Carbon Emissions and Stock Returns*

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Abstract

This paper provides an empirical investigation of the effect of the European Union's Emissions Trading Scheme (EU ETS) on German stock returns. In the initial two phases of the EU ETS, beginning in 2005 and ending in 2012, firms received free allowances for emitting carbon dioxide. We find that firms which received carbon emission allowances significantly outperformed firms which did not. This suggests the presence of a large and statistically significant "carbon premium" defined as the abnormal excess return of the portfolio of "dirty" firms minus that of the portfolio of "clean" firms. The carbon premium is up to 18% per annum, it cannot be explained by movements in the price for carbon allowances, and is unrelated to industry effects, size and market-to-book ratios.

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

JEL Classification: Q50; G12.

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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 is arguably the most important environmental regulation to ever be implemented. During the first two phases of the scheme, beginning in 2005 and ending in 2012, carbon emission allowances have been granted to European firms predominantly free of charge. Firms that choose to pollute more than the allowances they receive, have to purchase extra allowances in the open market from firms that use less allowances than they receive. This has lead to the emergence of the largest and fastest growing multinational carbon market in the world valued at 148 billion US dollars in 2011 (World Bank, 2012).

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 carbon emissions affect firm performance. This paper provides a comprehensive empirical investigation of the effect of the EU ETS on stock returns. Our empirical analysis uses an extensive data set of monthly stock returns from Germany as well as a manually collected data set on the number of carbon emission allowances received by each firm in the sample. We focus on Germany as it is by far the largest national market for carbon emissions and it accounts for a quarter of Europe's total carbon emissions. The sample period used in our main analysis ranges from November 2003 to March 2009. It begins with the passing of the EU directive on Phase I of the ETS that offered free carbon allowances to firms, and ends with the passing of the EU directive on Phase III announcing that carbon emission allowances will be made available predominantly in auctions from 2013 onwards. In this context, the main question of our empirical analysis is the following: did the EU ETS generate a "carbon premium" in stock returns and, if so, why?

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. The alpha capturing the carbon premium is assessed relative to the CAPM, the Fama and French (1993) three-factor model and the Carhart (1997) four-factor model.

We find that there is a large and statistically significant carbon premium in stock returns, which can be as high as 18% per year for our sample period. 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. However, even including the less dirty firms in the dirty portfolio, the carbon premium is still sizeable and significant. Furthermore, we find that the carbon premium cannot be explained by movements in the price for carbon allowances. Our results also indicate that size, market-to-book value ratios and industry effects are unlikely to explain the carbon premium. We conclude, therefore, that firms which received carbon emission allowances significantly outperformed firms which did not and, as a result, carbon emission allowances have been a primary determinant of stock performance in our sample.

This new finding of a high and statistically significant carbon premium informs policy-makers and investors about the design and implications of environmental regulation. It also indicates that carbon emitting firms are substantially overcompensated by receiving carbon emission allowances for free. This is consistent with the theoretical work of Demailly and Quirion (2008) and Goulder, Hafstead and Dworsky (2010), who show that introducing free allowances in a cap-and-trade system leads to substantially higher firm profits.[1] In essence, the carbon premium quantifies the transfer of wealth from the government (in terms of lost revenues) and consumers (in terms of likely higher prices) to firms (in terms of higher profits). Our analysis also contributes to the environmental policy debate as the EU ETS may become the model for regulating carbon emissions in North America and elsewhere. Even more so, the EU ETS could be the prototype for a global policy regime based on a cap-and-trade scheme.

This paper is related to Bushnell, Chong and Mansur (2012), who use an event study methodology to isolate the impact of a sharp decline in the price of carbon emission allowances on the returns of European firms for the three-day window of April 26-28 2006. They find that the decline in the price of carbon allowances had the highest negative impact on the returns of firms within carbon-intensive industries. This indicates that carbon regulation plays a significant role in determining the profits of the more dirty industries. Our paper, however, deviates substantially from Bushnell, Chong and Mansur (2012) as it provides a more comprehensive analysis in a number of directions: (i) instead of using a three-day window, we investigate the performance of firms affected by carbon regulation using the full length of data available; (ii) we implement an asset pricing methodology that allows us to measure the firms' abnormal excess returns while accounting for risk factors that may affect firm performance; (iii) our focus is on firms and carbon-based portfolios of firms rather than general industry effects. In the end, we quantify explicitly the effect of carbon regulation on German stock returns and the benefits to investors of holding carbon portfolios.

[1] See also Shibanov (2010) for a general-equilibrium model that captures the effect of a cap-and-trade system for carbon emissions on financial markets.

Other contributions to the literature include Anger and Oberndorfer (2008), who conduct a cross-sectional analysis of German firms for 2005 and find that carbon emission allowances are not significantly related to firm performance. Furthermore, Oberndorfer (2009) and Veith, Werner and Zimmermann (2009) use two years of daily data for European electricity and power stocks, respectively, and find that changes in the price for carbon emission allowances have a significant effect on stock returns. However, in both studies stocks did not exhibit an abnormal excess return.[2]

The remainder of the paper is organized as follows. In the next section we briefly review the institutional details of the EU ETS. Section 3 discusses the theoretical arguments suggesting a relation between carbon emission allowances and stock returns. In Section 4 we describe the data used in the empirical analysis. Section 5 provides a framework for measuring the carbon premium in stock returns and discusses the main empirical results. In Section 6 we report our findings on robustness and further analysis and, finally, Section 7 concludes.

2 The EU Emissions Trading Scheme

The European Union's Emissions Trading Scheme (EU ETS) is the world's first and largest cap-and-trade program for carbon dioxide (CO_2). From an environmental point of view, the ETS covers about half of CO_2 emissions, 40% of total greenhouse emissions, and involves about 11,500 installations (i.e., plants) in all EU member states emitting 2 billion tonnes of CO_2 emissions annually (see, e.g., Ellerman, Convery and de Perthuis, 2010). From a financial point of view, the value of the EU ETS in 2011 is 148 billion US dollars, which corresponds to 84% of the value of the global carbon market. It is noteworthy that the global carbon market has experienced very rapid growth in recent years as, for example, its market value in 2005 was only 11 billion US dollars and by 2011 it increased to 176 billion (World Bank, 2012). In short, the EU ETS is the most significant multinational initiative ever taken to mobilize markets to protect the environment. As such, it will have a profound impact on the development and implementation of future emission trading schemes in North America and elsewhere.

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 allocations does not exceed the cap. The units in which allocations are measured are called the European

[2] In a separate line of research that combines insights from climate change and financial markets, Bansal and Ochoa (2011, 2012) find that temperature is a global risk factor that can explain the cross-section of expected stock returns across countries. In particular, temperature has a negative price of risk and this relation is stronger for countries closer to the Equator. See also Dell, Jones and Olken (2009).

Union Allowances (EUAs), which give polluters the right to emit one tonne of CO_2. Note that the EUAs are given to individual installations, not the firms themselves. 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 emissions than they received, and vice versa. 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 the Energy Exchange Austria (EXAA) in Vienna. The ETS is designed to give an inventive to polluters to find ways to reduce emissions (e.g., through technological innovations) so they can sell the surplus EUAs for profit.

The EU ETS is implemented in three separate phases. Phase I runs from January 2005 to December 2007, Phase II from January 2008 to December 2012, and Phase III begins in January 2013. For the first two phases, the EUAs were predominantly given to installations free of charge. The allocation process was decentralized to the member states, each of which prepared a national allocation plan. In the third phase, the majority of the EUAs are scheduled to be sold in auctions.

3 The Effect of Free Carbon Emission Allowances on Firm Profits

The emissions trading scheme will increase the marginal cost of production to all carbon emitting firms but will have no effect on clean firms. The increase in marginal cost is equal to the market value of the EUAs used by the firm at the time they are used. This will be 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 firms uses, either it has to purchase this unit or it has to forego one unit from the surplus allowances it can sell. This cost will be taken into account in the valuation of the firm's projects. Other things being equal, the net present value (NPV) of production will decrease by an amount equal to the present value of the new opportunity or actual cost of the carbon allowances. To keep the NPV at previous levels (or at least positive), firms may respond by increasing revenue through higher prices, reducing production so that less carbon allowances are used up, switching to less carbon-intensive production technology or a combination of the three.

Following Goulder, Hafstead and Dworsky (2010), we can capture the effect of carbon allowances on firm profits with a simple diagram. Suppose that firms operate in a competitive industry. Figure 1 shows the standard demand and supply curves for market equilibrium. In the absence of carbon regulation, the initial equilibrium price and quantity are given by p_0 and X_0 respectively. Then we introduce a cap-and-trade scheme for carbon emissions. As a result, the supply curve shifts up for two reasons: (i) the higher production cost due to the actual or opportunity cost of the value of carbon allowances required per unit of output, denoted by r; and (ii) the higher production cost associated with a less carbon-intensive technology, denoted by c. 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 $c + r$.

The introduction of a cap-and-trade system with 100% free allocation of carbon allowances can generate significant profits to carbon emitting firms. In the figure, these are 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 be made available at auctions, area A would reflect the actual cost to firms of emitting carbon and the revenue to the government. Furthermore, in this figure the rents to producers captured by area A seem to be much larger than the loss of producer surplus represented by the shaded trapezoidal area B (or area $p_0 bdp_S$). Since the net effect is positive, we conclude that the free allocation of carbon allowances provides the firm with higher profits in the presence of carbon regulation.

The graphical illustration of Figure 1 presents a static view of the effects of carbon allowances on firm profits. Goulder, Hafstead and Dworsky (2010) propose an intertemporal general equilibrium model of the US economy designed to quantify the rents generated by the cap-and-trade system. Their analysis demonstrates that 100% free allocation of carbon allowances overcompensates firms and can lead to large increases in profits. For some industries, the profits can actually double as a result of the free allocation. Furthermore, the allocation that preserves profits in the most affected industries corresponds to only 14% of the allowances given for free and 86% of them being auctioned off. In a similar theoretical study of the effect of the ETS on the European iron and steel industry, Demailly and Quirion (2009) find that about 50% of the allowances need to be allocated for free to achieve profit neutrality. Hence 100% free allocation of allowances is very likely to lead to a substantial increase in profits for the carbon emitting firms under the EU ETS.

