to be high and significant.

First, we maintain the same composition for the dirty portfolio that contains eight stocks, and assess whether the carbon premium is driven by any one particular stock. Figure 5 displays the alpha of the dirty-minus-clean portfolio when one of the eight stocks is dropped from the dirty portfolio. In other words, this shows the carbon premium for alternative dirty portfolios when any seven of the eight original stocks are used. We find that overall the carbon premium is not driven by a single stock. The eight-stock portfolio delivers a CAPM-based carbon premium of 16.8%. The lowest CAPM-based carbon premium among the seven-stock portfolios is around 14%, which corresponds to the case of the chemical company SDF being dropped. Using any one of the seven-stock dirty portfolios gives similar results to using the eight-stock dirty portfolio. We conclude, therefore, that the carbon premium remains largely unaffected when we exclude any one stock, including the one with the largest effect.

Second, we use alternative criteria for inclusion of stocks into the dirty portfolio. As seen in Table 6, when the cutoff point of carbon allowances reduces from one million EUAs to 0.5 million EUAs, the number of stocks increases from eight to 10. Similarly, at 0.1 million EUAs, there are 14 stocks in the dirty portfolio and, finally, when all dirty stocks are included their number reaches a maximum of 24. In setting a lower number of EUAs as the criterion for inclusion in the dirty portfolio, we find that the alphas decrease monotonically. The decay is initially slow and then accelerates as more firms are included in the dirty portfolio. Specifically, the CAPM-based carbon premium is as follows: for the eight-stock portfolio it is 16.8% and significant; it decreases to 13.9% for the 10-stock portfolio and is still significant; then goes down further to 11.1% for the 14-stock portfolio and is still significant; and, finally, ends at 4.3% for the all-inclusive portfolio but now is insignificant.

These results are graphically illustrated in Figure 6. The figure shows the annualized CAPM-based carbon premium when we add one stock at a time to the original dirty portfolio of eight stocks. The stocks are added in sequence according to the number of their carbon allowances: each time the stock with the highest number of carbon allowances not already in the portfolio is added to it. The figure also shows the 95% confidence interval of the CAPM-α based on Newey-West (1987) standard errors. The figure clearly illustrates the monotonicity in the relation of performance and carbon allowances: the more stocks we add to the dirty portfolio, the lower the number of carbon emissions the additional stock contributes the portfolio, and the lower the CAPM-α of the dirty-minus-clean portfolio. This is further evidence that high carbon emissions lead to high abnormal excess returns for our sample.

8.3 The Carbon Premium and the Number of Firms

Our analysis uses data on 65 of the 80 firms included in the DAX and MDAX stock indexes. We exclude the 15 firms for which we do not have monthly return observations for the full sample period. For robustness, we also assess the performance of the carbon portfolios when all 80 stocks are included in the analysis. We do so by using all available data on all stocks, where for 15 stocks the data available is shorter than the full sample. This approach implies that the composition of the portfolios changes over time. The effect of the inclusion of additional stocks on the portfolio composition is as follows: the dirty portfolio still has the same 8 stocks; the medium portfolio now has a maximum of 21 stocks, which is 5 stocks more than previously; and the clean portfolio has a maximum of 51 stocks, which is 10 more stocks.

Table 7 shows that the results remain qualitatively the same and, overall, the carbon premium is in fact slightly higher. For the sample period of November 2003 to March 2009, the 80-stock cross-section delivers a highly significant carbon premium relative to the CAPM of 18.6% compared to 16.8% for the 65-stock cross-section. For the full sample period of November 2003 to December 2012, the carbon premium is 4.4% relative to 2.9% previously. For Phase I it is 17.6% compared to 15.3% previously. Finally, for Phase II it is −7.1% compared to −8.2% previously. In conclusion, therefore, our main findings are not affected by the inclusion of additional stocks for which the available data does not cover the full sample.

9 Extension: Evidence from the UK

In this section we provide an empirical investigation of the carbon premium for a second major European economy: the UK. This allows us to assess whether the carbon premium is predominantly a feature of the German economy or a feature that is also present elsewhere in Europe. For this purpose, we build a second data set on carbon emission allowances that is specific to the UK. In particular, we focus on the 100 UK firms that belong to FTSE 100 stock index, which capture more than 80% of the UK stock market capitalization.

In similar fashion to the German data, the UK data on carbon emission allowances have been collected manually. We use the *Community Independent Transaction Log* (CITL) database set up by the European Commission to manually match each production facility (installation) to the firm it belongs to. This is a painstaking process as some firms have numerous installations, often with different names, each receiving a different number of carbon allowances. All these installations are then manually matched to the parent firm that is listed in the stock exchange. Finally, we aggregate across installations for each firm to determine the total number of free EUAs issued to each UK firm.

Armed with these data, we build a dirty portfolio of all 16 firms that have received carbon allowances and a clean portfolio of all 67 firms that did not receive any carbon allowances. Hence we use data for 83 of the 100 firms for which we have monthly return observations for the full sample period of November 2003 to December 2012. Note that for the UK data we place all dirty firms in one portfolio and hence we do not distinguish between dirty and medium firms. This is because in the UK there are very few firms with a large number of carbon allowances. For instance, had we defined dirty firms as those receiving more than one million allowances, then only four firms would satisfy this criterion. Indeed, the majority of the 16 dirty firms received no more than 100,000 allowances. Furthermore, the market value of the average UK dirty firm is lower than in Germany and, therefore, the average UK dirty firm needs less carbon allowances than in Germany. Therefore, our analysis is based on the argument that the distinct structure of the UK market justifies placing all dirty firms in one portfolio.

In the asset pricing regressions, we use data on UK Fama-French factors provided by the Xfi Centre for Finance and Investment at the University of Exeter. These data are specifically constructed for the UK economy and are discussed in Gregory, Tharayan and Christidis (2013).

Our main finding is that the UK results are qualitatively similar to the German results. Figure 7 plots the rolling carbon premium for the UK and shows the striking similarity between Germany and the UK. The figure reveals that the timing for the carbon premium in Germany and the UK is the same: the carbon premium begins at the end of 2003, grows dramatically during Phase I, diminishes in Phase II and disappears after 2009. Table 8 reports more detailed results. Notably the UK carbon premium is high and significant in Phase I but not for the other sample periods. Overall, this empirical evidence confirms the presence of a carbon premium in the UK that lasted for as long as it did in Germany.

10 Discussion and Conclusions

The EU ETS is the world's first and largest multinational cap-and-trade program for regulating carbon emissions. At the center of this scheme is the creation of a new market for trading carbon emission allowances. From 2013 onwards, these allowances are auctioned off at a price thus generating significant revenues for EU governments. From 2005 to 2012, however, during the initial two phases of the ETS, allowances were granted to carbon emitting firms for free. As a result, firms receiving these allowances could either sell them for profit or they could use them for production thus making these allowances an opportunity cost to be accounted for in setting prices and quantities.

The free allocation of carbon allowances in the initial two phases of the ETS is a crucial aspect of the scheme. Previous theoretical work suggests that the free allocation overcompensates firms and can lead to large increases in profits. The mechanism that leads to substantial additional profits for carbon emitting firms has two direct channels: (i) firms face higher marginal costs, which to a large extent are passed through to consumers through higher output prices, thus increasing firm revenue; and (ii) output falls and, since carbon allowances are allocated freely, the allowances not used in production can be sold for a profit. In a separate argument, carbon emitting firms are exposed to higher risk and hence require higher expected returns due to uncertainty about the future price of carbon allowances, which also generates uncertainty about future cash flows.