It is important to note that the effect of the free allocation of carbon allowances on profits is not a one-off event. The analysis above makes the case for consistently higher profits to firms receiving carbon allowances for as long as they keep receiving the allowances for free. The higher expected profits will directly lead to higher expected returns for these firms. In an efficient forward-looking market, the higher returns due to carbon regulation will be expected from the time that the market can safely anticipate that the free allocation will indeed take place in the future.

Overall, this analysis informs the following two testing hypotheses:

H1: Other things being equal, firms receiving free carbon allowances will on average experience higher returns.

H2: On average, the higher the number of carbon allowances received for free, the higher the expected returns.

4 Data on Carbon Emissions and Stock Returns

4.1 Sample Period

The sample period used in our main analysis ranges from November 2003 to March 2009. This period begins with the passing of the EU directive on Phase I of the ETS that offered free carbon allowances to firms. It ends with the passing of the EU directive on Phase III announcing that EUAs will be made available mainly in auctions from 2013 onwards. The sample period commences 14 months before the beginning of Phase I and stops 15 months after the beginning of Phase II. It captures the period over which firms knew with certainty that they will be receiving free carbon allowances. Hence it differs from the period over which the two phases are implemented. Note that Phase I runs from January 2005 to December 2007, and Phase II from January 2008 to December 2012. A detailed timeline is shown in Figure 2.

4.2 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 the MDAX (50 mid caps). Together the DAX and MDAX companies comprise more than 95% of the German stock market capitalization.

Our main analysis excludes 14 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 66 firms. 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 the firm's equity (ME) and the market-to-book value ratio (ME/BE) are 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 SMB and HML Fama-French (1993) size and value factors and the MOM 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, however, that these factors are available until December 2010, which covers our main sample but does not cover the full range of Phase II examined later in our subsample analysis.

4.3 Carbon Emissions

We manually collect information on the number of allowances given for free to each company 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 facility (i.e., plant) of each company. We match each facility to the firm it belongs to and aggregate across facilities 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 for emission trading 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.

4.4 Descriptive Statistics

Table 1 reports monthly descriptive statistics for the 66 German stocks over the sample period of November 2003 to March 2009. As the table indicates, the firms belong to wide range of industries effectively capturing every aspect of the German economy. Of the 66 firms, 25 received carbon emission allowances (the "dirty" firms), whereas 41 firms are "clean." 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 8 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 size of the dirty firms is captured by the average market value of equity (ME), which for dirty firms ranges from 775 million euros (Aurubis) to 61.1 billion euros (E.ON). Similarly, the range of size for the clean firms is from 353 million (Gerry Weber) to 57.9 billion (Deutsche Telekom). The market-to-book value of equity ratio (ME/BE) of dirty firms ranges from 0.775 (Merck) to 3.252 (K+S). For clean firms it ranges from 0.954 (Aareal bank) to 10.448

(Rational).

The table also reports the annualized mean return, standard deviation and Sharpe ratio as well as the monthly skewness, kurtosis and serial correlation at a one-month lag. For example, the best performing stock is K+S with an annual mean return of 38.8%, standard deviation of 41.7% and a Sharpe ratio of 0.930. The worst performing stock is Infineon with an annual mean return of −47.2%, standard deviation of 57.3% and a Sharpe ratio of −0.823. Most stocks exhibit negative skewness, large kurtosis and low serial correlation. In short, therefore, the sample of 66 firms represents the vast majority of the German stock market capitalization while reflecting a wide distribution of firms across industries, size, growth opportunities, performance and use of carbon emission allowances.

5 Measuring the Carbon Premium in Stock Returns

Our empirical analysis provides a framework for investigating whether firms which received carbon emission allowances significantly outperformed firms which did not. In particular, we are interested in whether on average "dirty" firms exhibit abnormal excess returns relative to "clean" firms. If so, this would indicate the presence of a carbon premium in stock returns.

5.1 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 each year of the two phases of the EU ETS have received more than one million free EUAs. The medium portfolio is a portfolio of firms, which for the same period have received more than zero and less than one million free EUAs. The clean portfolio is a portfolio of firms, which for the same period have not received any EUAs.[3] Throughout our analysis we also form the "dirty-minus-clean" portfolio and the "medium-minus-clean" portfolio. These are equivalent to going long on either the dirty or the medium portfolio and short on the clean portfolio. These two difference portfolios allow us to better understand the role of carbon allowances in determining financial performance. All portfolios are formed either with equal weights (EW) or with value weights

[3] Note that the composition of the three portfolios is based on carbon allowances that were distributed after the beginning of Phase I of the EU ETS in January 2005. Before this date, we could not have known the composition of these portfolios. Hence our analysis is meant to provide an ex-post evaluation of the performance of carbon portfolios as we could not have formed ex ante these portfolios before their composition was known. However, once the composition of the three portfolios is known it stays the same over time since it is the same firms that each year satisfy the criteria for inclusion in the portfolios. This remains true as we move from Phase I to Phase II where, for example, the same firms receive more than one million carbon allowances in both phases. Therefore, there is no portfolio rebalancing.

(VW). Our discussion will focus on the VW portfolios unless stated otherwise.

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, 25 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 firms receiving a low number of carbon allowances (belonging to the medium portfolio) is however ad hoc. For most of our analysis, we draw the line between the dirty and medium portfolios on the basis of whether the firms have received more or less than one million free EUAs. This implies that eight stocks belong to the dirty portfolio and 17 stocks to the medium portfolio. Note, however, that in the next section we conduct numerous robustness checks on the composition of the dirty portfolio to assess the validity and implications of the second criterion for portfolio formation.

5.2 Portfolio Returns

Our first empirical finding is illustrated in Figure 3, which plots the cumulative returns of the three carbon portfolios for two sample periods. The first period ranges from November 1998 to October 2003, which corresponds to the five years immediately before the main sample period used in our analysis. The second period is the main sample period, which ranges from November 2003 to March 2009, beginning with the passing of the EU directive on Phase I of the ETS that offered free carbon allowances to firms, and ending with the passing of the EU directive on Phase III announcing that the EUAs will be made available mainly in auctions from 2013 onwards.

The figure provides a stark contrast in the performance of the three carbon portfolios before (upper graph) and after (lower graph) the introduction of the EU ETS. In the five years before, the performance of the three portfolios is similar and the dirty portfolio fails to consistently outperform the clean portfolio. In the second period, however, the results are markedly different as the dirty portfolio consistently generates substantially higher returns. For example, in the second period the dirty portfolio reaches a maximum cumulative return of close to 150%, whereas the clean portfolio reaches about 60%. This is a considerable difference for a sample of just over five years. At the end of the main sample period, the dirty portfolio delivers a cumulative return of over 100%, whereas the other two portfolios deliver a cumulative return of under 20%. In short, this is preliminary evidence suggesting that firms which received carbon emission allowances outperformed firms which did not.

Table 2 reports the annualized mean returns for the three carbon portfolios for the same before (Panel A) and after (Panel B) periods. Note that the return of the dirty-minus-clean portfolio is only 1.7% per year in the first period, but rises to 17.6% in the second period. In fact, the annualized return of the dirty portfolio alone is 19.7% and has a Sharpe ratio of 0.762. This is further evidence that dirty firms have substantially outperformed clean firms during the sample period.

5.3 Factor Models

An alternative to simply computing the portfolio returns is to assess the size and statistical significance of the alpha (α) of the three carbon portfolios. We measure the alpha 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:

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

where $r_{j,t}$ is the monthly return of portfolio j at time t, where j is 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, which is specified as follows:

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

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, which is specified as follows:

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

where MOM_t is the monthly return to the "winners-minus-losers" 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).

5.4 The Carbon Premium

The results on the alphas for the main sample period are reported in Panel B of Table 2. The first important finding here is that for the dirty portfolio the alphas are high and statistically significant: 15.9% per year for the $CAPM$, 14.1% for $FF3$ and 11.5% for $FF4$. The first two are significant at the 1% level and the last one at the 5% level. None of the medium and clean portfolios exhibits a significant alpha.[4]

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. Table 2 shows that the carbon premium is high and significant ranging from 12.8% to 17.7% per year depending on which factor model we use. In all cases, it is significant at the 1% level. In short, this empirical evidence strongly suggests that there is a large and significant carbon premium in stock returns which can be as high as almost 18% per year. It is also noteworthy that, as shown in Panel A of Table 2, there is no carbon premium for the five years preceding the main sample period. Hence the carbon premium is specific to the sample period reflecting the passing of EU laws initiating and ending the delivery of free carbon emission allowances.

Overall, this is an important new finding with considerable implications for the design of environmental policy. A high and significant carbon premium indicates that carbon emitting firms are substantially overcompensated by receiving carbon emission allowances for free. This is also consistent with the theoretical work of Demailly and Quirion (2009) and Goulder, Hafstead and Dworsky (2010), who show that granting most allowances for free will lead to substantially higher firm profits. In essence, the carbon premium quantifies the transfer of wealth from the government (in terms of lost revenues) and consumers (in terms of likely higher prices) to firms (in terms of higher profits). In the end, the size and significance of the carbon premium provides strong empirical support for our first testing hypothesis (*H1*) that firms receiving free carbon allowances will on average experience higher returns.

In addition to helping us understand the workings of the EU ETS, the evidence of a high and significant carbon premium is also important for guiding future environmental regulation. For example, beginning in January 2012 the EU ETS has expanded to include aviation emissions by the European airline industry, which is an industry previously excluded from the scheme. In the new system, airlines will receive about 85% of their allowances for free.[5] If a

[4] Note that the $\overline{R}^2$ in these regressions ranges from 60% to 80% (not reported in the tables).

[5] More specifically, for 2012, 85% of the total available allowances will be allocated to airlines free of charge and the remaining 15% will be auctioned by member states. For the 2013-2020 trading period (Phase III of EU ETS as a whole), the total amount of available allowances decreases to 95% of historical aviation emissions. Furthermore, 82% of the total available allowances will be allocated free of charge, 15% will be auctioned and 3% will be set aside in a special reserve for new entrants and fast-growing airlines.

portfolio of dirty European airlines exhibits similar behaviour to the dirty portfolio used here, then the allocation of free allowances may have a significant effect on the returns of firms in the aviation industry as well. Moreover, the EU ETS may become the model for regulating carbon emissions in North America and elsewhere. Even more so, it could be the prototype for a global policy regime based on a cap-and-trade scheme. In all these cases, the presence of a high and statistically significant carbon premium informs policy-makers and investors about the design and implications of such environmental regulation.

6 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.