This paper fills a gap in the literature by providing a comprehensive empirical evaluation of whether firms that received carbon emission allowances significantly outperformed firms that did not. In particular, we examine the effect of the EU ETS on stock returns. We do so by assessing the size, significance and timing of the carbon premium, which is defined as the abnormal excess return of a portfolio of dirty firms over and above the abnormal excess return of a portfolio of clean firms in the context of standard asset pricing models. Our analysis focuses on Germany, which is the largest market affected by the ETS, but for robustness we also examine data from the UK.

Our main finding is that there is a large and statistically significant carbon premium in stock returns. The carbon premium can be as high as 17% and highly significant for the sample period that begins in November 2003 and ends in March 2009. This sample period begins with the passing of an EU law establishing the initial two phases of the EU ETS and ends with the passing of another EU law establishing Phase III of the EU ETS beginning in

2013 during which carbon allowances are mainly sold in auctions. Hence this is the period over which the market knew with certainty that carbon emitting firms will be receiving free carbon allowances. Our evidence clearly indicates that after March 2009 the carbon premium dissipates. Furthermore, the timing of the carbon premium based on German data is confirmed when using UK data.

Our cross-sectional analysis indicates that for the relevant sample period, we can construct a carbon risk factor based on the returns of the dirty-minus-clean portfolio, which can explain a considerable part of the cross-sectional variation in expected stock returns. For this sample period, the significance of the carbon risk factor is robust to the inclusion of a large set of control variables. This suggests that firms with high carbon emissions have higher exposure to carbon risk and exhibit higher expected returns.

As a final note, the evidence suggests that a carbon premium is present for a specific period that commences about one year before the beginning of Phase I and disappears about one year into Phase II. It is possible, therefore, that the carbon premium may have been a one-off event, which was only present during this particular period. Indeed, this is likely as the carbon premium is primarily driven by the free allocation of carbon allowances. Still, our analysis contributes to the current environmental policy debate because it informs policy-makers and investors about the design and implications of similar cap-and-trade environmental regulation implemented elsewhere.

References

Amihud, Y. (2002). "Illiquidity and Stock Returns: Cross-Section and Time-Series Effects," *Journal of Financial Markets* **5**, 31–56.

Ang, A., R.J. Hodrick, Y. Xing, and X. Zhang (2006). "The Cross-Section of Volatility and Expected Returns," *Journal of Finance* **61**, 259–299.

Ang, A., J. Chen, and Y. Xing (2006). "Downside Risk," *Review of Financial Studies* **19**, 1191–1239.

Artmann, S., P. Finter, A. Kempf, S. Koch, and E. Theissen (2012). "The Cross-Section of German Stock Returns: New Data and New Evidence," *Schmalenbach Business Review* **64**, 20–43.

Bali, T.G., N. Cakici, R.F. Whitelaw (2011). "Maxing Out: Stocks as Lotteries and the Cross-Section of Expected Returns," *Journal of Financial Economics* **99**, 427–446.

Benz, E., and S. Truck (2009). "Modeling the Price Dynamics of CO_2 Emission Allowances," *Energy Economics* **31**, 4–15.

Bruckner, R., P. Lehmann, M.H. Schmidt, and R. Stehle (2014). "Fama/French Factors for Germany: Which Set is Best?" Working paper, available at SSRN: http://ssrn.com/abstract=2390063.

Bushnell, J.B., H. Chong, and E.T. Mansur (2013). "Profiting from Regulation: Evidence from the European Carbon Market," *American Economic Journal: Economic Policy* **5**, 78–106.

Campbell, J.Y., and R.J. Shiller (1988). "The Dividend Price Ratio and Expectations of Future Dividends and Discount Factors," *Review of Financial Studies* **1**, 195–228.

Carhart, M. (1997). "On Persistence in Mutual Fund Performance," *Journal of Finance* **52**, 57–82.

Daskalakis, G., D. Psychoyios, and R.N. Markellos (2009). "Modelling CO_2 Emission Allowance Prices and Derivatives: Evidence from the European Trading Scheme," *Journal of Banking and Finance* **33**, 1230–1241.

Demailly, D., and P. Quirion (2008). "European Emission Trading Scheme and Competitiveness: A Case Study on the Iron and Steel Industry," *Energy Economics* **30**, 2009–2027.

Ellerman, A.D., F.J. Convery, and C. de Perthuis (2010). *Pricing Carbon: The European Union Emissions Trading Scheme*. Cambridge: Cambridge University Press.

Fama, E., and K. French (1993). "Common Risk Factors in the Returns on Stocks and Bonds," *Journal of Financial Economics* **33**, 3–56.

Fama, E., and J. MacBeth (1973). "Risk, Return and Equilibrium: Empirical Tests," *Journal of Political Economy* **81**, 607-636.

Goulder, L., M. Hafstead, and M. Dworsky (2010). "Impacts of Alternative Emissions Allowance Allocation Methods Under a Federal Cap-and-Trade Program," *Journal of Environmental Economics and Management* **60**, 161–181.

Gregory, A., R. Tharayan, and A. Christidis (2013). "Constructing and Testing Alternative Versions of the Fama-French and Carhart Models in the UK," *Journal of Business Finance and Accounting* **40**, 172–214.

Harvey, C.R., and A. Siddique (2000). "Conditional Skewness in Asset Pricing Tests," *Journal of Finance* **55**, 1263–1295.

Hintermann, B. (2010). "Allowance Price Drivers in the First Phase of the EU ETS," *Journal of Environmental Economics and Management* **59,** 43–56.

Jong, T., O. Couwenberg, and E. Woerdman (2014). "Does EU Emissions Trading Bite? An Event Study," *Energy Policy* **69,** 510–519.

Koch, N., and A. Bassen (2013). "Valuing the Carbon Exposure of European Utilities. The Role of Fuel Mix, Permit Allocation and Replacement Investments," *Energy Economics* **36**, 431–443.

Litterman, B. (2013). "What is the Right Price for Carbon Emissions?" *Regulation*, Summer 2013, 38–43.

Newey, W.K., and K.D. West (1987). "A Simple, Positive Semi-Definite Heteroskedasticity and Autocorrelation Consistent Covariance Matrix," *Econometrica* **55**, 703–708.

Oberndorfer, U. (2009). "EU Emission Allowances and the Stock Market: Evidence from the Electricity Industry," *Ecological Economics* **68**, 1116–1129.

Paolella, M.S., and L. Taschini (2008). "An Econometric Analysis of Emission Trading Allowances," *Journal of Banking and Finance* **32**, 2022–2032.

Pastor, L., and P. Veronesi (2012). "Uncertainty about Government Policy and Stock Prices," *Journal of Finance* **67**, 1219–1264.

Pindyck, R.S. (2013). "Pricing Carbon When We Don't Know the Right Price," *Regulation*, Summer 2013, 43–46.

Sijm, J.P.M., K. Neuhoff, and Y. Chen (2006). "CO_2 Cost Pass-Through and Windfall Profits in the Power Sector," *Climate Policy* **6**, 49-72.

Smale, R., M. Hartley, C. Hepburn, J. Ward, and M. Grubb (2006). "The Impact of CO_2 Emissions Trading on Firm Profits and Market Prices," *Climate Policy* **6**, 29–46.

Veith, S., J. Werner, and J. Zimmermann (2009). "Capital Market Response to Emission Rights Returns: Evidence from the European Power Sector," *Energy Economics* **31**, 605–613.

Weitzman, M. (2009). "On Modeling and Interpreting the Economics of Catastrophic Climate Change," *Review of Economics and Statistics* **91**, 1–19.

World Bank (2014). *State and Trends of Carbon Pricing 2014*.

Table 1. Timeline

This table provides a timeline with important dates regarding the implementation of the EU Emissions Trading Scheme (ETS).

2003	*October*	EU passes law establishing Phases I and II of EU ETS
2005	*January*	Phase I of EU ETS begins
2005	*April*	EUA trading begins
2006	*April*	EU publicizes emissions reports for the first time
2008	*January*	Phase II begins
2009	*April*	EU passes law establishing Phase III of EU ETS
2013	*January*	Phase III begins

Table 2. Descriptive Statistics

The table reports monthly descriptive statistics for 65 German stocks included in the DAX and MDAX indexes for two sample periods: November 2003 to March 2009 and November 2003 to December 2012. ME is the average market value of equity in million euros over the longer sample period. Free allowances is the average number of carbon emission allowances issued annually and is measured in million. "Dirty" are firms which were issued allowances and "clean" are firms which were not. The dirty firms are listed by the number of allowances, whereas the clean firms are listed alphabetically. The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units.

					Free Allowances		*Nov 2003 – Mar 2009*			*Nov 2003 – Dec 2012*		
	Company	*Ticker*	*Industry*	*ME*	*Phase I*	*Phase II*	*Mean*	*SDev*	*SR*	*Mean*	*SDev*	*SR*
					Dirty Firms							
1	RWE	RWE	Electric	29,387	109.633	57.720	0.175	0.237	0.610	0.075	0.262	0.208
2	E.ON	EOA	Electric	54,047	42.033	28.980	0.102	0.256	0.281	0.044	0.273	0.087
3	ThyssenKrupp	TKA	Iron/Steel	12,373	24.033	24.000	0.024	0.369	−0.016	0.053	0.393	0.083
4	Salzgitter	SZG	Iron/Steel	3,575	10.200	12.000	0.323	0.420	0.697	0.186	0.396	0.419
5	Heid. Cement	HEI	Building Materials	7,928	5.500	4.780	−0.055	0.380	−0.223	0.047	0.391	0.067
6	BASF	BAS	Chemical	38,799	4.867	5.520	0.059	0.249	0.116	0.177	0.278	0.563
7	Volkswagen	VOW	Auto Manufacturer	31,892	2.504	1.986	0.324	0.415	0.710	0.161	0.458	0.307
8	K+S	SDF	Chemical	5,620	1.441	1.140	0.382	0.420	0.838	0.243	0.408	0.546
9	Suedzucker	SZU	Food	3,270	0.785	0.887	0.038	0.240	0.032	0.110	0.235	0.382
10	Henkel	HEN	Household Products	7,713	0.560	0.491	0.007	0.220	−0.102	0.120	0.207	0.484
11	Daimler	DAI	Auto Manufacturer	43,123	0.383	0.376	−0.063	0.334	−0.279	0.057	0.350	0.106
12	Bayer	BAY	Chemical	34,060	0.290	0.283	0.135	0.255	0.411	0.169	0.251	0.591
13	BMW	BMW	Auto Manufacturer	25,481	0.272	0.294	−0.065	0.276	−0.345	0.097	0.297	0.258
14	Merck	MRK	Pharmaceutical	4,231	0.141	0.108	0.162	0.251	0.528	0.147	0.246	0.515
15	Krones	KRN	Machinery	1,184	0.078	0.073	0.055	0.317	0.080	0.103	0.302	0.275
16	Continental	CON	Auto Parts	9,941	0.077	0.069	−0.139	0.495	−0.341	0.133	0.489	0.231
17	MAN	MAN	Machinery	8,856	0.055	0.024	0.092	0.385	0.160	0.156	0.371	0.365
18	Infineon	IFX	Semiconductors	6,050	0.038	0.017	−0.506	0.571	−0.938	−0.067	0.592	−0.147
19	Hochtief	HOT	Construction	3,360	0.034	0.033	0.080	0.504	0.099	0.098	0.443	0.177
20	Fresenius Med.	FME	Healthcare Products	10,062	0.027	0.032	0.120	0.170	0.533	0.140	0.165	0.726
21	Lufthansa	LHA	Airline	6,026	0.019	0.020	−0.059	0.272	−0.326	0.040	0.298	0.066
22	Siemens	SIE	Manufacturing	64,592	0.015	0.016	−0.037	0.293	−0.229	0.058	0.273	0.137
23	Aurubis	NDA	Metal	1,107	0.008	0.008	0.175	0.313	0.465	0.222	0.295	0.685
24	Heid. Druck.	HDD	Machinery	1,476	0.005	0.006	−0.351	0.588	−0.647	−0.284	0.573	−0.531

(continued)

Table 2. Descriptive Statistics (*continued*)

	Company	*Ticker*	*Industry*	*ME*	*Free Allowances* *Phase I*	*Phase II*	*Nov 2003 – Mar 2009* *Mean*	*SDev*	*SR*	*Nov 2003 – Dec 2012* *Mean*	*SDev*	*SR*
					Clean Firms							
25	Aareal Bank	ARL	Bank	966	0.000	0.000	−0.251	0.535	−0.525	−0.038	0.520	−0.111
26	Adidas	ADS	Apparel	8,033	0.000	0.000	0.049	0.264	0.071	0.143	0.249	0.492
27	Allianz	ALV	Insurance	44,320	0.000	0.000	−0.050	0.353	−0.228	0.044	0.325	0.073
28	Axel Springer	SPR	Media	3,139	0.000	0.000	−0.007	0.245	−0.151	0.083	0.257	0.245
29	Baywa	BYW6	Retail	831	0.000	0.000	0.125	0.438	0.216	0.149	0.353	0.363
30	Beiersdorf	BEI	Cosmetics	10,468	0.000	0.000	0.020	0.209	−0.046	0.085	0.201	0.323
31	Bilfinger Berger	GBF	Construction	1,993	0.000	0.000	0.047	0.356	0.048	0.151	0.320	0.409
32	Celesio	CLS1	Pharmaceutical	4,417	0.000	0.000	−0.021	0.290	−0.175	−0.016	0.316	−0.114
33	Commerzbank	CBK	Bank	11,446	0.000	0.000	−0.253	0.520	−0.544	−0.238	0.495	−0.522
34	D. Bank	DBK	Bank	36,449	0.000	0.000	−0.081	0.422	−0.263	−0.024	0.411	−0.107
35	D. Boerse	DB1	Financial	10,643	0.000	0.000	0.142	0.349	0.320	0.104	0.335	0.249
36	D. Euroshop	DEQ	Real Estate	955	0.000	0.000	0.091	0.224	0.272	0.119	0.201	0.491
37	D. Post	DPW	Transportation	19,280	0.000	0.000	−0.107	0.330	−0.413	0.037	0.302	0.054
38	D. Telekom	DTE	Telecommunication	51,262	0.000	0.000	−0.027	0.203	−0.280	0.007	0.196	−0.066
39	Deutz	DEZ	Machinery	573	0.000	0.000	−0.050	0.480	−0.165	0.019	0.463	−0.003
40	Douglas	DOU	Retail	1,308	0.000	0.000	0.067	0.193	0.192	0.076	0.204	0.275
41	Elringklinger	ZIL2	Auto Parts	960	0.000	0.000	0.062	0.419	0.076	0.173	0.400	0.381
42	Fielmann	FIE	Retail	2,007	0.000	0.000	0.218	0.212	0.889	0.195	0.194	0.901
43	Fraport	FRA	Construction	3,820	0.000	0.000	0.040	0.315	0.031	0.095	0.290	0.259
44	Fresenius	FRE	Healthcare Products	3,487	0.000	0.000	0.078	0.255	0.190	0.173	0.234	0.653
45	FUCHS Petrolub	FPE3	Oil & Gas	746	0.000	0.000	0.176	0.344	0.425	0.315	0.316	0.931
46	GEA	G1A	Food and Energy	3,109	0.000	0.000	−0.050	0.357	−0.224	0.099	0.348	0.225
47	Gerry Weber	GWI1	Apparel	574	0.000	0.000	0.195	0.304	0.542	0.296	0.271	1.019
48	Gildemeister	GIL	Machine Tools	497	0.000	0.000	0.025	0.522	−0.009	0.127	0.466	0.229
49	Hannover Reuck.	HNR1	Insurance	3,988	0.000	0.000	0.026	0.273	−0.016	0.129	0.237	0.458
50	Hugo Boss	BOS3	Apparel	1,306	0.000	0.000	−0.043	0.353	−0.207	0.201	0.363	0.499
51	KUKA	IWK	Machine Tools	509	0.000	0.000	−0.067	0.392	−0.246	0.068	0.351	0.137
52	Leoni	LEO	Electrical	742	0.000	0.000	−0.133	0.468	−0.347	0.089	0.485	0.142
53	Linde	LIN	Chemical	12,807	0.000	0.000	0.072	0.225	0.188	0.155	0.218	0.615
54	Metro	MEO	Food	13,279	0.000	0.000	−0.039	0.273	−0.253	−0.030	0.292	−0.171
55	Munich Re	MUV	Insurance	22,507	0.000	0.000	0.004	0.203	−0.127	0.067	0.200	0.233
56	Prosieben	PSM	Media	1,673	0.000	0.000	−0.390	0.580	−0.724	0.095	0.616	0.122
57	Puma	PUM	Apparel	3,607	0.000	0.000	−0.013	0.308	−0.141	0.072	0.306	0.168
58	Rational	RAA	Home Furnishings	1,393	0.000	0.000	0.105	0.349	0.215	0.210	0.299	0.635
59	Rheinmetall	RHM	Machinery	1,585	0.000	0.000	0.005	0.373	−0.065	0.053	0.367	0.089
60	Rhoen-Klinikum	RHK	Healthcare Services	1,840	0.000	0.000	0.067	0.271	0.137	0.056	0.277	0.128
61	SAP	SAP	Software	46,231	0.000	0.000	−0.023	0.240	−0.222	0.082	0.229	0.269
62	SGL Carbon	SGL	Chemical	1,532	0.000	0.000	0.080	0.495	0.101	0.102	0.420	0.194
63	Stada	SAZ	Pharmaceutical	1,607	0.000	0.000	−0.098	0.383	−0.333	0.024	0.400	0.010
64	TUI	TUI1	Travel	2,904	0.000	0.000	−0.210	0.321	−0.749	−0.054	0.472	−0.157
65	Vossloh	VOS	Electrical	960	0.000	0.000	0.153	0.267	0.460	0.097	0.250	0.307