6.1 The Composition of the Dirty Portfolio

The performance of the dirty portfolio, and hence the findings on the carbon premium, depend crucially on the how the dirty portfolio is defined. We assess the sensitivity of returns to the composition of the dirty portfolio with two robustness checks. First, we maintain the same composition for the dirty portfolio that contains eight stocks, and assess whether the alpha of this portfolio is driven by any one particular stock. Figure 4 displays the alpha of the dirty portfolio when one of the eight stocks is dropped from the portfolio. In other words, this shows the alpha for alternative dirty portfolios when any seven of the eight original stocks are used. We find that the performance of the dirty portfolio is not driven by a single stock. The eight-stock portfolio delivers a CAPM-α of about 16%. The lowest CAPM-α among the seven-stock portfolios is over 10%, which corresponds to the case of Volkswagen (VOW) being excluded. In most cases, the seven-stock portfolio alphas are very close to the eight-stock portfolio alpha. We conclude, therefore, that the carbon premium remains largely unaffected when we exclude any one stock, including the one with the highest impact.

Second, we use alternative criteria for inclusion of stocks into the dirty portfolio. As seen in Table 3, 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 25. 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-α of the eight-stock portfolio is 15.9%, which decreases to 14.4% for the 10-stock portfolio, then goes down further to 9.7% for the 14-stock portfolio and, finally, ends at 6.8% for the all-inclusive portfolio. It is important to note that these CAPM-α are all significant with at least 95% confidence.

These results are graphically illustrated in Figure 5. The figure shows the annualized CAPM-α of the dirty portfolio when we add one stock at a time to the original portfolio of eight stocks. The stocks are added in sequence according to the number of their carbon emission 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 emission 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 portfolio. This is further evidence that high carbon emissions lead to high abnormal excess returns for our sample. Having said that, however, even when all 25 dirty stocks are included in the portfolio, the alpha is still sizeable and significant.

In short, we can conclude that: (i) the dirty portfolio delivers a high and significant alpha that drives the carbon premium in stock returns; (ii) the performance of the dirty portfolio is not driven by any one particular stock; (iii) the dirtier the portfolio the higher the alpha; and (iv) even including the less dirty firms, the dirty portfolio still delivers a sizeable and significant alpha. These findings provide strong empirical support for our second hypothesis (*H2*) that the higher the number of carbon allowances received for free, the higher the expected returns. Overall, we take these findings as further evidence that, for the sample of German stocks examined in this paper over the selected sample period, receiving free carbon emission allowances is a primary determinant of stock performance.

6.2 Subsample Analysis

Recall that the sample period used in our main analysis ranges from November 2003 to March 2009, commencing 14 months before the beginning of Phase I and stopping 15 months after the beginning of Phase II. In Table 4, we provide further results using three subsamples: (i) the period of January 2005 to December 2007 corresponding to the implementation of Phase I; (ii) the period of January 2008 to February 2012 corresponding to the implementation of Phase II; and (iii) the period of January 2005 to February 2012 that encompasses both phases.[6] The table focuses on the dirty-minus-clean portfolio as this captures the carbon

[6] Note that Phase II is scheduled to end in December 2012 but our data set ends in February 2012. Moreover, the FF3 and FF4 factors for Germany are not available past December 2010 and hence we cannot estimate

premium. The results indicate that Phase I was a period of high returns as well as high and significant alphas. For the example, the dirty-minus-clean portfolio delivers an annualized return of 19.2%, a Sharpe ratio of 1.616, and a highly significant CAPM-α of 20.5% per year. In contrast, for Phase II and the combined Phase I and II period, the returns and alphas are small and insignificant. For example, the CAPM-α for Phase II is -0.9% and insignificant, whereas for the combined Phase I and II period it is 7.2% and insignificant. This leads us to conclude, therefore, that the carbon premium is high and significant during the full length of Phase I but for the full length of Phase II.

This finding is also reflected in Figure 6, which plots rolling estimates of the carbon premium using a three-year rolling window.[7] This is intended to capture the time-variation of the alphas and identify the timing of the performance of the dirty portfolio. Statistical significance is assessed by plotting rolling p-values of the alpha based on Newey-West (1987) standard errors. The shaded area in the figure corresponds to the main sample period used in our analysis: November 2003 to March 2009. The figure is quite revealing about the timing of the large significant alphas associated with the dirty portfolio. It shows that the alphas are high and significant only during our sample period but not immediately before or after. To be more specific on the timing of the good performance of the dirty-minus-clean portfolio, the figure suggests that: (i) it starts early, more than a year before the implementation of Phase I; (ii) it then continues during all of Phase I; (iii) it diminishes in the first year of Phase II; and (iv) it afterwards disappears.

It is interesting to note the behaviour of the carbon premium from the end of 2009 onwards, which coincides with the end of the main sample period and hence the passing into law of the EU directive on Phase III announcing that EUAs will be made available mainly in auctions from 2013 onwards. In particular, the figure illustrates that the carbon premium actually becomes highly negative and significant. In other words, it changes from a carbon premium to a "carbon penalty." This result indicates that when financial markets realized that polluting firms will have to incur the cost of buying carbon allowances in auctions, the alphas of dirty firms become significantly lower than these of clean firms. This is further empirical evidence of the effect of the allocation rule of carbon emission allowances on stock returns.

the FF3 and FF4 regressions for Phase II.

[7] 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.

6.3 Is the Carbon Premium Related to the Price of Carbon Allowances?

We have previously established that there is a positive relation between the quantity of carbon allowances included in the dirty portfolio and the performance of this portfolio. This also implies a positive relation between the quantity of allowances and the carbon premium. Next we provide an empirical examination of whether the price of carbon allowances is also related to the carbon premium. In particular, we investigate whether we can explain the carbon premium by conditioning on contemporaneous movements in the price of carbon allowances. For example, is it the case that when the allowance price rises the carbon premium (and hence the excess return to the dirty-minus-clean portfolio) tends to be higher? This is an important question that is related to previous work in this literature. As mentioned earlier, Oberndorfer (2009) and Veith, Werner and Zimmermann (2009) find that the EUA price change has a significant effect on the daily stock returns of European electricity and power stocks. Note, however, that the stocks used in these two studies did not exhibit an abnormal excess return.

Figure 7 plots the price of one unit of carbon allowances (EUA) in euros. The figure shows two separate EUA prices, one for Phase I (EUA-1) and one for Phase II of the ETS (EUA-2). It is worth noting in this figure that EUA-2 began trading well before Phase II commenced. In fact, for the first year of its trading, the price of EUA-2 was nearly identical to that of EUA-1. Then, the price of EUA-1 declined sharply in mid-2006 and eventually collapsed around 2007 as Phase I neared its end.[8]

In our analysis, we generate a single time series for the price of EUA by switching from EUA-1 to EUA-2 in December 2005. We denote this series as $P_{EUA,t}$ and we use it to examine the contemporaneous relation between the EUA price and the alpha of the dirty-minus-clean portfolio. The return on the EUA is defined as: $r_{EUA,t} = ln(P_{EUA,t}) - ln(P_{EUA,t-1})$. We then estimate the CAPM, FF3 and FF4 regressions as described in Equations (1) to (3), while also adding $r_{EUA,t}$ as a further explanatory variable in all cases.

Table 5 reports the results for three sample periods: Phase I, Phase II and the combined Phase I and II period.[9] The table indicates three main findings. First, during Phase I there is a positive relation between the excess returns of the dirty-minus-clean portfolio and the return on the EUA. Note, however, that this relation is only mildly significant and occasionally insignificant, which is especially true for the value-weighted portfolios. Second, conditioning

[8] The sharp decline in the EUA-1 price around the end of April 2006 is the focus of the event study by Bushnell, Chong and Mansur (2012). This paper argues that the decline was partly due to the release of information about aggregate emissions in the EU indicating an unanticipated surplus in available EUAs.

[9] Note that although the first month of Phase I is January 2005, the first observation for $P_{EUA,t}$ is available in April 2005. Hence the first observation for the return $r_{EUA,t}$ is for May 2005.

on the return of the EUA does not reduce the alpha of the dirty-minus-clean portfolio. In other words, the carbon premium remains intact even after we account for movements in the EUA price. Third, during phase II, not only the carbon premium disappears (as we have seen before) but so does the relation between portfolio returns and the return on the EUA. We conclude, therefore, that the carbon premium we observe primarily during Phase I of the ETS cannot be explained by movements in the price for carbon allowances.

6.4 Is the Carbon Premium Related to Size or Value?

It is possible that the performance of the dirty portfolio may be driven by another factor that is unrelated to carbon emissions. For example, if all dirty stocks happen to be small stocks, and all small stocks deliver high and significant abnormal excess returns, then it could be that the carbon premium is another reflection of the size premium: i.e., dirty stocks may outperform the rest not because they are dirty but because they are small. In this section, we provide a further robustness test on the carbon premium by analyzing the relation between carbon portfolios, portfolios formed on size, and portfolios formed on market-to-book equity.

We do so by forming three size portfolios (small, medium and big), which rank stocks according to the market value of equity (ME). Similarly, we form three value portfolios (low, medium and high), which rank stocks according to the market-to-book (ME/BE) ratio. Each of these portfolios contains one third of the stocks and is rebalanced at the end of June every year. This is motivated by the work of Fama and French (1992), who find that size and the market-to-book ratio can explain well the cross-section of expected stock returns. In particular, it is now an established empirical fact that small size (low ME) portfolios and high value (low ME/BE) portfolios display significant abnormal excess returns relative to the CAPM.

The performance of the size and value portfolios is reported in Table 6. We find that the small size portfolio displays a significant alpha ranging from 11.1% per year for the CAPM to 15.5% per year for FF4. The alphas of the medium size and big portfolios are not significant. Hence the well-known small size effect is present in our sample of German stocks. At the same time, however, most of the dirty firms (on average 5.5 out of 8) belong to the big portfolio. Less than one dirty firm on average belongs to the small portfolio. Hence the small size premium seems to be unrelated to the carbon premium in our sample.

We also find that the low ME/BE (i.e., the value) portfolio displays a significant alpha ranging from 5.2% to 8.7% per year. Although these alphas are large, they are far smaller than the ones displayed by the dirty portfolio. Furthermore, less than half of the dirty firms belong to the value portfolio. In fact, the distribution of dirty, medium and clean firms across the ME/BE portfolios is rather uniform. For example, on average there are 11.6 clean firms in the low ME/BE portfolio, 11.6 clean firms in the medium ME/BE portfolio, and 16.1 clean firms in the high ME/BE portfolio. We can therefore, conclude that it is unlikely that size or value can explain the carbon premium. In other words, carbon emission allowances provide an explanation for the large carbon premium that remains by far the most plausible and the one most supported by the empirical evidence.