Table 3. The Performance of Carbon Portfolios

The table presents the performance of carbon portfolios. *Dirty* is a portfolio of firms, which during the initial two phases of the EU ETS received annually more than 1 million free carbon emission allowances. *Medium* is a portfolio of firms, which for the same period received more than zero but less than 1 million free carbon allowances. *Clean* is a portfolio of firms, which did not receive any carbon allowances. All portfolios are formed with equal weights. The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. CAPM-a is the alpha of a CAPM regression, FF3-a is the alpha of the Fama-French (1993) 3-factor regression, FF4-a is the alpha of the Carhart (1997) 4-factor regression. All alphas are annualized. t-statistics based on Newey-West (1987) standard errors are reported in parentheses. The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level respectively.

Mean	*SDev*	*SR*	*CAPM-α*	*FF3-α*	*FF4-α*
		November 2003 to March 2009			
		Dirty Portfolio [8 stocks]			
0.167	0.235	0.583	0.149***	0.130**	0.144**
			(3.007)	(2.544)	(2.388)
		Medium Portfolio [16 stocks]			
−0.022	0.236	−0.221	− 0.039	− 0.038	− 0.004
			(−1.064)	(−1.078)	(−0.094)
		Clean Portfolio [41 stocks]			
−0.001	0.224	−0.141	− 0.019	− 0.013	0.026
			(−0.485)	(−0.450)	(0.812)
		Dirty-minus-Clean Portfolio			
0.168	0.119	1.167	0.168***	0.143***	0.118**
			(3.863)	(3.425)	(2.372)
		November 2003 to December 2012			
		Dirty Portfolio [8 stocks]			
0.123	0.248	0.415	0.040	0.026	0.033
			(0.988)	(0.648)	(0.739)
		Medium Portfolio [16 stocks]			
0.081	0.230	0.265	0.001	− 0.014	0.016
			(0.031)	(−0.476)	(0.571)
		Clean Portfolio [41 stocks]			
0.074	0.227	0.239	− 0.004	− 0.022	0.010
			(−0.115)	(−0.792)	(0.343)
		Dirty-minus-Clean Portfolio			
0.036	0.128	0.119	0.029	0.031	0.014
			(0.635)	(0.842)	(0.332)
		Phase I: January 2005 to December 2007			
		Dirty-minus-Clean Portfolio			
0.190	0.078	2.041	0.153***	0.131***	0.121***
			(3.642)	(3.732)	(2.766)
		Phase II: January 2008 to December 2012			
		Dirty-minus-Clean Portfolio			
−0.084	0.152	−0.646	− 0.082	− 0.070	− 0.075
			(−1.270)	(−1.318)	(−1.318)

Table 4. The Price of Carbon Risk

This table reports the price of carbon risk based on Fama-MacBeth (1973) cross-sectional regressions for the average returns of 65 German stocks. Entries are the percent monthly factor risk premiums for the following factors: DMC is the dirty-minus-clean factor; MKT is the excess market return; SMB is the small-minus-big factor; HML is the high-minus-low factor, MOM is the momentum factor; IND is the industry factor; MAX is the maximum daily return factor; ILLIQ is the illiquidity factor; IVOL the idiosyncratic volatility factor; COSKEW the coskewness factor; and, finally, the downside beta and upside beta. t-statistics are in parentheses.

	November 2003 to March 2009						*November 2003 to December 2012*					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.32	1.18	1.38	0.85	1.03	−0.11	0.71	1.33	1.38	0.25	0.32	−0.24
	(2.47)	(3.57)	(4.38)	(2.48)	(2.71)	(−0.58)	(6.82)	(5.44)	(6.01)	(1.01)	(1.11)	(−1.25)
DMC	1.35	1.05	0.93	0.91	0.87	0.54	0.40	0.25	0.33	0.22	0.22	−0.01
	(6.28)	(4.53)	(4.26)	(4.47)	(4.22)	(4.98)	(1.74)	(1.10)	(1.55)	(1.32)	(1.32)	(−0.03)
MKT		−0.78	−1.09	−0.38	−0.34	–		−0.50	−0.64	0.62	0.63	–
		(−2.85)	(−3.86)	(−1.07)	(−0.96)			(−2.26)	(−2.97)	(2.45)	(2..47)	
SMB			0.52	0.41	0.44	−0.21			0.73	0.47	0.47	0.18
			(1.76)	(1.46)	(1.58)	(−1.59)			(2.66)	(2.17)	(2.17)	(1.49)
HML			0.50	0.50	0.54	0.03			0.09	0.50	0.52	0.18
			(1.85)	(1.99)	(2.12)	(0.30)			(0.29)	(2.01)	(2.03)	(1.48)
MOM				1.51	1.37	0.26				1.90	1.84	0.35
				(4.65)	(3.87)	(1.58)				(7.06)	(6.34)	(1.61)
IND					−0.28	0.34					−0.10	0.18
					(−1.09)	(2.58)					(−0.50)	(1.22)
MAX						0.89						0.60
						(3.37)						(1.98)
ILLIQ						0.00						−0.00
						(0.13)						(−0.49)
IVOL						−5.33						0.50
						(−1.56)						(0.16)
COSKEW						−0.34						−0.54
						(−8.47)						(−6.74)
Downside β						−2.88						−3.61
						(−10.02)						(−8.67)
Upside β						3.35						4.46
						(13.76)						(10.76)
$\overline{R}^2$ (%)	37.5	43.6	51.9	58.0	58.1	94.2	3.1	12.4	23.9	55.3	54.7	90.2

Table 5. The Carbon Premium, the EUA Price and Energy Factors

The table presents the carbon premium, which is the alpha of the *Dirty-minus-Clean* portfolio, for three regressions: (i) the plain CAPM, (ii) the CAPM with the log-price change to the EUA, and (iii) the CAPM with the log-price change to the EUA and the log-price change to four energy factors: oil, gas, coal and electricity. a is the annualized intercept of the CAPM regression and β are the slopes on the log-price changes to the EUA and the four energy factors. t-statistics based on Newey-West (1987) standard errors are in parentheses. The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level respectively. The two sample periods begin in May 2005, which is the earliest month for which we have an observation for the return to the EUA. The first sample period ends in March 2009 and the second period in December 2012.