6.5 Industry Effects

The composition of the dirty portfolio represents a particular mix of German industries. For example, the dirty portfolio used in our main analysis consists of eight stocks, including two from the electrical industry, two from iron/steel, two from the chemical industry, one from building materials and one auto manufacturer. In this section we seek to disentangle the effect of carbon emissions from the effect of belonging to a particular industry on the performance of the dirty portfolio. In other words, we investigate the possibility that the dirty portfolio has performed well not because of carbon emissions but because of the good performance of the industries it represents.

For our German data set it is practically impossible to separate the two effects since carbon allowances were received by most firms within a specific group of industries. We address this complication by making use of data from US industries in order to build portfolios that replicate the composition of the dirty portfolio for the same sample period. If, for example, the particular mix of German industries exhibits a high abnormal excess return regardless of allowances, we may be able to see that in the US data to some extent.

We begin by forming four equally-weighted US industry portfolios. Portfolio 1 replicates the composition of the dirty portfolio of eight German stocks, portfolio 2 the one with 10 stocks, portfolio 3 the one with 14 stocks and portfolio 4 the one with all 25 stocks. The composition of the four US industry portfolios therefore corresponds to that of each of the dirty portfolios shown in Table 3. The four US portfolios invest in industries selected among the 49 industry portfolios available on the website of Ken French. The weights placed on the US industries are displayed in Table 7. The sample period is the same as for our main analysis: November 2003 to March 2009.

The results are reported in Table 8. The main finding here is that none of the four US industry portfolios exhibits a significant alpha for any of the three factor models we use. In fact, all four portfolios exhibit negative Sharpe ratios. In light of this evidence, it is unlikely that the carbon premium for German firms is driven by industry effects.

7 Conclusions

The EU Emissions Trading Scheme (ETS) is the world's first and largest cap-and-trade program for regulating carbon emissions. It aims at reducing overall carbon emissions in Europe and giving firms an incentive to adopt less carbon-intensive technologies. At the center of this scheme is the creation of a new market for trading carbon emission allowances. From 2013 onwards, these allowances will be auctioned off at a price thus generating significant revenues for EU governments. From 2005 to 2012, however, the first two phases of the ETS offered the allowances to carbon emitting firms for free. As a result, firms receiving these allowances could either sell them for a 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 allowances in the initial two phases of the ETS is a crucial aspect of the scheme. It was arguably meant to build political support from energy-related industries as the free allocation would likely increase profits (e.g., Goulder, Hafstead and Dworsky, 2010). The ETS also created a barrier to entry for new market entrants as they would have to buy all their required allowances from existing firms. Moreover, there is evidence that lobbying from industrial groups representing large carbon emitters strongly pushed for the free allocation of allowances (e.g., Markussen and Svendsen, 2005). In this context, previous theoretical work by Demailly and Quirion (2008) and Goulder, Hafstead and Dworsky (2010) suggests that 100% free allocation of carbon allowances overcompensates firms and can lead to large increases in profits. There appears to be a gap in the literature, however, as we know little about whether this is indeed the case for the EU ETS.

This paper bridges this gap by providing a comprehensive empirical evaluation of whether firms which received carbon emission allowances significantly outperformed firms which did not. In other words, we examine the effect of the EU ETS on firm profits from the point of view of the stock market. Our analysis focuses on Germany, the largest market affected by the ETS. We find that there is a large and statistically significant carbon premium in stock returns, which can be as high as 18% per year for our sample period. The carbon premium captures 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. The carbon premium cannot be explained by movements in the price for carbon allowances and is robust to size, market-to-book ratios, and industry effects.

It is important to note that the evidence for a carbon premium is there for the period that firms know with certainty they will be receiving allowances for free. The carbon premium seems to have disappeared after 2009 when an EU law was passed announcing that allowances will be made available predominantly in auctions beginning in 2013. For Europe, therefore, the carbon premium may have been a one-off event. Still, the large and statistically significant carbon premium remains an important finding because it informs policy-makers and investors about the design and implications of environmental regulation. Our analysis contributes to the environmental policy debate as the EU ETS may become the model for regulating carbon emissions in North America and elsewhere. Even more so, the EU ETS could be the prototype for a global policy regime based on a cap-and-trade scheme.

Table 1. Descriptive Statistics

The table reports monthly descriptive statistics for 66 German stocks included in the DAX and MDAX indexes for the period of November 2003 to March 2009. ME is the market value of the firm's equity in million euros and ME/BE is the market-to-book value ratio. ME and ME/BE are average values over the sample period. Free allowances is the average number of carbon emission allowances issued annually in one of the two phases and is measured in million. "Dirty" are firms which were issued carbon allowances and "clean" are firms which were not. The dirty firms are listed by the number of carbon allowances, whereas the clean firms are listed alphabetically. The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. The skewness, kurtosis and serial correlation at one month are reported for monthly returns.

						Free Allowances		*November 2003 to March 2009 Returns*					
	Company	*Ticker*	*Industry*	*ME*	*ME/BE*	*Phase I*	*Phase II*	*Mean*	*SDev*	*SR*	*Skew*	*Kurt*	*AR(1)*
						"Dirty" Firms							
1	RWE	RWE	Electric	32,538	2.884	109.633	57.720	0.181	0.236	0.643	−1.018	5.769	0.094
2	E.ON	EOA	Electric	61,112	1.487	42.033	28.980	0.106	0.254	0.418	−1.405	5.674	0.126
3	ThyssenKrupp	TKA	Iron/Steel	12,857	1.358	24.033	24.000	0.063	0.378	0.168	−1.122	7.891	0.226
4	Salzgitter	SZG	Iron/Steel	3,923	1.140	10.200	12.000	0.330	0.417	0.791	−0.778	4.982	0.258
5	Heid. Cement	HEI	Building Materials	8,394	1.446	5.500	4.780	−0.030	0.382	−0.079	−1.969	9.578	0.256
6	BASF	BAS	Chemical	33,120	1.890	4.867	5.520	0.066	0.248	0.267	−1.037	4.578	0.061
7	Volkswagen	VOW	Auto Manufacturer	29,856	1.312	2.504	1.986	0.341	0.413	0.825	−0.387	5.363	−0.067
8	K+S	SDF	Chemical	3,960	3.252	1.441	1.140	0.388	0.417	0.930	−2.339	11.796	0.274
9	Suedzucker	SZU	Food	2,920	1.399	0.785	0.887	0.051	0.240	0.213	−0.460	3.423	0.154
10	Henkel	HEN	Household Products	6,630	2.021	0.560	0.491	0.026	0.223	0.115	−0.643	4.395	−0.087
11	Daimler	DAI	Auto Manufacturer	43,588	1.269	0.383	0.376	−0.050	0.333	−0.150	−0.427	3.206	0.040
12	Bayer	BAY	Chemical	28,385	1.979	0.290	0.283	0.152	0.256	0.592	−0.437	3.121	−0.042
13	BMW	BMW	Auto Manufacturer	22,369	1.280	0.272	0.294	−0.055	0.274	−0.200	−0.542	3.938	−0.111
14	Merck	MRK	Pharmaceutical	3,996	0.775	0.141	0.108	0.184	0.254	0.723	0.333	2.907	−0.003
15	Krones	KRN	Machinery	1,111	1.727	0.078	0.073	0.072	0.317	0.228	−0.742	4.894	−0.100
16	Continental	CON	Auto Parts	9,598	2.142	0.077	0.069	−0.107	0.497	−0.215	−3.084	15.129	0.243
17	MAN	MAN	Machinery	8,002	1.965	0.055	0.024	0.132	0.394	0.335	−1.154	5.004	−0.016
18	Infineon	IFX	Semiconductors	6,125	1.526	0.038	0.017	−0.472	0.573	−0.823	−0.606	5.793	0.410
19	Hochtief	HOT	Construction	3,103	1.592	0.034	0.033	0.133	0.516	0.258	−1.015	5.287	−0.026
20	Fresenius Med.	FME	Healthcare Products	7,693	2.317	0.027	0.032	0.114	0.169	0.677	0.006	2.335	0.077
21	Lufthansa	LHA	Airline	6,429	1.238	0.019	0.020	−0.021	0.284	−0.075	−0.444	3.409	0.078
22	Siemens	SIE	Manufacturing	62,465	2.253	0.015	0.016	−0.010	0.298	−0.035	−0.739	4.174	0.063
23	Aurubis	NDA	Metal	775	1.030	0.008	0.008	0.182	0.311	0.587	−0.319	2.918	0.077
24	EADS	EAD	Aerospace	17,650	.	0.006	0.009	−0.053	0.378	−0.139	0.055	3.464	−0.185
25	Heid. Druck.	HDD	Machinery	2,144	1.876	0.005	0.006	−0.310	0.591	−0.525	−1.571	8.620	−0.204

(*continued*)

Table 1. Descriptive Statistics (*continued*)

	Company	Ticker	Industry	ME	ME/BE	Free Allowances Phase I	Free Allowances Phase II	Nov 2003 to Mar 2009 Returns Mean	SDev	SR	Skew	Kurt	AR(1)
						"Clean" Firms							
26	Aareal Bank	ARL	Bank	1,072	0.954	0.000	0.000	−0.200	0.545	−0.367	−0.478	6.135	0.075
27	Adidas	ADS	Apparel	6,870	2.567	0.000	0.000	0.061	0.263	0.232	−1.191	5.084	0.064
28	Allianz	ALV	Insurance	48,048	1.487	0.000	0.000	−0.010	0.363	−0.027	−1.307	8.419	0.010
29	Axel Springer	SPR	Media	3,182	2.806	0.000	0.000	0.015	0.248	0.061	−1.090	6.373	0.233
30	Baywa	BYW6	Retail	760	1.128	0.000	0.000	0.135	0.436	0.309	−1.053	5.645	−0.022
31	Beiersdorf	BEI	Cosmetics	9,915	5.813	0.000	0.000	0.002	0.212	0.007	−0.566	3.648	0.161
32	Bilfinger Berger	GBF	Construction	1,598	1.338	0.000	0.000	0.069	0.357	0.192	−0.838	3.505	−0.215
33	Celesio	CLS1	Pharmaceutical	5,510	2.316	0.000	0.000	−0.014	0.288	−0.048	−0.778	4.008	0.221
34	Commerzbank	CBK	Bank	13,658	0.978	0.000	0.000	−0.200	0.531	−0.376	−1.303	8.727	0.196
35	D. Bank	DBK	Bank	39,656	1.264	0.000	0.000	−0.065	0.420	−0.155	−0.758	9.658	0.120
36	D. Boerse	DB1	Financial	11,269	4.637	0.000	0.000	0.148	0.346	0.426	−0.250	4.435	0.165
37	D. Euroshop	DEQ	Real Estate	775	0.992	0.000	0.000	0.095	0.223	0.425	0.419	6.019	−0.208
38	D. Post	DPW	Transportation	21,897	2.358	0.000	0.000	−0.079	0.334	−0.238	−1.579	7.591	−0.019
39	D. Telekom	DTE	Telecommunication	57,965	1.433	0.000	0.000	−0.010	0.205	−0.049	−0.111	2.444	0.023
40	Deutz	DEZ	Machinery	593	1.658	0.000	0.000	−0.027	0.480	−0.056	−0.586	3.877	0.078
41	Douglas	DOU	Retail	1,290	2.085	0.000	0.000	0.069	0.192	0.361	−0.088	2.596	0.142
42	Elringklinger	ZIL2	Auto Parts	791	3.684	0.000	0.000	0.068	0.416	0.164	−2.635	14.526	0.217
43	Fielmann	FIE	Retail	1,515	3.771	0.000	0.000	0.232	0.213	1.091	0.082	2.727	0.037
44	Fraport	FRA	Construction	3,752	1.624	0.000	0.000	0.039	0.313	0.125	−1.389	8.942	0.070
45	Fresenius	FRE	Healthcare Products	1,586	1.002	0.000	0.000	0.066	0.255	0.260	−0.536	3.889	0.069
46	FUCHS Petrolub	FPE3	Oil & Gas	496	3.537	0.000	0.000	0.194	0.344	0.565	−0.422	3.521	0.158
47	GEA	G1A	Food and Energy	2,821	1.938	0.000	0.000	−0.042	0.355	−0.117	−1.445	7.097	0.105
48	Gerry Weber	GWI1	Apparel	353	2.495	0.000	0.000	0.202	0.302	0.668	0.314	3.507	−0.014
49	Gildemeister	GIL	Machine Tools	408	1.299	0.000	0.000	0.040	0.519	0.078	−0.632	3.829	0.006
50	Hannover Reuck.	HNR1	Insurance	3,603	1.342	0.000	0.000	0.044	0.274	0.160	0.131	4.487	0.057
51	Hugo Boss	BOS3	Apparel	989	5.317	0.000	0.000	−0.025	0.353	−0.071	−0.720	4.262	0.055
52	KUKA	IWK	Machine Tools	523	2.611	0.000	0.000	−0.025	0.401	−0.063	−0.449	3.045	−0.041
53	Leoni	LEO	Electrical	709	1.575	0.000	0.000	−0.119	0.466	−0.256	−1.779	7.684	0.206
54	Linde	LIN	Chemical	9,601	1.440	0.000	0.000	0.092	0.228	0.404	−1.541	7.122	−0.105
55	Metro	MEO	Food	14,015	2.556	0.000	0.000	−0.017	0.275	−0.062	−0.893	6.561	0.052
56	Munich Re	MUV	Insurance	23,991	.	0.000	0.000	0.049	0.228	0.217	0.843	4.614	−0.132
57	Prosieben	PSM	Media	1,697	3.953	0.000	0.000	−0.320	0.599	−0.534	−0.745	5.616	0.047
58	Puma	PUM	Apparel	3,760	4.175	0.000	0.000	0.015	0.313	0.048	−0.823	4.797	0.109
59	Rational	RAA	Home Furnishings	1,185	10.448	0.000	0.000	0.113	0.347	0.325	−0.707	4.535	0.023
60	Rheinmetall	RHM	Machinery	1,467	1.742	0.000	0.000	0.041	0.379	0.107	−0.828	5.144	0.149
61	Rhoen-Klinikum	RHK	Healthcare Services	1,549	2.261	0.000	0.000	0.083	0.271	0.307	−0.260	3.051	−0.189
62	SAP	SAP	Software	43,819	7.409	0.000	0.000	0.011	0.251	0.045	−0.745	5.424	−0.005
63	SGL Carbon	SGL	Chemical	1,226	2.340	0.000	0.000	0.092	0.492	0.186	−1.586	7.404	0.083
64	Stada	SAZ	Pharmaceutical	1,757	2.211	0.000	0.000	−0.100	0.380	−0.263	−1.153	5.367	0.006
65	TUI	TUI1	Travel	3,706	1.518	0.000	0.000	−0.194	0.320	−0.605	−1.569	6.625	0.345
66	Vossloh	VOS	Electrical	836	2.088	0.000	0.000	0.167	0.267	0.624	−0.231	3.035	0.063

Table 2. The Performance of Carbon Portfolios

The table presents the performance of three carbon portfolios before and after the introduction of the EU Emissions Trading Scheme (ETS). The *Dirty* portfolio is a portfolio of firms, which during each of the two phases of the EU ETS have received more than 1 million free carbon emission allowances. The *Medium* portfolio is a portfolio of firms, which for the same period have received more than zero and less than 1 million free carbon emission allowances. The *Clean* portfolio is a portfolio of firms, which for the same period have not received any carbon allowances. All portfolios are formed either with equal weights (EW) or with value weights (VW). The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. ME is the market value of the firm's equity in million euros and ME/BE is the market-to-book value ratio. ME and ME/BE are average values over the sample period. 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. 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.

Panel A: Before the Introduction of the EU Emissions Trading Scheme

5 years Before the EU Directive on ETS-1
November 1998 to October 2003

	Mean	*SDev*	*SR*	*ME*	ME/BE	*CAPM-α*	*FF3-α*	*FF4-α*
				Dirty Portfolio [8 stocks]				
EW	0.030	0.221	−0.019	13,364	1.507	0.031 (0.489)	− 0.060 (−1.054)	− 0.050 (−0.997)
VW	0.032	0.231	−0.009	23,901	1.793	0.031 (0.425)	− 0.104 (−1.513)	− 0.097 (−1.385)
				Medium Portfolio [12 stocks]				
EW	0.038	0.267	0.013	11,291	1.879	0.048 (0.757)	− 0.007 (−0.116)	0.006 (0.113)
VW	0.113	0.334	0.236	34,849	2.336	0.142*** (2.838)	0.116** (2.027)	0.130** (2.424)
				Clean Portfolio [35 stocks]				
EW	0.040	0.224	0.024	9,796	2.436	0.045 (0.942)	0.051 (1.147)	0.063 (1.447)
VW	0.016	0.323	−0.058	57,916	3.442	0.043 (0.869)	0.068 (1.334)	0.067 (1.290)
				Dirty-minus-Clean Portfolio				
EW	−0.010	0.120	−0.368			− 0.014 (−0.269)	− 0.111 ** (−2.523)	− 0.112 ** (−2.430)
VW	0.017	0.262	−0.066			− 0.012 (−0.116)	− 0.172 ** (−2.180)	− 0.164 ** (−2.012)
				Medium-minus-Clean Portfolio				
EW	−0.002	0.108	−0.335			0.003 (0.069)	− 0.057 (−1.307)	− 0.056 (−1.305)
VW	0.097	0.179	0.351			0.099 (1.148)	0.048 (0.504)	0.063 (0.698)

Panel B: After the Introduction of the EU Emissions Trading Scheme								
				EU Directive on ETS-1 to EU Directive on ETS-3 *November 2003 to March 2009*				
	Mean	*SDev*	*SR*	*ME*	ME/BE	*CAPM-α*	*FF3-α*	*FF4-α*
				Dirty Portfolio [8 stocks]				
EW	0.181	0.235	0.643	23,220	1.686	0.141*** (2.774)	0.121** (2.312)	0.147** (2.473)
VW	0.197	0.219	0.762	40,036	1.711	0.159*** (2.834)	0.141*** (2.810)	0.115** (2.516)
				Medium Portfolio [17 stocks]				
EW	−0.002	0.235	−0.134	13,705	1.552	− 0.042 (−1.210)	− 0.043 (−1.318)	− 0.019 (−0.446)
VW	0.025	0.224	−0.023	34,132	1.814	− 0.015 (−0.526)	− 0.017 (−0.607)	− 0.017 (−0.547)
				Clean Portfolio [41 stocks]				
EW	0.017	0.227	−0.056	8,542	2.739	− 0.023 (−0.558)	− 0.018 (−0.598)	0.027 (0.845)
VW	0.020	0.197	−0.047	32,531	2.801	− 0.018 (−0.840)	− 0.011 (−0.591)	− 0.013 (−0.553)
				Dirty-minus-Clean Portfolio				
EW	0.164	0.118	1.139			0.164*** (3.744)	0.140*** (3.340)	0.120*** (2.430)
VW	0.176	0.194	0.755			0.177*** (2.453)	0.152*** (2.432)	0.128*** (2.154)
				Medium-minus-Clean Portfolio				
EW	−0.019	0.083	−0.585			− 0.019 (−0.544)	− 0.025 (−0.678)	− 0.046 (−0.902)
VW	0.004	0.094	−0.272			0.003 (0.088)	− 0.005 (−0.156)	− 0.004 (−0.091)

Table 3. The Performance of Alternative Dirty Portfolios

The table displays the performance of four dirty portfolios for the period of November 2003 to March 2009. The composition of the dirty portfolios varies according to the number of free carbon emission allowances the firms in the portfolio were granted. The first dirty portfolio includes firms which were granted more than 1 million free carbon emission allowances. The second dirty portfolio includes firms which were granted more than 0.5 million free carbon emission allowances. The third dirty portfolio includes firms which were granted more than 0.1 million free carbon emission allowances. Finally, the fourth dirty portfolio includes firms which were granted any (more than 0) free carbon emission allowances. All portfolios are formed either with equal weights (EW) or with value weights (VW). The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. ME is the market value of the firm's equity in million euros and ME/BE is the market-to-book value ratio. ME and ME/BE are average values over the sample period. 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. 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.