May 2005 to March 2009

CAPM	*CAPM + EUA*		*CAPM + EUA + Energy Factors*					
α	α	β_{EUA}	α	β_{EUA}	β_{oil}	β_{gas}	β_{coal}	β_{elec}
0.185**	0.186**	0.488	0.188**	0.423	0.187	0.985	0.067	−0.035
(2.287)	(2.357)	(1.092)	(2.404)	(0.819)	(0.083)	(1.470)	(0.058)	(−0.278)

May 2005 to December 2012

CAPM	*CAPM + EUA*		*CAPM + EUA + Energy Factors*					
α	α	β_{EUA}	α	β_{EUA}	β_{oil}	β_{gas}	β_{coal}	β_{elec}
0.029	0.034	0.398	0.025	0.249	0.680	0.497	0.198	−0.076
(0.397)	(0.471)	(1.040)	(0.302)	(0.690)	(0.372)	(0.968)	(0.218)	(−0.702)

Table 6. The Carbon Premium for Alternative Compositions of the Dirty Portfolio

The table displays the performance of the *Dirty-minus-Clean* portfolio for four alternative specifications of the Dirty portfolio. The composition of the four Dirty portfolios varies according to the number of free carbon emission allowances received by the firms in the portfolio. All portfolios are formed with equal weights. The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. CAPM-a is the intercept of a CAPM regression, FF3-a is the intercept of the Fama-French (1993) 3-factor regression, FF4-a is the intercept of the Carhart (1997) 4-factor regression. All as are for annualized returns. t-statistics based on Newey-West (1987) standard errors are in parentheses. The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level respectively.

Mean	*SDev*	*SR*	*CAPM-α*	*FF3-α*	*FF4-α*
November 2003 to March 2009					
8 dirty stocks (>1 mil carbon allowances)					
0.168	0.119	1.167	0.168***	0.143***	0.118**
			(3.863)	(3.425)	(2.372)
10 dirty stocks (>0.5 mil carbon allowances)					
0.139	0.104	1.057	0.139***	0.121***	0.081**
			(3.823)	(3.573)	(2.128)
14 dirty stocks (>0.1 mil carbon allowances)					
0.112	0.092	0.894	0.111***	0.094***	0.057*
			(3.482)	(3.354)	(2.220)
24 dirty stocks (>0 carbon allowances)					
0.042	0.070	0.179	0.043	0.031	0.019
			(1.500)	(1.114)	(0.471)
November 2003 to December 2012					
8 dirty stocks (>1 mil carbon allowances)					
0.036	0.128	0.119	0.029	0.031	0.014
			(0.635)	(0.842)	(0.332)
10 dirty stocks (>0.5 mil carbon allowances)					
0.034	0.107	0.128	0.034	0.040	0.009
			(0.916)	(1.343)	(0.278)
14 dirty stocks (>0.1 mil carbon allowances)					
0.033	0.097	0.129	0.033	0.041*	0.012
			(1.002)	(1.705)	(0.471)
24 dirty stocks (>0 carbon allowances)					
0.008	0.072	−0.176	0.002	0.004	0.003
			(0.107)	(0.208)	(0.105)

Table 7. The Performance of Carbon Portfolios - 80 stocks

The table reports the same information as Table 3 on the performance of carbon portfolios but uses a larger cross-section of 80 German stocks. This cross-section consists of the 65 firms for which we have data for the full sample period of November 2003 to December 2012 plus the 15 firms for which we do not have data for the full sample period.

Mean	*SDev*	*SR*	*CAPM-α*	*FF3-α*	*FF4-α*
			November 2003 to March 2009		
			Dirty Portfolio [8 stocks]		
0.167	0.235	0.583	0.149***	0.130**	0.144**
			(3.007)	(2.544)	(2.388)
			Medium Portfolio [21 stocks]		
−0.015	0.226	−0.200	− 0.033	− 0.033	− 0.020
			(−0.949)	(−1.037)	(−0.469)
			Clean Portfolio [51 stocks]		
−0.020	0.237	−0.211	− 0.037	− 0.031	0.024
			(−0.842)	(−0.966)	(0.663)
			Dirty-minus-Clean Portfolio		
0.187	0.125	1.226	0.186***	0.160***	0.120**
			(4.025)	(3.700)	(2.411)
			November 2003 to December 2012		
			Dirty Portfolio [8 stocks]		
0.123	0.248	0.415	0.040	0.026	0.033
			(0.988)	(0.648)	(0.739)
			Medium Portfolio [21 stocks]		
0.082	0.221	0.281	0.005	− 0.011	0.016
			(0.159)	(−0.433)	(0.564)
			Clean Portfolio [51 stocks]		
0.074	0.227	0.239	− 0.004	− 0.022	0.010
			(−0.115)	(−0.792)	(0.343)
			Dirty-minus-Clean Portfolio		
0.049	0.130	0.219	0.044	0.048	0.024
			(0.963)	(1.282)	(0.582)
			Phase I: January 2005 to December 2007		
			Dirty-minus-Clean Portfolio		
0.211	0.079	2.270	0.176***	0.156***	0.147***
			(3.857)	(4.201)	(3.567)
			Phase II: January 2008 to December 2012		
			Dirty-minus-Clean Portfolio		
−0.072	0.154	−0.561	− 0.071	− 0.057	− 0.068
			(−1.100)	(−1.066)	(−1.192)

Table 8. The UK Carbon Portfolios

The table reports the performance of carbon portfolios for the UK. *Dirty* is an equally weighted portfolio of 16 dirty stocks in the FTSE 100. *Clean* is an equally weighted portfolio of 67 clean stocks in the FTSE 100. The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. CAPM-a is the intercept of a CAPM regression, FF3-a is the intercept of the Fama-French (1993) 3-factor regression, FF4-a is the intercept of the Carhart (1997) 4-factor regression. All as are for annualized returns. t-statistics based on Newey-West (1987) standard errors are reported in parentheses. The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level respectively.

Mean	*SDev*	*SR*	*CAPM-α*	*FF3-α*	*FF4-α*
		November 2003 to March 2009			
		Dirty Portfolio [16 stocks]			
0.092	0.128	0.379	0.059**	0.049*	0.058*
			(2.119)	(1.823)	(1.932)
		Clean Portfolio [67 stocks]			
0.023	0.194	−0.106	− 0.005	0.015	0.070**
			(−0.118)	(0.447)	(2.323)
		Dirty-minus-Clean Portfolio			
0.069	0.118	0.213	0.064	0.034	− 0.012
			(1.438)	(0.984)	(−0.298)
		November 2003 to December 2012			
		Dirty Portfolio [16 stocks]			
0.118	0.116	0.776	0.051**	0.043**	0.047**
			(2.517)	(2.217)	(2.334)
		Clean Portfolio [67 stocks]			
0.103	0.186	0.408	0.010	0.009	0.030
			(.342)	(.374)	(1.20)
		Dirty-minus-Clean Portfolio			
0.014	0.115	−0.121	0.041	0.034	0.017
			(1.272)	(1.337)	(0.599)
		Phase I: January 2005 to December 2007			
		Dirty-minus-Clean Portfolio			
0.063	0.076	0.196	0.112**	0.084***	0.070**
			(2.559)	(3.129)	(2.346)
		Phase II: January 2008 to December 2012			
		Dirty-minus-Clean Portfolio			
−0.007	0.142	−0.135	0.006	− 0.003	− 0.018
			(0.118)	(−0.517)	(−0.360)

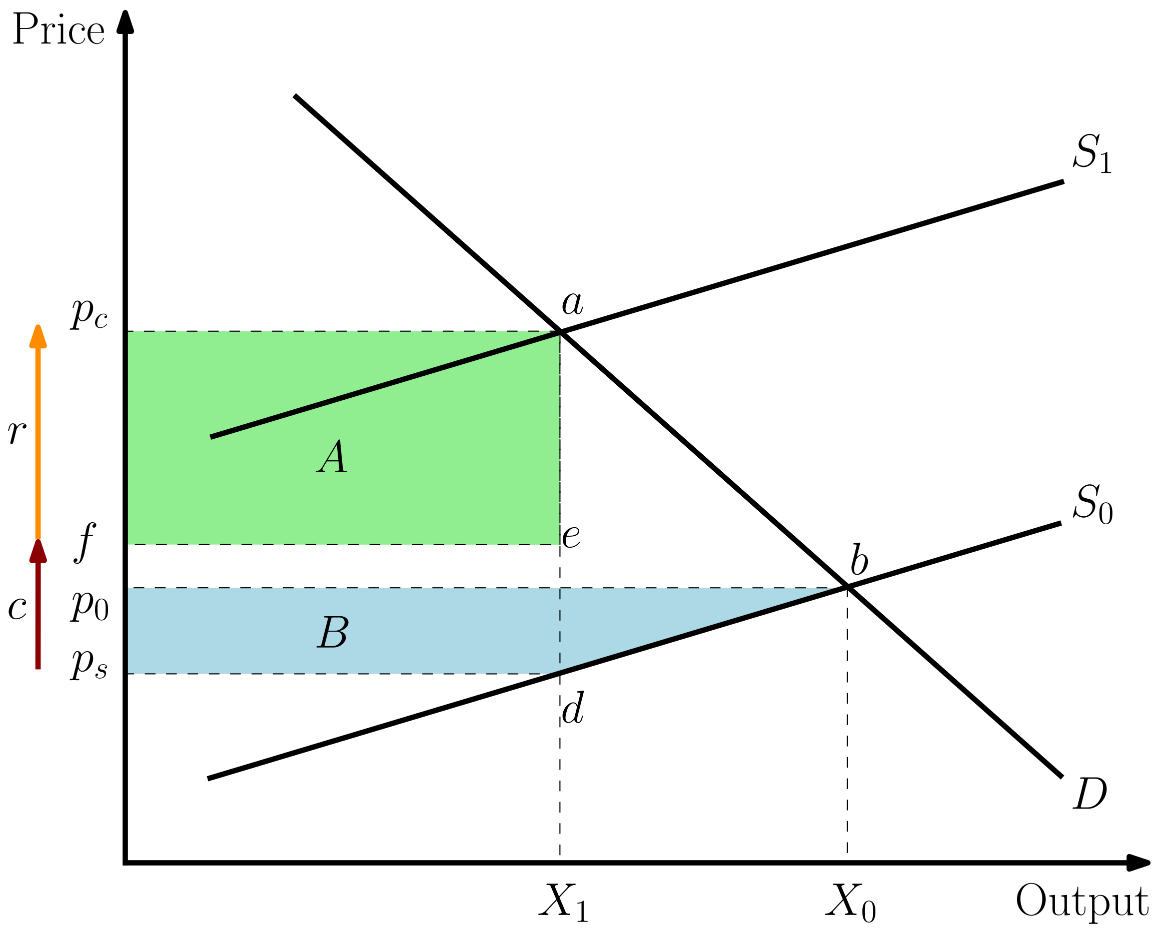

Figure 1. The Effect of Free Carbon Emission Allowances on Firm Profits

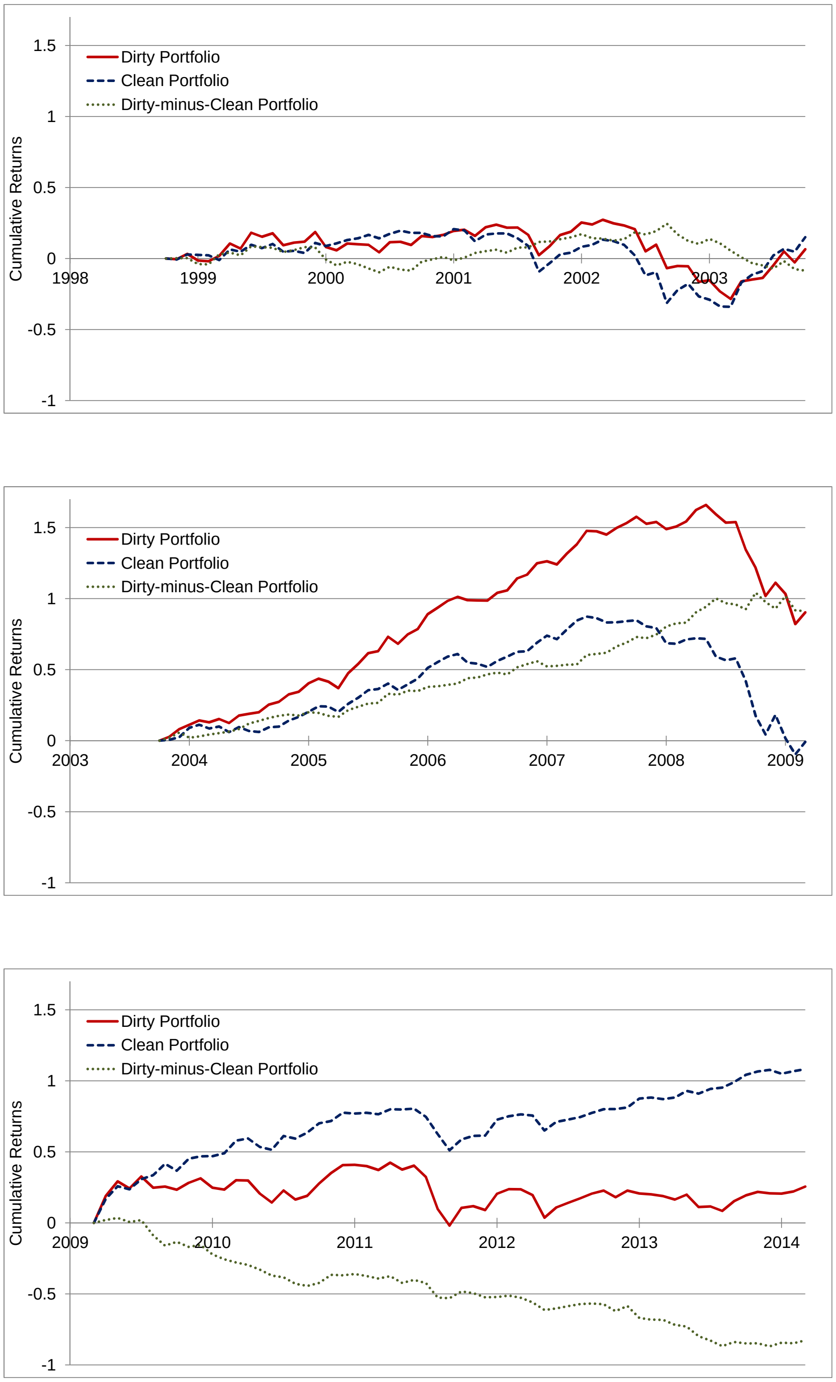

Figure 2. Cumulative Returns of Carbon Portfolios

The figure plots the cumulative returns of the Dirty, Clean and Dirty-minus-Clean portfolios for the sample period of November 2003 to March 2009 (middle), as well as for the five years before (upper) and five years after (bottom).