	EU Directive on ETS-1 to EU Directive on ETS-3, November 2003 to March 2009							
	Mean	*SDev*	*SR*	*ME*	ME/BE	*CAPM-α*	*FF3-α*	*FF4-α*
	Dirty Portfolio (>1 mil carbon allowances) [8 stocks]							
EW	0.181	0.235	0.643	23,220	1.686	0.141*** (2.774)	0.121** (2.312)	0.147** (2.473)
VW	0.197	0.219	0.762	40,036	1.711	0.159*** (2.834)	0.141*** (2.810)	0.115** (2.516)
	Dirty Portfolio (>0.5 mil carbon allowances) [10 stocks]							
EW	0.152	0.211	0.581	19,531	1.703	0.114*** (2.887)	0.101** (2.498)	0.109** (2.422)
VW	0.189	0.214	0.745	38,355	1.724	0.152*** (2.833)	0.135*** (2.820)	0.107** (2.427)
	Dirty Portfolio (>0.1 mil carbon allowances) [14 stocks]							
EW	0.125	0.204	0.467	20,974	1.594	0.086*** (2.794)	0.074** (3.395)	0.085** (2.326)
VW	0.142	0.206	0.546	37,121	1.629	0.104** (2.525)	0.086** (2.390)	0.066* (1.961)
	Dirty Portfolio (>0 carbon allowances) [25 stocks]							
EW	0.057	0.227	0.118	16,749	1.585	0.017 (0.532)	0.010 (0.318)	0.034 (0.869)
VW	0.107	0.201	0.386	37,272	1.818	0.069** (2.476)	0.059** (2.367)	0.036 (1.521)

Table 4. The Carbon Premium across Subsamples

The table shows the carbon premium across subsamples. The carbon premium is defined as the abnormal excess return (a) of the *Dirty-minus-Clean* portfolio. The *Dirty* portfolio is a portfolio of firms, which during each of the two phases of the EU ETS have received more than 1 million free carbon emission allowances. The *Clean* portfolio is a portfolio of firms, which for the same period have not received any free carbon emission allowances. All portfolios are formed either with equal weights (EW) or with value weights (VW). 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 model 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. Note that the FF3 and FF4 factors for Germany are not available past December 2010 and hence we cannot estimate the FF3 and FF4 regressions for Phase II.

	Dirty-minus-Clean Portfolio					
	Mean	*SDev*	*SR*	*CAPM-α*	*FF3-α*	*FF4-α*
	Main Sample Period: November 2003 to March 2009					
EW	0.164	0.118	1.139	0.164***	0.140***	0.120***
				(3.744)	(3.340)	(2.430)
VW	0.176	0.194	0.755	0.177***	0.152***	0.128***
				(2.453)	(2.432)	(2.154)
	Phase I: January 2005 to December 2007					
EW	0.179	0.079	1.882	0.143***	0.114***	0.108**
				(3.378)	(3.106)	(2.365)
VW	0.192	0.100	1.616	0.205***	0.159***	0.135*
				(3.420)	(2.780)	(1.946)
	Phase II: January 2008 to February 2012					
EW	0.076	0.160	0.372	− 0.073	−	−
				(−0.984)		
VW	−0.010	0.228	−0.116	− 0.009	−	−
				(−0.088)		
	Phases I and II: January 2005 to February 2012					
EW	0.028	0.139	0.042	0.024	−	−
				(0.458)		
VW	0.067	0.190	0.236	0.072	−	−
				(0.982)		

Table 5. The Carbon Premium and the Price of Carbon Allowances

The table presents regression results on the relation between the carbon premium and the price of the European Union Allowance (EUA) for carbon emissions across subsamples. The carbon premium is defined as the abnormal excess return (a) of the *Dirty-minus-Clean* portfolio. The *Dirty* portfolio is a portfolio of firms, which during each of the two phases of the EU ETS have received more than 1 million free carbon emission allowances. The *Clean* portfolio is a portfolio of firms, which for the same period have not received any free carbon emission allowances. All portfolios are formed either with equal weights (EW) or with value weights (VW). The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. CAPM-a is the intercept of a CAPM regression that also conditions on the EUA log-price change and CAPM-β_{EUA} is the slope on the EUA log-price change in this regression. FF3-a is the intercept of the Fama-French (1993) 3-factor model regression that also conditions on the EUA log-price change and FF3-β_{EUA} is the slope on the EUA log-price change in this regression. FF4-a is the intercept of the Carhart (1997) 4-factor regression that also conditions on the EUA log-price change and FF4-β_{EUA} is the slope on the EUA log-price change in this 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. Note that the FF3 and FF4 factors for Germany are not available past December 2010 and hence we cannot estimate the FF3 and FF4 regressions for Phase II.

	Dirty-minus-Clean Portfolio								
	Mean	*SDev*	*SR*	*CAPM-α*	*CAPM-β_{EUA}*	*FF3-α*	*FF3-β_{EUA}*	*FF4-α*	*FF4-β_{EUA}*
				Phase I: May 2005 to December 2007					
EW	0.205	0.079	2.196	0.163***	0.582**	0.124***	0.535*	0.099*	0.579*
				(3.981)	(2.049)	(3.115)	(1.859)	(1.868)	(2.013)
VW	0.201	0.099	1.716	0.210***	0.560	0.163***	0.684	0.119	0.759*
				(3.395)	(1.521)	(2.650)	(1.627)	(1.536)	(1.830)
				Phase II: January 2008 to February 2012					
EW	0.076	0.160	0.372	− 0.081	− 0.519	–	–	–	–
				(−1.054)	(−0.652)				
VW	−0.010	0.228	−0.116	− 0.016	− 0.392	–	–	–	–
				(−0.153)	(−0.421)				
				Phases I and II: May 2005 to February 2012					
EW	0.032	0.140	0.071	0.028	0.097	–	–	–	–
				(0.504)	(0.223)				
VW	0.071	0.191	0.257	0.071	0.138	–	–	–	–
				(0.944)	(0.282)				

Table 6. The Performance of Size and Value Portfolios

The table displays the performance of three portfolios formed on size proxied by the market value of equity (ME) and three portfolios formed on the market-to-book value ratio (ME/BE). The portfolios are rebalanced at the end of June each year. The *Dirty* firms have received more than 1 million free carbon emission allowances during each of the two phases of the EU ETS. The *Medium* firms have received more than zero and less than 1 million free carbon emission allowances for the same period. The *Clean* firms have not received any free carbon emission allowances for the same period. All portfolios are formed using value weights. The mean, standard deviation and Sharpe ratio of monthly returns are reported in annualized units. ME is the market value of the firm's equity in million euros and ME/BE is the market-to-book value ratio. ME and ME/BE are average values over the sample period. 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. 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.

EU Directive on ETS-1 to EU Directive on ETS-3
November 2003 to March 2009

	Mean	*SDev*	*SR*	*ME*	ME/BE	Average Number of Firms: Dirty	Medium	Clean	Total	*CAPM-α*	*FF3-α*	*FF4-α*
						Portfolios Formed on Size (ME)						
Small	0.149	0.218	0.548	910	2.454	0.666	2.167	19.167	22	0.111**	0.112***	0.155***
										(2.216)	(2.746)	(3.194)
Medium	0.082	0.191	0.273	4,396	2.067	1.833	8.667	11.500	22	0.045	0.048	0.044
										(1.112)	(1.401)	(0.940)
Big	0.064	0.193	0.178	28,827	2.423	5.500	6.167	10.333	22	0.026	0.022	0.002
										(1.521)	(1.489)	(0.136)
Total						8	17	41	66			
						Portfolios Formed on Market-to-Book Equity (ME/BE)						
Low	0.092	0.224	0.279	11,735	1.120	3.000	6.333	11.667	21	0.052*	0.042	0.087***
										(1.772)	(1.361)	(2.737)
Medium	0.068	0.214	0.179	12,126	1.858	2.167	6.667	11.167	20	0.030	0.029	− 0.014
										(0.672)	(0.717)	(−0.442)
High	0.041	0.186	0.061	10,050	3.916	1.833	3.000	16.167	21	0.003	0.013	− 0.004
										(0.118)	(0.479)	(−0.156)
Total						7	16	39	62			

Table 7. The Composition of US Industry Portfolios

The table displays the composition of four US industry portfolios that replicate the composition of four Dirty portfolios based on German firms that received carbon emission allowances. Portfolio 1 replicates the dirty portfolio of 8 German stocks, portfolio 2 the one with 10 stocks, portfolio 3 the one with 14 stocks and portfolio 4 the one with all 25 stocks. The industries are selected among the 49 industry portfolios available on the website of Ken French. The entries show the weights on each industry.

	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4
Aircraft				0.040
Automobiles and trucks	0.125	0.100	0.214	0.160
Chemicals	0.250	0.200	0.214	0.120
Construction				0.040
Construction materials	0.125	0.100	0.071	0.040
Consumer goods		0.100	0.071	0.040
Electrical equipment	0.250	0.200	0.143	0.120
Electronic equipment				0.040
Fabricated products				0.040
Food products		0.100	0.071	0.040
Healthcare				0.040
Pharmaceutical products			0.071	0.040
Machinery				0.120
Steel works	0.250	0.200	0.143	0.080
Transportation				0.040
TOTAL	1.000	1.000	1.000	1.000

Table 8. The Performance of US Industry Portfolios

The table presents the performance of four US industry portfolios that replicate the composition of the four Dirty portfolios based on German firms that received carbon emission allowances. Portfolio 1 replicates the dirty portfolio of 8 German stocks, portfolio 2 the one with 10 stocks, portfolio 3 the one with 14 stocks and portfolio 4 the one with all 25 stocks. The US industries are selected among the 49 industry portfolios available on the website of Ken French. All portfolios are formed with equal weights (EW). The sample period ranges from November 2003 to March 2009. 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 model 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.