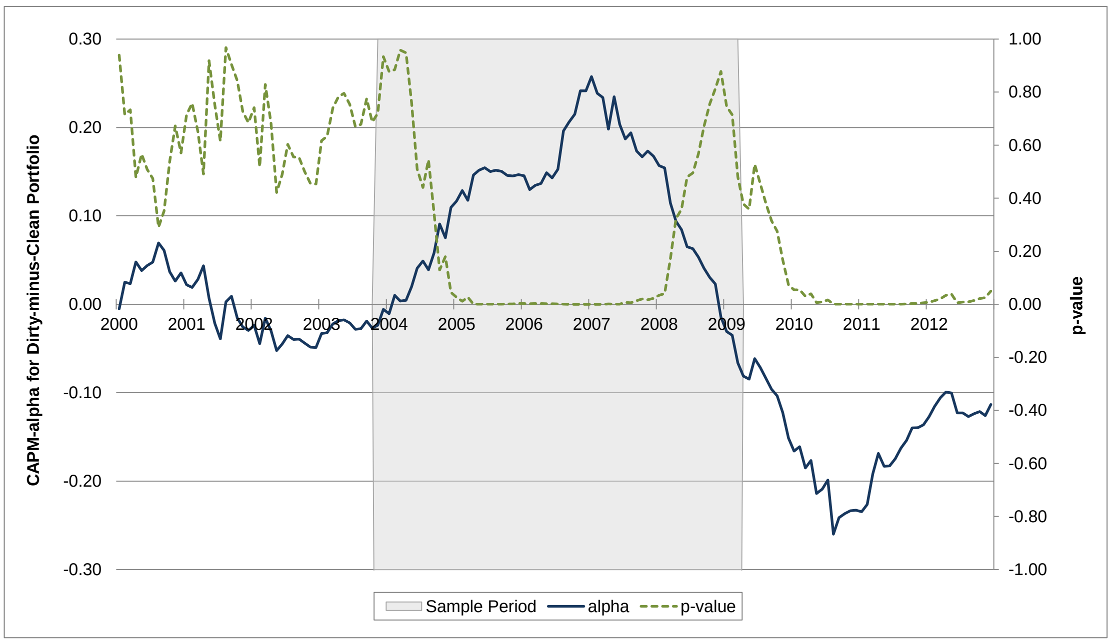

Figure 3. The Carbon Premium

The figure plots a rolling estimate of the annualized carbon premium (solid blue line) using a three-year rolling window. The carbon premium is defined as the CAPM-alpha of the Dirty-minus-Clean portfolio. The figure also plots the p-value of the carbon premium (dashed green line) based on Newey-West (1987) standard errors. The units of the alpha are shown on the left vertical axis, whereas the units of the p-value on the right vertical axis. Each alpha is plotted at the midpoint of the rolling window, thus using 18 months of data before this point and 18 months of data after. The shaded area corresponds to the sample period of November 2003 to March 2009.

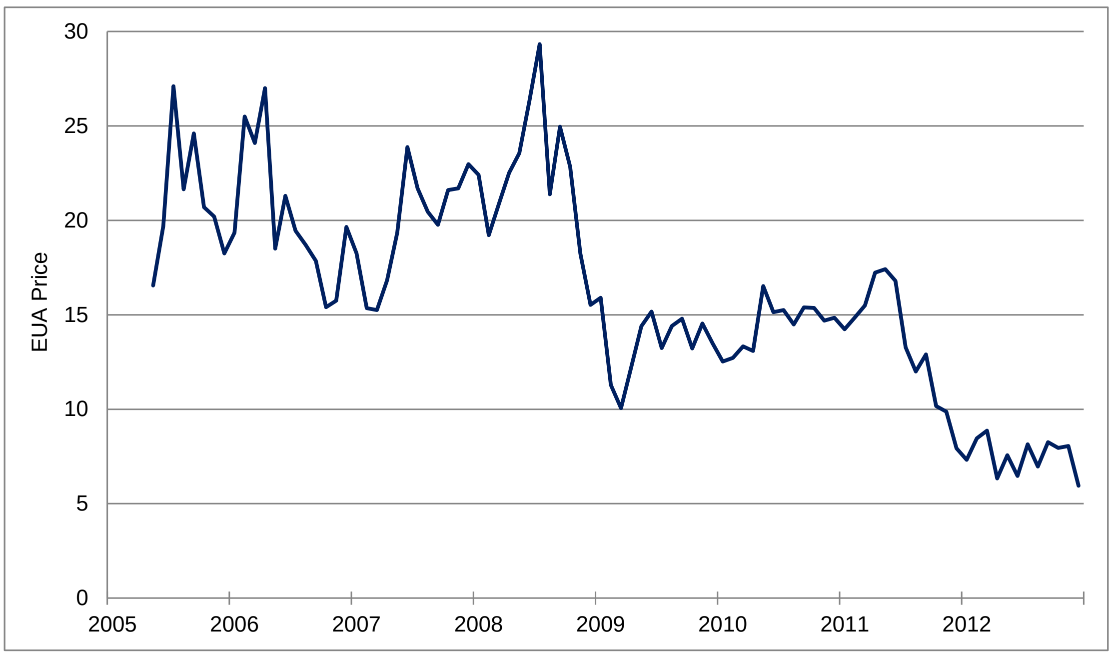

Figure 4. The Price of the European Union Allowance (EUA)

The figure plots in euros the futures price of the European Union Allowance (EUA) over time. We construct a continuous price series that combines a series of contracts as follows. In Phase I, the EUA price series is equal to the price of the December 2008 contract. In Phase II, the EUA price series uses the December 2009 contract until its last trading day, then switches to the December 2010 contract until its last trading day, and so on until December 2012.