	EU Directive on ETS-1 to EU Directive on ETS-3 November 2003 to March 2009					
	Mean	*SDev*	*SR*	*CAPM-α*	*FF3-α*	*FF4-α*
			US Industry Portfolio 1			
EW	0.002	0.810	−0.032	0.028	0.028	0.022
				(0.797)	(0.831)	(0.642)
			US Industry Portfolio 2			
EW	0.004	0.705	−0.034	0.023	0.023	0.089
				(0.857)	(0.850)	(0.699)
			US Industry Portfolio 3			
EW	−0.014	0.690	−0.061	0.004	0.005	0.006
				(0.174)	(0.205)	(0.260)
			US Industry Portfolio 4			
EW	−0.014	0.691	−0.062	0.004	0.005	0.004
				(0.182)	(0.204)	(0.158)

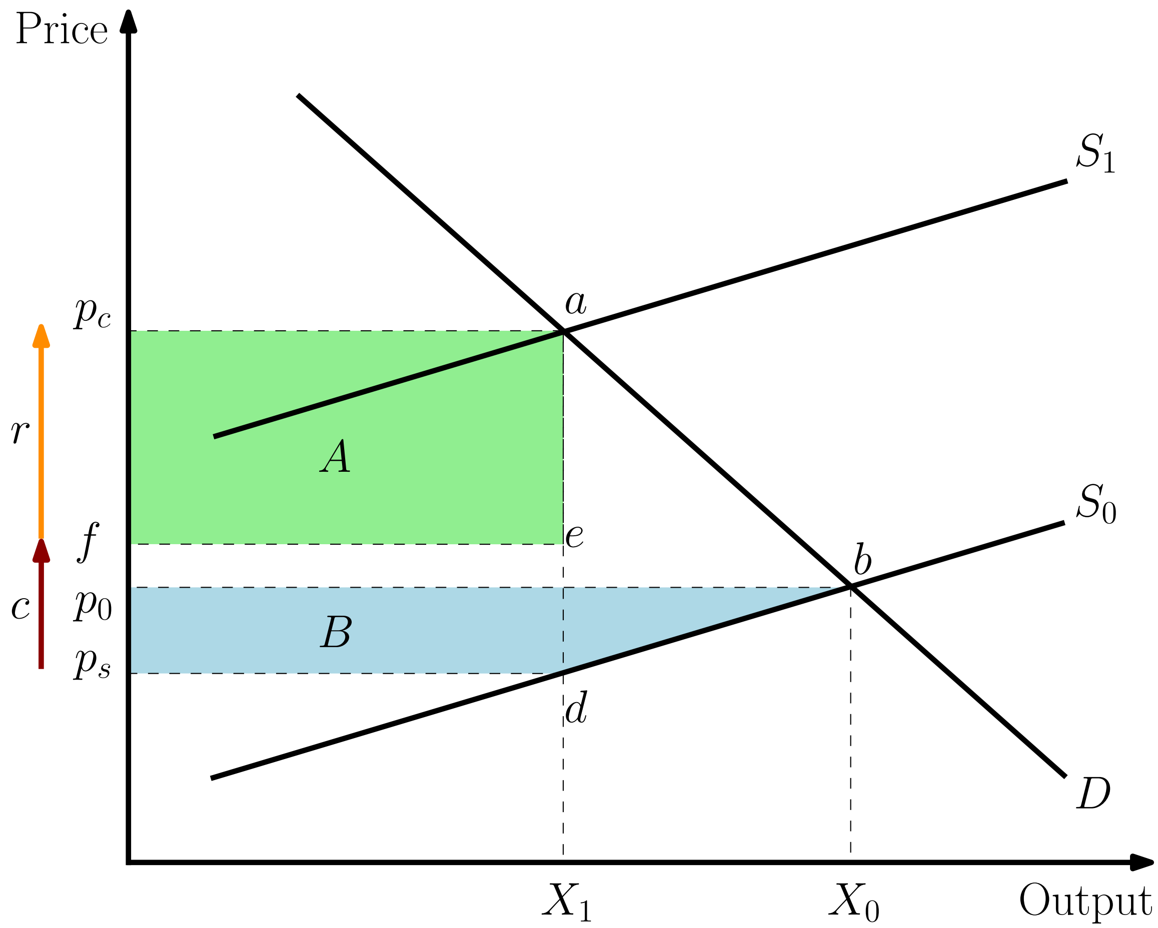


Figure 1. The Effect of Free Carbon Emission Allowances on Firm Profits

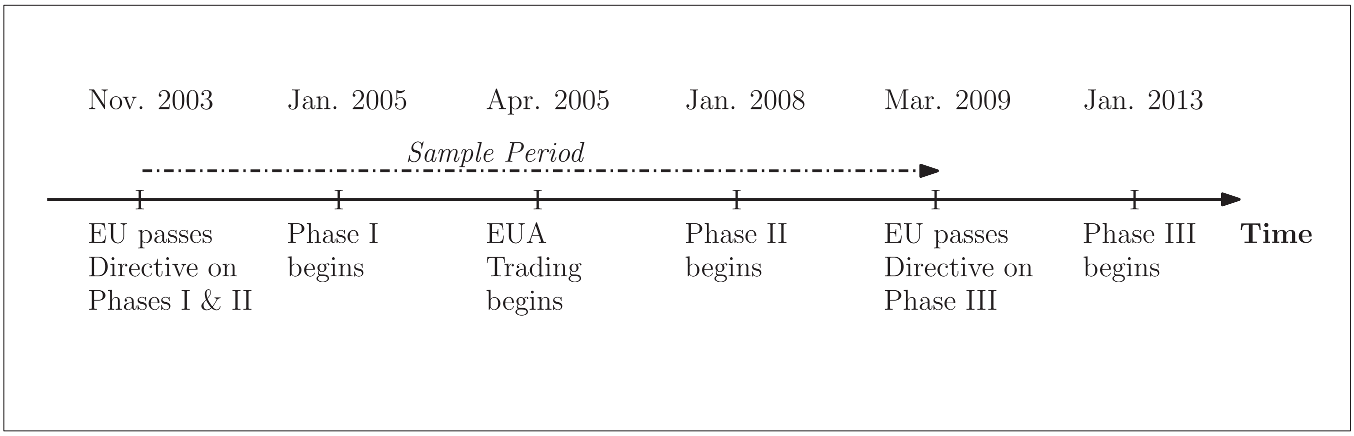
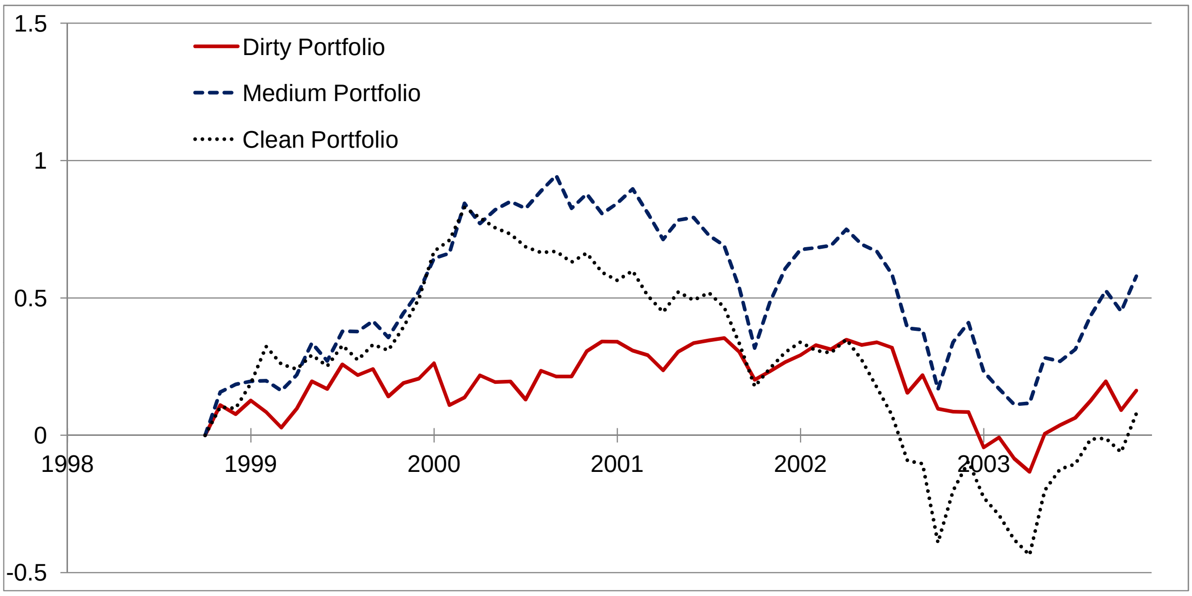


Figure 2. Timeline



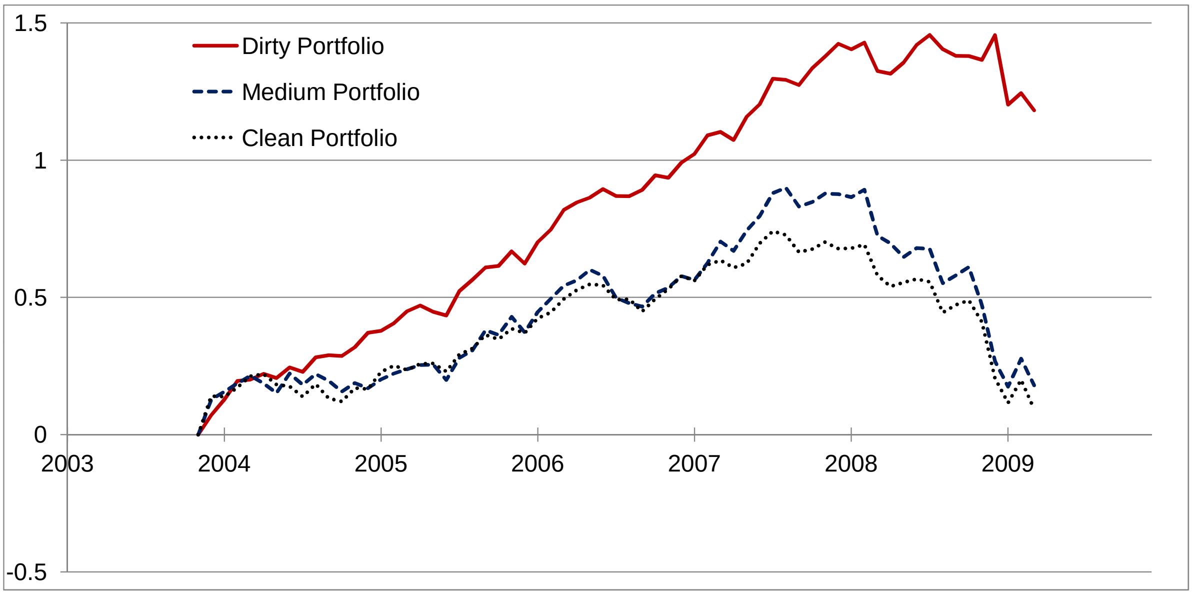


Figure 3. The Performance of Carbon Portfolios over Time

The figure plots the cumulative returns of three carbon portfolios for the five-year period immediately before the main sample period (upper graph) and during the main sample period (lower graph). The main sample period of our analysis ranges from November 2003 to March 2009. The *Dirty* portfolio is a portfolio of firms, which during each year of the two phases of the EU ETS have received more than 1 million free carbon emission allowances. The *Medium* portfolio is a portfolio of firms, which for the same period have received more than zero and less than 1 million free carbon emission allowances. The *Clean* portfolio is a portfolio of firms, which for the same period have not received any free carbon emission allowances. All portfolios are formed with value weights.