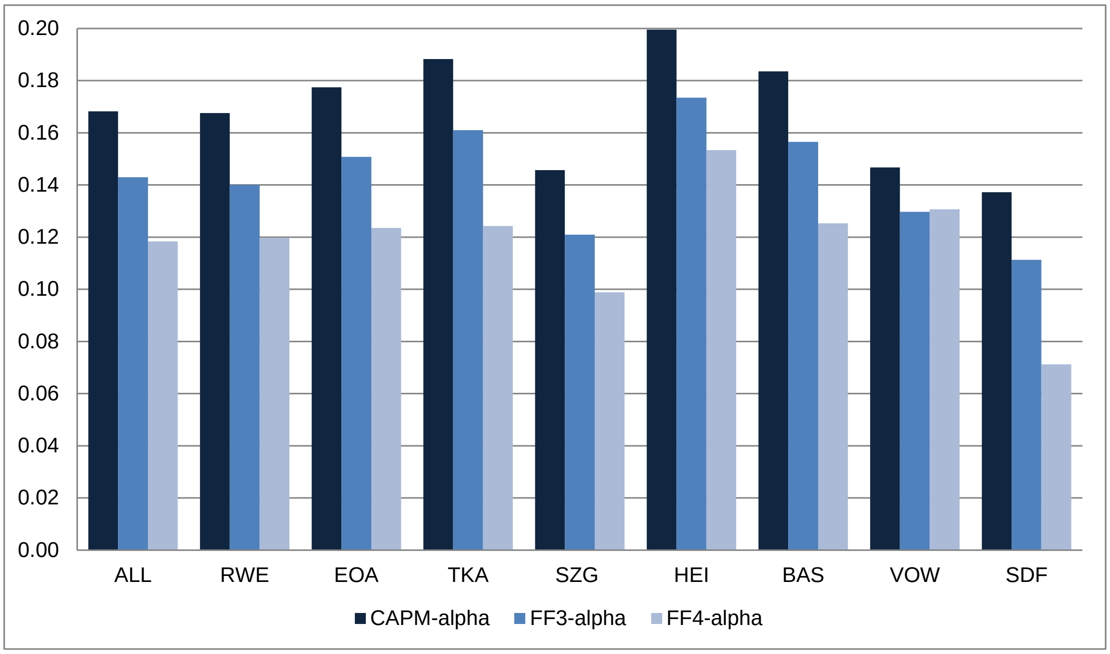

Figure 5. The Carbon Premium for One Less Dirty Stock

The figure displays the annualized alpha of the Dirty-minus-Clean portfolio when one of the eight stocks is dropped from the Dirty portfolio. The sample period ranges from November 2003 to March 2009. The original Dirty portfolio includes eight firms (ALL in the figure), which during each of the initial two phases of the EU ETS have received more than 1 million free carbon emission allowances. The horizontal axis shows the ticker of each stock dropped at a time from the Dirty portfolio. CAPM-a is the intercept of a CAPM regression, FF3-a is the intercept of the Fama-French (1993) 3-factor model regression, FF4-a is the intercept of the Carhart (1997) 4-factor regression.

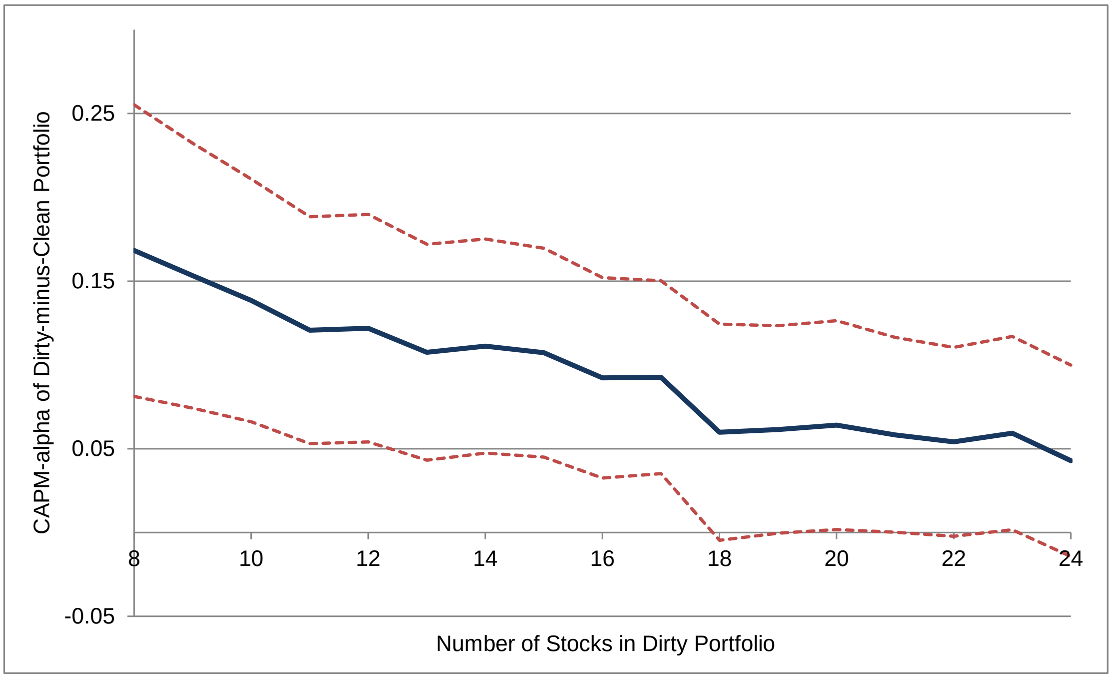

Figure 6. The Carbon Premium for More Dirty Stocks

The figure shows the annualized CAPM-alpha of the Dirty-minus-Clean portfolio (solid line) when we add one stock at a time to the original Dirty portfolio of eight stocks. The sample period ranges from November 2003 to March 2009. The figure also shows the 95% confidence interval of the CAPM-alpha (dotted lines) based on Newey-West (1987) standard errors. The original Dirty portfolio includes eight firms, which during each of the initial two phases of the EU ETS have received more than 1 million free carbon emission allowances. The sequence with which the stocks are added to the original portfolio is determined by their carbon allowances: each time the stock with the highest number of carbon allowances not already in the portfolio is added to it. The maximum number of stocks receiving carbon allowances is 24.

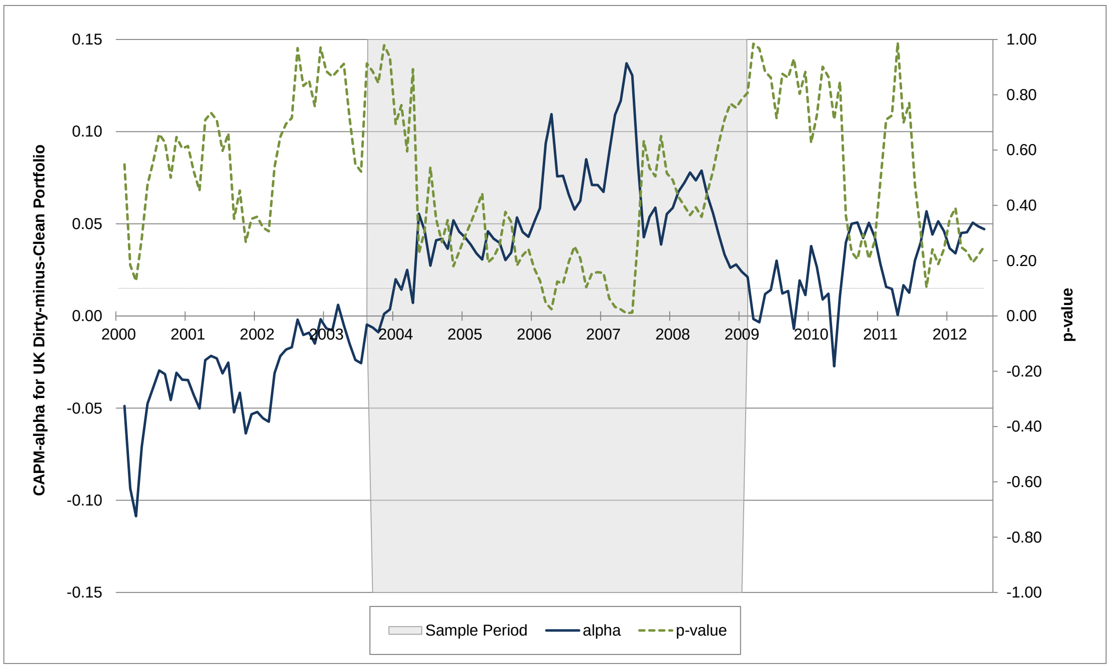

Figure 7. The UK Carbon Premium

The figure plots a rolling estimate of the annualized carbon premium for the UK (solid blue line) using a three-year rolling window. The carbon premium is defined as the CAPM-alpha of the Dirty-minus-Clean portfolio. The figure also plots the p-value of the carbon premium (dashed green line) based on Newey-West (1987) standard errors. The units of the alpha are shown on the left vertical axis, whereas the units of the p-value on the right vertical axis. Each alpha is plotted at the midpoint of the rolling window, thus using 18 months of data before this point and 18 months of data after. The shaded area corresponds to the sample period of November 2003 to March 2009.