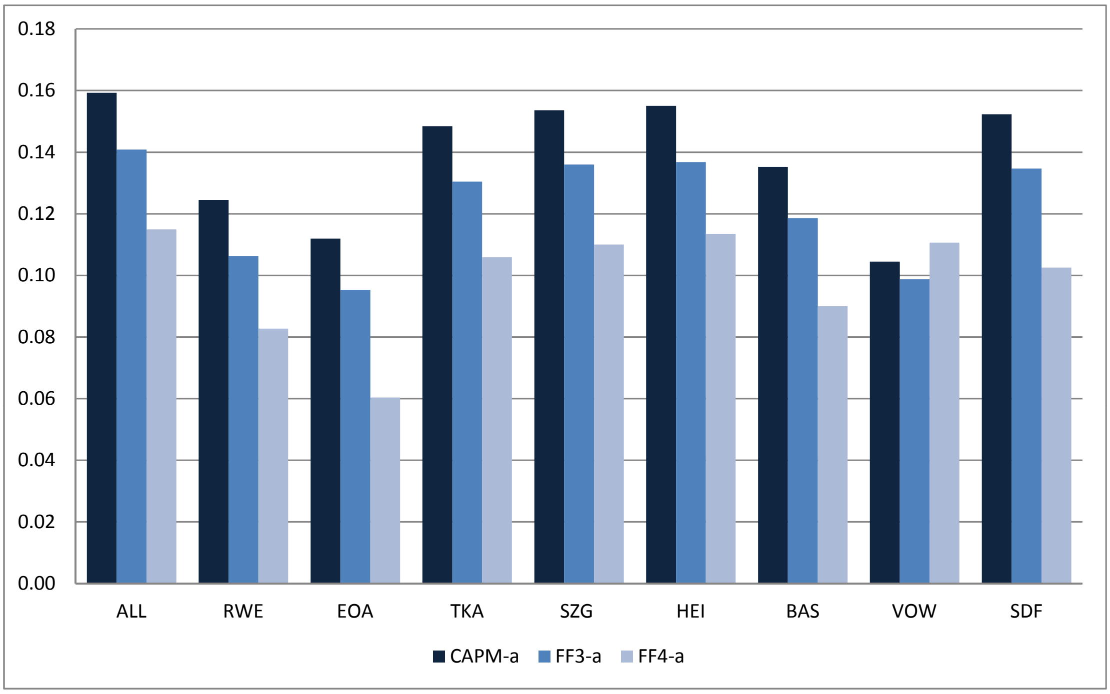


Figure 4. The Performance of the Dirty Portfolio when one Stock is Dropped

The figure displays the annualized abnormal excess return (alpha) of the Dirty portfolio when one of the eight stocks included in this portfolio is dropped. The sample period ranges from November 2003 to March 2009. The original Dirty portfolio is a value-weighted portfolio of eight stocks (ALL in the figure), which during each of the two phases of the EU Emissions Trading Scheme have received more than 1 million free carbon emission allowances. The horizontal axis shows the ticker of each stock dropped at a time. 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.

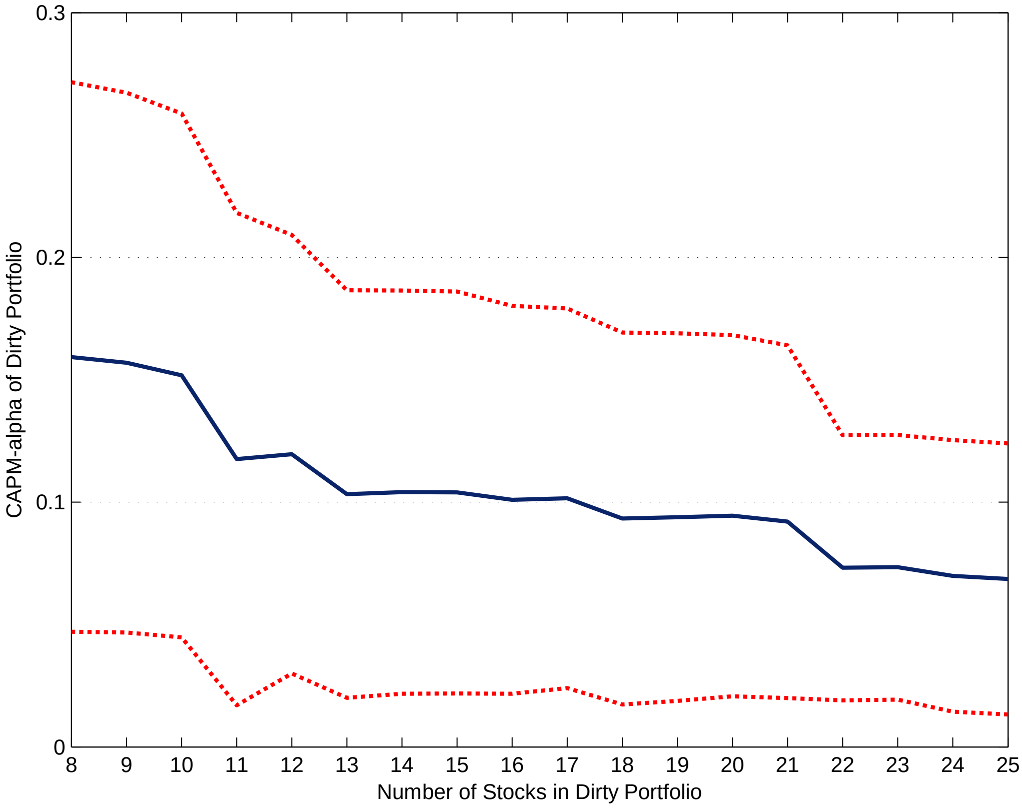


Figure 5. The Performance of the Dirty Portfolio when more Stocks are Added

The figure shows the annualized CAPM-alpha of the Dirty portfolio (solid line) when we add one stock at a time to the original portfolio of eight stocks. The figure also shows the 95% confidence interval of the CAPM-alpha (dotted line) based on Newey-West (1987) standard errors. The original Dirty portfolio is a value-weighted portfolio of eight firms, which during each of the two phases of the EU Emission Trading Scheme have received more than 1 million free certificates for 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 stock receiving carbon allowances is 25. The sample period ranges from November 2003 to March 2009.

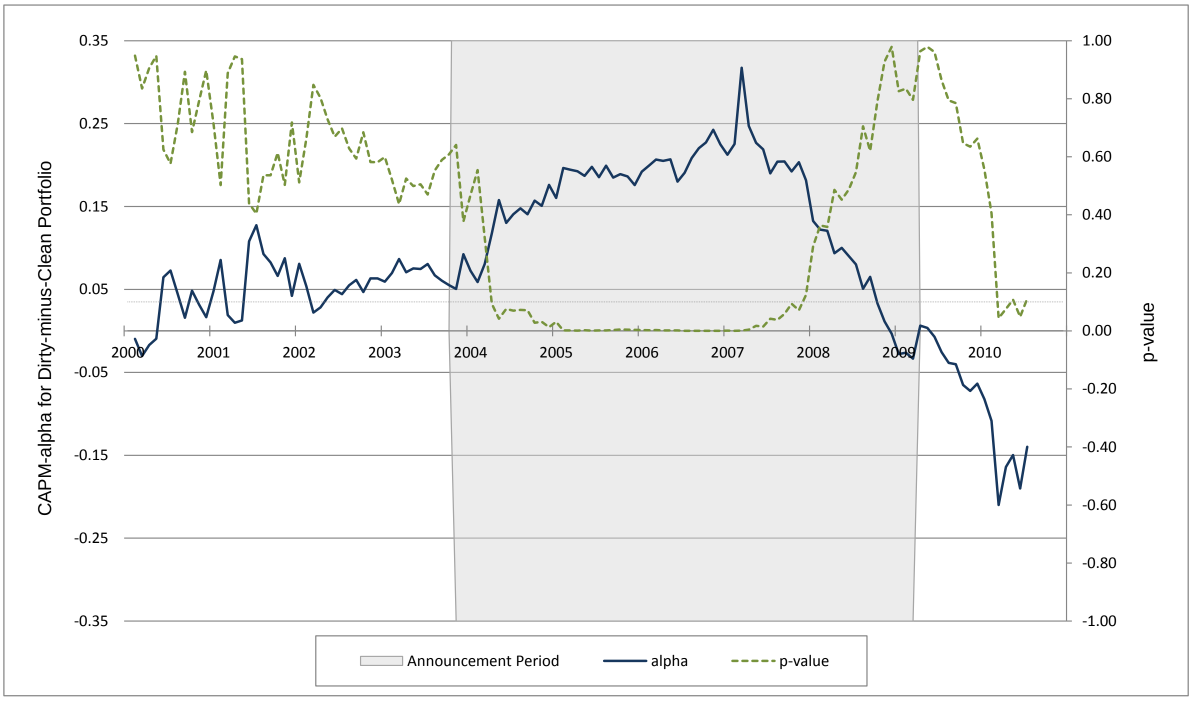


Figure 6. Rolling Estimate of the Carbon Premium

The figure plots a rolling estimate of the annualized carbon premium (solid line) using a three-year rolling window. The carbon premium is defined as the difference in the CAPM-alpha of the Dirty portfolio minus the CAPM-alpha of the Clean Portfolio. The figure also plots the p-value of the carbon premium (dashed 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 sample used for the rolling window begins in November 1998 and ends in February 2012. The shaded area corresponds to the main sample period used in our analysis: November 2003 to March 2009. The Dirty portfolio is a value-weighted portfolio of firms, which during each year of the two phases of the EU Emissions Trading Scheme have received more than 1 million free carbon emission allowances. The Clean portfolio is a value-weighted portfolio of firms, which for the same period have not received any free carbon emission allowances.

Figure 7. The Price of the European Union Allowance (EUA)

The figure plots the price of the European Union Allowance (EUA) for carbon emissions over time. EUA1 (dashed line) is the price for Phase I of the EU Emissions Trading Scheme (ETS), and EUA2 (solid line) is the price for Phase II. EUA1 and EUA2 are in euros.

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